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Ultrasound core curriculum in medical school: a literature review

Currículo essencial de ultrassonografia na graduação médica: uma revisão da literatura

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ABSTRACT

Introduction: Traditionally, inspection, palpation, percussion, and auscultation constitute the four pillars of bedside medicine. Point-of-care ultrasound (POCUS) has shown to be promising in improving the accuracy of clinical diagnosis.

Objective: To carry out a literature review on ultrasound curricula in medical courses.

Methods: A systematic review was carried out in PubMed, LILACS and SciELO databases, including the descriptors: "ultrasonography", "curriculum", "medicine" and "medical school".

Results: 36 studies were analyzed, focusing on the integration of ultrasound into the medical curriculum. Twelve articles that describe specific ultrasonography curricula in detail were identified. Comparative tables were created, grouped by region of the body or area of knowledge.

Conclusions: Ultrasonography is being integrated into medical curricula, contributing to the teaching of various medical course subjects, as well as supporting bedside diagnosis. For its implementation in medical curricula, one must consider the skills to be acquired from the general practitioner's training perspective. Investment in quality equipment and teacher training is necessary to achieve learning objectives.

Keywords: ultrasound, curriculum, medical school, medicine.

RESUMO

Introdução: *Tradicionalmente, inspeção, palpação, percussão e ausculta constituem os quatro pilares da medicina à beira do leito. A Ultrassonografia no Local do Atendimento (POCUS) tem se destacado em melhorar a acurácia do diagnóstico clínico.*

Objetivo: *Este estudo teve como objetivo realizar revisão de literatura sobre currículos de ultrassonografia em cursos médicos.*

Método: *Realizou-se uma revisão narrativa nas bases de dados PubMed, LILACS e SciELO, em que se utilizaram os descritores: "ultrassom", "ultrassonografia", "currículo", "medicina" e "escola médica".*

Resultado: *Foram analisados 36 artigos com enfoque na integração da ultrassonografia ao currículo de Medicina. Identificaram-se 12 artigos que detalham currículos específicos, a partir dos quais foram elaborados quadros comparativos, agrupados por região anatômica ou área de conhecimento.*

Conclusão: *A ultrassonografia está sendo integrada aos currículos médicos, contribuindo para o ensino de várias disciplinas, além de ser utilizada como apoio diagnóstico à beira do leito. Para sua incorporação curricular, é necessário considerar as competências a serem adquiridas dentro da perspectiva da formação do médico generalista. Sua adoção requer investimento em equipamentos e treinamento docente para que se alcancem os objetivos de aprendizagem.*

Palavras-chave: *Ultrassom; Ultrassonografia; Currículo; Medicina.*

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INTRODUCTION

Inspection, palpation, percussion, and auscultation have been the four pillars of bedside medicine for more than a century, and clinical examination techniques had virtually no modifications or improvements until 1816 with the invention of the stethoscope by physician Rene Laennec of Quimper, France, of the ophthalmoscope by Hermann Helmholtz in 1845, of the neurological reflex hammer by John Madison Taylor in 1888 and of the otoscope by Guy de Chauliac of Montpellier in 1893.

After the popularization of the stethoscope use, only minimal improvements occurred, such as the inclusion of electronic components that allowed amplification, filtering, and archiving of sounds[1].

The traditional clinical examination can often neglect or misinterpret findings, resulting in incorrect or missed diagnoses[2], since it has limitations, even when performed by experienced physicians who have undergone training and obtained appropriate certifications in accordance with existing training protocols[3].

A technological tool that has shown to be promising in terms of the possibility of improving the clinical diagnosis accuracy is the "POCUS: Point-of-Care Ultrasound" [4]. "POCUS" can be defined as the use of an ultrasound device for diagnosis, used by the attending physician at the point of care, allowing real-time correlation with the patient's signs and symptoms[5]. Ultrasound (US) has long been recognized as an extremely useful diagnostic imaging modality due to the presence of real-time imaging, non-invasiveness, portability, and relatively low cost. Moreover, it does not present the risks associated with the administration of intravenous contrast material or ionizing radiation.

POCUS exams are used to answer specific clinical questions, usually binomial, such as if a patient with pain in the right upper quadrant of the abdomen has a gallbladder stone, a trauma victim has intra-abdominal bleeding, someone with calf edema has deep vein thrombosis, or if dyspnea is being caused by heart or lung diseases[6]. This trend occurs mainly among emergency and intensive care physicians, whose training, in addition to being focused on performing ultrasound-guided procedures, includes training in performing basic thoracic and abdominal ultrasound exams[1].

Thus, many medical and surgical subspecialties are increasingly adopting the use of ultrasonography, as they consider it a complement or extension of the physical examination[7]. One of the facilitators of this process is the fact that the equipment and ultrasonography have become, in recent decades, of better quality, less expensive and more compact[4], and can be easily transported and used both in medical offices and in hospital visits[2].

Authors have referred to the portable point-of-care ultrasound as the "stethoscope of the future"[8], "sonoscope"[9] or as the "visual stethoscope of the 21st century"[10].

Would it be the time to add insonation as a fifth pillar to the physical examination, making POCUS this new element of the bedside examination? [3]. If so, how to train medical students for this new reality? What would be the ideal ultrasound curriculum from the perspective of the general practitioner's training?

Publications have shown the incorporation of ultrasonography in specific disciplines such as anatomy[11,12,13,14,15,16,17,18,19,20,21], physiology[20,22,23,24], semiology[25,26,27,28,29,30,31,32,33,34,35,36,37,38,39.40], emergencies[41,42] and guided procedures[43,44], as well as curricula with longitudinal axes implemented over several years or even all years of the medical course[7,45,46,47,48,49,50,51,52,53,54,55], with most publications showing gains in learning and student satisfaction.

OBJECTIVE

The objective of this study is to review the literature regarding the existing ultrasonography curricula in undergraduate medical courses, preparing a summary of the current state of the art in the teaching of this technique.

METHOD

A narrative review of the literature was carried out, including the PubMed, LILACS and SciELO databases, using the following descriptors in Portuguese: "*ultrassom*", "*ultrassonografia*", "*currículo*", "*medicina*" and "*escola médica*", as well as their corresponding terms in English: "ultrasound", "curriculum", "medicine" and "medical school".

A total of 36 studies were evaluated, all of which were submitted to qualitative analysis and with different approaches regarding the incorporation of ultrasonography into the medical curriculum. Of these, 12 articles were identified that describe ultrasonography curricula in undergraduate medical courses and tables were prepared according to the body regions evaluated or area of knowledge, containing the elements analyzed in each one, grouping the information by similarity and comparing the authors' proposals with each other.

RESULTS

Curricula with distinct characteristics were identified related to the focus on the incorporation of ultrasonography, such as for teaching anatomy, physiology, semiology, emergencies, guided procedures, as well as in a virtual learning environment *(e-learning)*. The respective studies are described in Table 1.

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Table 1. Different approaches to the incorporation of ultrasonography into the medical curriculum.

Field of knowledge	Authors
Anatomy	Teichgraber, 1996 Wittich et al., 2002 Tshibwabwa, 2005 Rao, 2008 Mircea, 2012 Dreher, 2014 Brown, 2012 Swamy, 2012 Sweetman, 2012 Griksaitis, 2014 Kondrashov, 2015
Physiology	Brunner, 1995 Hammoudi, 2013 Griksaitis, 2014 Kondrashova, 2015
Semiology	Shapiro et al., 2002 Kobal, 2005 Angtuaco, 2007 Butter, 2007 Wright, 2008 Afonso, 2010 Fodor, 2012 Jamniczky, 2014 Ahn, 2015; So, 2016 Nelson, 2016 Rempell, 2016 Parikh, 2017 Walrod, 2017 Zoll, 2017 Liu, 2018
Emergencies	Dickerson, 2016 Udrea, 2017
Guided procedures	Griswold-Theodorson, 2009 Osborn, 2012
E-learning or simulators	Cuca, 2013 Bernard, 2015 Florescu, 2015

Source: prepared by the authors.

The term "living anatomy" was introduced in 1996 at the University of Hannover, in Germany[11], related to the dynamic characteristics of the use of ultrasonography in living beings for the teaching of anatomy.

An article written at Durham University in the United Kingdom describes twelve tips for teaching ultrasound in the undergraduate curriculum: 1. Identify a session in which ultrasound can be integrated with the other basic clinical sciences, to help achieve the learning objectives; 2. Choose a suitable physical environment to maximize the students' learning experience, promoting interaction and optimizing opportunities for observation of the patient, the image and the equipment; 3. Ensure that students are familiar with the ultrasound equipment, its buttons and controls, as well as the appropriate configuration before the start of classes, so that classes run smoothly regarding this point. *(*Knobology: study of the handling of buttons and controls of the ultrasound device*)*; 4. Ensure that properly trained staff are available to conduct the exam, guide students on relevant anatomy, and integrate the lesson into the curriculum and learning objectives. 5. Obtain informed consent from the volunteers submitted to ultrasonography and perform an ultrasound scan of the area to be demonstrated before class, in case there is any incidental finding; 6. Have an established protocol for situations that require further investigation if an incidental pathology is identified in an asymptomatic volunteer; 7. Conduct an introductory lecture to set the scene, signal the key points of the required anatomy, and guide students on the ultrasound images that will be studied; 8. Consider patient dignity, positioning, and ergonomics before and throughout the training session; 9. When conducting the training class, permit the initial *"wow-factor"* and then consistently reinforce key learning objectives, transducer orientation, and anatomy, explaining clinical relevance; 10. Allow students supervised *play time*, as they learn significantly when handle the transducer and correlate the transducer orientation and organ anatomy on their own; 11. The evaluation of the class is essential to further develop the pedagogical axis of ultrasound; 12. Incorporate the application of ultrasound into formal course evaluations[20].

A total of 15 comparative tables were prepared among 12 published ultrasonography curricula, grouping items by similarity. Table 2 describes competencies related to the use of the ultrasound device. From Table 3 to Table 13, competencies are included according to the body region or type of anatomical element analyzed. Table 14 includes the area of pediatrics. Table 15 describes the curricular elements related to the use of ultrasonography for guided procedures and Table 16 describes specific ultrasound protocols.

Table 2. Ultrasonography curricula in medical schools. Technical knowledge about the equipment.

Author	Principles of Ultrasonography and Knobology
Heinzow, 2013	• Principles of Ultrasound • Knowledge of standard ultrasound planes • Transducer types • Handling of the ultrasound device
Baltarowich, 2014	• Image acquisition: sound transmission and reflection, dispersion, acoustic window. • Image optimization: depth, focus, gain compensation curve, scan field. • Posterior acoustic properties: posterior enhancement, attenuation, acoustic shadowing. • Artifacts: Near field, reverberation, edge refraction, mirror image. • Terminology: echogenic, hyperechoic, hypoechoic, anechoic, isoechoic. • Characteristics of simple fluid, complex fluid, soft /solid tissue, air/gas, bone/calcium. • Characterization of simple, complex cystic and solid masses. • Imaging modes: B-mode, Doppler (spectral, color, and power), M-mode. • Transducer and image orientation: sagittal, axial, coronal. • Transducers: frequencies, types (linear, convex, sector, transvaginal), near field, far field. • Machine settings: transducer frequency, depth, focus, gain, gain compensation curve • Control buttons: freeze, save images, cine-loop, measures with calipers.
Dinh, 2016-2	• Terminology: echogenic, hyperechoic, hypoechoic, anechoic, isoechoic. • Artifacts: Posterior shadowing, posterior enhancement, reverberation, comet tail, mirror image • Transducers: Linear, Phased Array, Curvilinear • Orientation of the transducer on the patient. • Transducer Care (Cleaning and Routines) • Depth adjustment, gain adjustment, • B-mode, image freeze, image saving, Cine-Loop, use of calipers for measurements, M mode, color Doppler
Mullen, 2018	• Device Initialization • Selecting the appropriate scan setting • Gain and depth adjustment • Demonstration of proper orientation of the transducer indicator • Image Capture • Advantages and disadvantages of each transducer • Change of axial and longitudinal planes
Wakefield, 2018	• Ultrasound physics • Ultrasound artifacts • Knobology
Celebi, 2019	• Artifacts: reverberation, posterior acoustic enhancement, posterior acoustic shadowing, cystic margin shadowing. • Image planes. • Doppler effect and flow velocities. • Image optimization with gain and depth control. • Name of each transducer position, identifying on the monitor where the left and right sides and the cranial, caudal, ventral or dorsal regions are.
Ma, 2020	• Physics of ultrasound: frequency, wavelengths. • Interactions of sound with tissue: reflection, dispersion, refraction. • Common artifacts: reverberation, attenuation, acoustic shadowing, posterior acoustic enhancement. • B-mode image. • M-mode image. • Transducer characteristics. • Transducer orientation. • Scanning plane terminology: coronal, sagittal, axial. • Transducer movements: sliding, heel-toeing/rocking tilting. • Terminology: anechoic, hypoechoic, hyperechoic, complex, heterogeneous. • Recognition of cystic, solid, and non-cystic structures. • Basic knobology : depth, gain. • Primary control: freeze image, save image, cine-loop.

Table 3. Sonography curricula in medical schools: Head and Neck.

Author	Eye	Mouth	Cervical and Thyroid Region
Heinzow, 2013			• Demonstration of normal findings. • Volumetry. • Evaluation of suspicious focal lesions. • Evaluation of different types of thyroiditis. • Color Doppler analysis of cervical vascularization. • Parathyroids.
Fox, 2014	• Retinal detachment. • Vitreous body injury. • Lens dislocation • Rupture of the eyeball • Foreign body • Optic neuritis • Optic nerve sheath widening (intracranial hypertension) • Image of pupillary constriction with the eyelid closed. • Evaluation of afferent pupillary dysfunction.	Additional information about: • Peritonsillar abscess • Peri-apical abscess • Sialolithiasis • Ludwig's Angina	• Location and characterization of superficial and deep neck masses. • Visualization of the thyroid lobes. • Detection of small volume tumor. • Differentiation between solid and cystic tumors. • Patients with hyperparathyroidism: localization of parathyroid adenomas.
Baltarowich, 2014			• Thyroid • Evaluation of cervical/thyroid mass
Dinh, 2015	• Anterior chamber • Vitreous chamber • Crystalline • Optic nerve		• Thyroid • Trachea
Chiem, 2016	• Optic nerve sheath diameter (intracranial pressure). • Normal extraocular movement and pupillary response • Retinal detachment • Vitreous hemorrhage • Vitreous detachment • Lens dislocation • Retroocular hematoma • Masses • Foreign bodies		• Differentiation of lymph nodes, cysts, abscesses, masses. • Normal thyroid lobes.
Wakefield, 2018			• Anterior scanning of the cervical region. • Ultrasonographic appearance of the thyroid and its relationship with the common carotid artery, internal jugular vein and trachea • Cervical examination, including thyroid, trachea, lymph nodes, and muscles.
Celebi, 2019			• Thyroid • Explain how to recognize thyroid nodules, thyroiditis and enlarged lymph nodes.
Ma, 2020			• Thyroid • Thyroid cartilage • Trachea

Table 4. Sonography curricula in medical schools: Thorax.

Author	Lungs	Heart
Heinzow, 2013	• Pneumothorax • Pleural effusion	• Evaluation of pericardial effusion
Fox, 2014	• Detection of various pulmonary pathologies is considerably better than auscultation or even chest X-ray. • Safe, fast and cost-effective alternative to chest CT scan.	• *Ictus cordis* • Different forms of cardiomyopathy • Atrial and ventricular dyskinesia • Normal heart valve movement • Early-stage aortic and mitral regurgitation. • Myocardial thickness • Screening for asymptomatic hypertrophic cardiomyopathy in young athletes
Baltarowich, 2014	• Normal lung • Pleural line • Lung sliding • Pleural effusion • Pneumothorax • Normal diaphragm (hyperechogenicity and movement) • Hemidiaphragm paralysis	• Pericardial effusion (subxiphoid window) • Compression of right chambers and cardiac tamponade • Valve dysfunction • Enlargement of heart chambers and cardiomegaly • Ejection fraction
Dinh, 2015	• Pleural line • Rib shadow • Right hemidiaphragm	• Longitudinal parasternal window • Left ventricle • Right ventricle • Interventricular septum • Aortic valve • Mitral valve
Dinh, 2016-2	• Pleural line • Rib shadow • Lung sliding • (B-mode) • Lung sliding • (M-Mode) • Diaphragm • A-Lines • B-Lines • Pneumothorax (B-Mode) • Pneumothorax (M-Mode) • Pleural effusion • Pulmonary oedema • Interstitial syndrome	• Longitudinal parasternal window • Transverse parasternal window • Apical 4-chamber window • Subxiphoid window • Valve identification • Identification of heart chambers • Left ventricular outflow tract • Pericardial sac • Descending aorta • Global left ventricular function • Pericardial effusion • Cardiac arrest • Cardiac tamponade
Chiem, 2016	• Pneumothorax • Pneumonia • Pulmonary oedema • Acute respiratory distress syndrome (ARDS) • Pleural effusion • Lung contusion	• Normal cardiac structure and function • Pericardial effusion vs tamponade • Valve stenosis, insufficiency, and prolapse • Atrial septal defect, ventricular septal defect, patent foramen ovale • Systolic and diastolic heart failure • Obstructive hypertrophic cardiomyopathy • Heart failure
Mullen, 2018	• Lung parenchyma • Pulmonary oedema • Pleural line • Pneumothorax • Hemothorax • A-Lines • B Lines • Fluid in the costophrenic sinus	• Subxiphoid cardiac window • 4-chamber apical window • Heart longitudinal parasternal window • Transverse window of the heart, with ejection fraction assessment
Wakefield, 2018	• Ribs and their relationship to intercostal muscles and pleura. • Correlation between lung sliding and auscultation of the corresponding lung field.	• Correlation between the four chambers, valves and associated large vessels in the various cardiac windows. • Correlation between heart sounds on cardiovascular examination and valve closure.
Kondrashova and Kondrashov, 2018	• Right and left pleural spaces in costophrenic sinuses • Pneumothorax	• Pericardial effusion

Continue...

Table 4. Continuation.

Author	Lungs	Heart
Celebi, 2019	• Ribs • Visceral pleura • Pleura parietalis • Diaphragm • Pleural effusion • Pneumothorax • Pulmonary edema • Pulmonary consolidation	• Heart in longitudinal and axial parasternal window, four-chambered subxiphoid window. • Left atrium • Right atrium • Left ventricle • Right ventricle • Interventricular septum • Aortic valves • Mitral valve • Tricuspid valve • Aortic root • Papillary muscles • Pericardium • Describe how to recognize: • Pericardial effusion • Severe left ventricular dysfunction • Right heart failure • Volume depletion • Severe valve dysfunction • True pulseless electrical activity
Ma, 2017	• Lung • B-Lines • Pleural effusion • Consolidation • Pneumothorax	• Left ventricular systolic function • Pericardial effusion • Right ventricular overload
Ma, 2020	• Ribs • Pleura • Normal lung: A-lines • Interstitial syndrome: • B-Lines • Pleural effusion • Consolidation • Pneumothorax	• Longitudinal parasternal cardiac window • Axial parasternal cardiac window • Apical 4-chamber window • Subcostal 4-chamber window • Right ventricle • Left ventricle • Left atrium • Right atrium • Interatrial septum • Interventricular Septum • Heart valves • Cardiac apex • Pericardium • Cardiac cycle • Generation of heart sound • Systole / Diastole • Global left ventricular function • Pericardial effusion

Table 5. Ultrasonography curricula in medical schools: Peritoneal Cavity.

Author	Peritoneal cavity
Heinzow, 2013	• Intra-abdominal free fluid
Fox, 2014	• Small-volume ascites, detectable prior to the mobility of ascitic fluid seen on examination. • Measurement of the volume of the "small fluid depth" to evaluate the amount of drainable fluid by paracentesis. • Characterize the presence of free fluid in Morrison Space.
Baltarowich, 2014	• Ascites • Hemoperitoneum
Dinh, 2016-2	• Peritoneal free fluid (ascites and hemoperitoneum)
Chiem, 2016	• Ascites
Mullen, 2018	• Morrison Space • Splenorenal space
Kondrashova and Kondrashov, 2018	• Right upper quadrant: free fluid in the hepatorenal recess • Left upper quadrant: free fluid in the splenorenal recess • Free fluid in the pelvis

Continue...

Table 5. Continuation.

Author	Peritoneal cavity
Celebi, 2019	• Morrison Pouch • Koller Pouch (splenorenal recess) • Douglas Pouch • Describe how to recognize ascites
Ma, 2017	• Free liquid • Ascites
Ma, 2020	• Free fluid in the upper right quadrant • Free fluid in the upper left quadrant • Free fluid in the pelvis

Table 6. ltrasonography curricula in medical schools: Upper Abdomen.

Author	Liver	Gallbladder and Bile Ducts	Pancreas	Spleen
Heinzow, 2013	• Demonstration of normal findings • Liver volumetry • Hepatic steatosis • Suspicious focal lesions • Color-Doppler analysis of portal vein and intrahepatic blood flow	• Normal findings • Cholestasis • Gallbladder wall measurement • Cholecystolithiasis • Choledocholithiasis • Gallbladder volumetry • Gallbladder polyps.	• Normal findings • Fatty infiltration of the pancreas • Suspicious focal lesions • Pancreatitis	• Normal findings • Spleen volumetry • Suspicious focal lesions
Fox, 2014	• Delimitation of the liver margins. • Small masses • Nodules • Hepatitis • Liver volumetry • Lesion measurement • Liver disease detectable prior to physical examination. • Inflammation of the liver detectable prior to fulminant hepatic failure.	• Gallbladder wall thickness measurement • Cholecystitis • Bile duct obstruction • Bile flow measurement • Cholelithiasis		• Spleen measurements • Splenic masses and characterization in cystic or solid
Baltarowich, 2014	• Liver	• Gallbladder • Bile ducts • Assessment of right upper quadrant pain • Obstructive jaundice • Gallstones • Acute cholecystitis • Biliary obstruction	• Pancreas • Head of the pancreas	• Spleen • Splenomegaly
Dinh, 2015	• Liver			• Spleen
Dinh, 2016-2	• Liver	• Gallbladder • Cholelithiasis • Ultrasonographic Murphy's sign		• Spleen
Chiem, 2016	• Normal anatomy and vascularity • Hepatic masses • Cysts • Angiomas	• Cholecystitis • Choledocholithiasis • Cholecystolithiasis		
Mullen, 2018		• Gallbladder		

Continue...

Table 6. Continuation.

Author	Liver	Gallbladder and Bile Ducts	Pancreas	Spleen
Wakefield, 2018	• Location and size of the liver in the abdomen, with particular attention to its projection to the thorax and epigastrium. • Relationship between the gallbladder and the liver. • Correlation of the identification of the liver margin with abdominal physical examination.	• Gallbladder identification • Relationship between the gallbladder and the liver		• Location and size of the spleen in the abdomen, with particular attention to its projection to the thorax.
Celebi, 2019	• Liver • Splenic vein • Portal vein • Portal vein confluence • Explain the anatomical relationships between the vessels. • Describe how to recognize: • Hepatic steatosis • Advanced • cirrhosis of the liver • Liver cyst • Hepatic hemangioma • Liver metastases	• Common bile duct • Gallbladder • Describe how to recognize: • Intra- and extrahepatic cholestasis • Gallstones • Billiary sludge • Cholecystitis • Biliary polyps	• Pancreas • Describe how to recognize: • Pancreatitis • Pancreatic pseudocyst • Pancreatic tumor	• Spleen • Describe how to recognize splenomegaly
Ma, 2020	• Liver	• Gallbladder		• Spleen

Table 7. Ultrasonography curricula in medical schools: Retroperitoneum.

Author	Aorta	Inferior Vena Cava	Retroperitoneum/ Retroperitoneal Lymph Nodes
Heinzow, 2013			• Normal findings • Lymph node enlargement
Fox, 2014	• Abdominal aortic aneurysm and measurements	• Inferior vena cava • Monitoring of caliber variations with respiration for central venous pressure estimation.	
Baltarowich, 2014	• Aorta • Screening and follow-up of abdominal aortic aneurysm	• Inferior vena cava	
Dinh, 2016-2	• Abdominal aorta: proximal, middle, distal and bifurcation • • Abdominal aortic aneurysm	• Inferior vena cava • Differentiation between vein and artery • Compressibility • Color Doppler • Variations of the inferior vena cava in volume replacement	
Chiem, 2016	• Abdominal aortic aneurysm • Aortic abnormalities	• Evaluation of the inferior vena cava in volume replacement	
Mullen, 2018	• Abdominal aorta	• Inferior vena cava	
Wakefield, 2018	• Aorta and its main branches	• Inferior vena cava and its main tributaries	

Continue...

Table 7. Continuation.

Author	Aorta	Inferior Vena Cava	Retroperitoneum/ Retroperitoneal Lymph Nodes
Kondrashova and Kondrashov, 2018	• Abdominal aortic measurements	• Inferior vena cava	
Celebi, 2019	• Aorta • Celiac trunk • Superior mesenteric artery • Renal arteries • Describe how to recognize aortic aneurysm	• Describe how to recognize a collapsible and dilated inferior vena cava	• Describe how to recognize para-aortic lymph node enlargement
Ma, 2017		• Inferior vena cava • Blood volume assessment	
Ma, 2020	• Aorta • Abdominal aortic aneurysm	• Inferior vena cava	• Spine

Table 8. Ultrasonography curricula in medical schools: Bowel and Appendix.

Author	Intestine	Appendix	Perineum
Fox, 2014			• Aid in the detection and characterization of perianal fistulas. • Internal sphincter for evaluation of atrophy or small lacerations.
Baltarowich, 2014		• Suspected appendicitis in children, young patients, or pregnant women	
Chiem, 2016	• Intestinal obstruction	• Appendicitis	
Wakefield, 2018		• Correlation with abdominal examination and identification of McBurney's point.	

Table 9. Ultrasonography curricula in medical schools: Urinary System.

Author	Adrenal	Kidneys	Bladder
Heinzow, 2013	• Adrenal glands	• Normal findings • Kidney volume • Relationship between renal parenchyma and pelvis • Hydronephrosis	
Fox, 2014		• Kidneys • Hydronephrosis • Cysts • Masses • Calculi • Renal parenchymal changes	• Bladder • Measurement of bladder wall thickness • Calculi • Diverticula • Small tumors • Obstruction search • Postvoid residual urine • Ureteric expulsion of urine
Baltarowich, 2014		• Kidneys • Renal failure • Hematuria • Flank pain • Hydronephrosis • Kidney stones	• Urinary bladder • Overdistended urinary bladder • Foley catheter in the bladder
Dinh, 2015		• Right kidney • Left kidney	• Bladder
Dinh, 2016-2		• Kidneys • Hydronephrosis	• Bladder • Qualitative evaluation of bladder volume

Continue...

Table 9. Continuation.

Author	Adrenal	Kidneys	Bladder
Chiem, 2016		• Hydronephrosis • Hydroureter	• Urinary retention
Mullen, 2018		• Right kidney • Left kidney	• Urinary bladder • Bladder volume measurement
Wakefield, 2018		• Location of the kidneys • Correlation of abdominal examination and identification of renal angle	
Kondrashova and Kondrashov, 2018			• Urinary bladder
Celebi, 2019		• Kidneys • Pyelocaliceal system • Renal pyramids • Describe how to recognize: • Cysts • Renal masses • Ureter obstruction	• Describe how to recognize: • Foreign body in the bladder • Masses in the bladder
Ma, 2020		• Kidneys • Hydronephrosis	• Bladder

Table 10. Ultrasonography curriculums in Medical Schools: Male Pelvis.

Author	Prostate	Scrotum
Fox, 2014	• Prostate measurement • Asymmetries in the gland • Prostatic nodules • Rectal masses	• Differentiation between: • Infectious masses, cystic masses, solid tumors, and intestinal loop inside the hernial sac. • Testicular torsion. • Pathological flow patterns.
Baltarowich, 2014	• Prostate • Prostate enlargement	• Testicular pain • Testicular mass • Hydrocele • Testicular torsion • Epididymitis • Varicocele
Chiem, 2016		• Testicular torsion • Masses • Cysts
Celebi, 2019	• Prostate • Seminal vesicles. • Describe how to recognize prostate enlargement	

Table 11. Ultrasonography curricula in medical schools: Gynecology and Obstetrics.

Author	Breast	Gynecology	Obstetrics
Fox, 2014		• Small uterine and adnexal masses from 1 cm.	• First Trimester: • Location of the fetus • Fetal viability (5 weeks)
Baltarowich, 2014	• Differentiation between cystic and solid lesion	• Uterus • Ovaries • Pelvic mass • Pain assessment • Anomalous vaginal bleeding • Trans-abdominal and transvaginal scan: bladder, uterus, ovaries, Douglas Pouch • Uterine fibroid • Endometrial thickening • Hemorrhagic ovarian cyst • Corpus luteum • Ovarian cancer • Hysterosonography *(saline infusion sonography)*	Basic fetal anatomy: • Head • Abdomen • Heartbeat • Limbs • Umbilical cord • Placenta • Cervix Obstetrics: • Abnormal bleeding • Heartbeat • Fetal anatomy • Decreased fetal activity • Suspected ruptured membranes • Premature labor First Trimester: • Gestational sac • Yolk sac • Embryo • M-Mode • Heartbeat Second and third trimesters: • Fetal heartbeat • Placenta • Amniotic fluid • Cervix Pregnancy complications in the first trimester: • Subchorionic hemorrhage • Embryonic death • Ectopic pregnancy • Placenta previa • Isthmus-cervical incompetence • Polyhydramnios • Oligohydramnios
Dinh, 2016-2		• Uterus	• Gestational sac • Yolk sac • Fetal pole • Fetal heartbeat (fetal heart rate assessment) • Recognition of ectopic pregnancy
Chiem, 2016		• Uterine masses • Adnexal and ovarian masses • Cysts • Ovarian torsion	• Normal intrauterine pregnancy: • Crown-Rump length • Fetal heartbeat • Biparietal diameter • Ectopic pregnancy • Fetal anomalies
Kondrashova and Kondrashov, 2018	• Breast layers • Axillary lymph nodes • Lactiferous ducts • Benign tumor • Cysts • Intraductal papilloma • Ductal carcinoma	• Free liquid in Douglas Pouch • Uterus • Fallopian tubes • Endometriosis • Right and left ovaries • Ovarian follicles • Uterine fibroid • Ovarian mass • Ovarian abscess	• Placenta • Fetus • Fetus head with face profile • Heart • Stomach • Cerebellum • Cerebral ventricles • Spine • Fetal sex • Fetal position • Fetal age estimation: • Biparietal diameter, Head circumference, Femur length

Continue...

Table 11. Continuation.

Author	Breast	Gynecology	Obstetrics
Celebi, 2019		• Uterus and vagina • Describe how to recognize uterine fibroids	
Ma, 2020		• Uterus	

Table 12. Ultrasonography curricula in medical schools: Musculoskeletal System.

Author	General Musculoskeletal	Shoulder	Hand	Hip	Knee	Achilles tendon	Fasciculations	Reflexes
Fox, 2014	• Visualization of • Joints • Tendons • Muscles	• Dislocations • Joint effusion • Visualization of muscles and tendons	• Hand Anatomy: • Joints • Bones • Tendons • Cysts • Neuromas • Dislocations • Fractures • Foreign bodies • Erosive arthritis and tenosynovitis in patients with lupus and other joint rheumatic diseases	• Differentiation between fluid collection in the hip and fracture of the proximal femur	• Ligaments • Tendons • Muscles • Nerves • Menisci • Synovium • Articular cartilage • Differentiation between joint effusion, abscess, cellulitis, septic arthritis of the knee.	• Partial and complete rupture of the Achilles tendon	• Fine tremors and fasciculations of muscles that may not be detected on physical examination	• Assessment of the presence of body reflexes (non-invasive alternative to electromyography)
Baltarowich, 2014	• Tendon (principle of anisotropy), • Muscle • Bone surface • Joint fluid • Fluid accumulations (abscess, hematoma) • Evaluation of musculoskeletal pain (muscle, tendon or origin in other superficial soft tissue), effusions, collections							
Dinh, 2016-2	• Skin (dermis and epidermis) • Muscle • Bone • Nerve • Abscess • Foreign bodies • Cellulitis • Joint effusion							
Chiem, 2016	• Differentiation between abscess and cellulitis • Foreign body identification • Long bone fracture and post-reduction • Tendon and ligament rupture	• Shoulder dislocation • Post-reduction shoulder			• Patellar tendon rupture	• Achilles tendon rupture		

Continue...

Table 12. Continuation.

Author	General Musculoskeletal	Shoulder	Hand	Hip	Knee	Achilles tendon	Fasciculations	Reflexes
Wakefield, 2018	• Identification of joint effusion.				• Differentiation of musculoskeletal tissues: • Bone • Cartilage • Tendon • Ligaments • Muscles • Blood vessels • Popliteal fossa • Correlate between anatomy and ultrasonographic anatomy			
Ma, 2017					• Joint effusion			

Table 13. Ultrasonography curricula in medical schools: Vascular.

Author	Cervical Veins	Carotid Arteries and Branches	Peripheral arteries	Peripheral veins
Fox, 2014	• Non-invasive measurement of central venous pressure • Analysis of waveforms consistent with heart disease.	• Blood flow in the carotid arteries. • Atheromatous plaque in the carotid arteries. • Measurement of carotid artery intimal-medial thickness for atherosclerosis • Arterial stenosis or occlusion in the anterior, middle, and posterior brain circulation. • Monitoring of thrombolytic drug effects. • Characterization of vessels at high resolution.	• Arterial pulses at specific points on the body. • Local pressure beat by beat and flow waveform.	• Deep vein thrombosis
Baltarowich, 2014	• Internal jugular vein and subclavian vein for venous access • Differentiation of the corresponding arteries	• Carotid artery (anatomical relationship with the internal jugular vein, carotid bifurcation). • Carotid murmur, evaluation of transient ischemic attack (TIA).		• Deep vein thrombosis in the lower and upper limbs • Femoropopliteal venous system with and without compression
Dinh, 2015	• Internal jugular vein	• Common carotid artery		
Dinh, 2016-2	• Internal jugular vein	• Common carotid artery		• Deep veins of the lower limb • Common femoral vein • Popliteal vein • Vein vs Artery Differentiation • Upper limb veins • Axillary vein • Brachial vein • Cephalic vein • Basilic vein • Deep vein thrombosis (lack of compressibility and/or visualization of the thrombus)

Continue...

Table 13. Continuation.

Author	Cervical Veins	Carotid Arteries and Branches	Peripheral arteries	Peripheral veins
Chiem, 2016	• Normal neck vascularity	• Normal neck vascularity • Carotid artery intimal thickness • Transcranial Doppler		• Deep vein thrombosis
Mullen, 2018		• Carotid arteries		
Wakefield, 2018			• Ultrasonographic appearance of arteries • Transverse and longitudinal axis of vessels • Image acquisition and optimization • Upper limb arteries and their trajectories.	• Ultrasonographic appearance of veins • Transverse and longitudinal axis of vessels. • Image acquisition and optimization • Lower limb arteries and their trajectories.
Celebi, 2019	• Internal jugular vein	• Carotid arteries		• Compression of the deep veins of the thigh • Explain how to exclude deep vein thrombosis.
Ma, 2017	• Internal jugular vein • Blood volume assessment			
Ma, 2020	• Internal jugular vein • Jugular vein height	• Carotid arteries	• Inguinal region • Femoral artery	• Inguinal region • Femoral vein • Great saphenous vein

Table 14. Ultrasonography curricula in medical schools: Pediatrics.

Author	Pediatrics
Heinzow, 2013	
Baltarowich, 2014	• Recurrent urinary tract infections • Neonatal cerebral hemorrhage • Abdominal or pelvic mass • Neonatal hip • Thetered chord • Neonatal brain • Intussusception • Pyloric stenosis • Intracranial hemorrhage
Dinh, 2016-2	• Procedures (demonstrate ultrasound orientation in a simulator/*phantom*) • Central venous access: internal jugular vein • Central venous access: femoral vein • Peripheral venous access • Thoracentesis • Paracentesis
Chiem, 2016	• Differentiation between cellulitis vs abscess • Pre-catheterization bladder volume • Pneumonia • Skull fracture • Long bone fracture • Foreign body identification • Intussusception

Table 15. Ultrasonography curricula in medical schools: Guided Procedures.

Author	Guided Procedures	Anesthesiology
Heinzow, 2013		
Fox, 2014	• Procedure guidance • Ultrasound-guided soft tissue puncture • Example procedures: • Paracentesis • Thoracentesis • Arthrocentesis • Pericardiocentesis • Lumbar puncture • Regional anesthesia • Vascular access • Guided puncture with precision in the joint space for fluid aspiration • Achilles tendon: infiltration of anti-inflammatory drugs • Obliteration of local neovessels	
Baltarowich, 2014	• Pericardiocentesis (tamponade) • Biopsy/aspiration guidance or fluid drainage (if possible) • Paracentesis, thoracentesis • Vascular access: peripherally inserted central catheter, venous or arterial access • Biopsies: liver, kidney, transplant, breast, prostate, thyroid, lymph nodes, masses • Cyst aspiration and breast mass biopsy • Location for aspiration and drainage: abscess, hydronephrosis, cysts • Musculoskeletal procedures: injections, aspirations, foreign body location, biopsies • Amniocentesis, fetal therapeutic procedures	
Chiem, 2016	• Pericardiocentesis • Swan-Ganz Catheter • Thoracentesis • Paracentesis • Lumbar puncture • Pericardiocentesis • Arthrocentesis • Central venous access • Ultrasound-guided biopsies • Procedure guidance: prostate biopsy	• Ultrasound-guided peripheral nerve block • Central Access Insertion • Response to volume responsiveness
Wakefield, 2018	• Central venous access • Needle guidance in dynamic procedures	
Kondrashova and Kondrashov, 2018	• Lumbar Puncture • Central Venous Access • Thoracentesis	
Ma, 2017	• Central venous access • Thoracentesis • Paracentesis • Knee arthrocentesis • Arterial line insertion • Arterial blood gases • Peripheral venous access	
Ma, 2020	• Peripheral venous access • Ultrasound-guided needle orientation	

Table 16. Ultrasonography curricula in medical schools: Specific Protocols.

Author	Protocol
Heinzow, 2013	FAST
Chiem, 2016	FAST RUSH
Wakefield, 2018	ACES RUSH
Celebi, 2019	FAST

FAST: Focused Assessment with Sonography in Trauma.
RUSH: Rapid Ultrasound in Shock.
ACES: Abdominal and Cardiac Evaluation with Sonography in Shock.

DISCUSSION

Point of Care Ultrasound

Radiographic images have been used in the understanding of macroscopic anatomy since the beginning of the last century. From the 1990s onwards, when better performance and relatively less expensive equipment started to emerge, several experts in the field of education foresaw the enormous resource that ultrasound could become in the field of medicine[15].

Many clinical and surgical subspecialties are increasingly adopting the use of ultrasonography, as they consider it a complement or extension of the physical examination[7]. The integration of ultrasound into traditional clinical examination can be a safe tool to improve diagnostic accuracy and immediately confirm suspicious findings at a reasonable cost[46] and can be easily repeated if the patient's condition changes[4]. Its use can improve patient safety and satisfaction, making medical care faster and more economical[56]. One of the facilitators of this process is the fact that the ultrasound equipment has become of better quality, less expensive and more compact in recent decades[4], and can be comfortably transported and used both in medical offices and in hospital visits[2]. Probably its main limitation is its dependence on the operator, and there are several levels of competence that need to be acquired[57]. A study carried out with 196 hospitalized patients, where cardiac and abdominal ultrasonography was performed using a portable device, showed a significant change in the main diagnosis and management in 36 (18.4%) patients, confirmation of the diagnosis in 38 (19.4%) and an important additional diagnosis in 18 (9.2%) of the cases[58]. The use of the point of care as an initial evaluation method in the selection of patients to undergo more detailed examinations has also been mentioned[59].

There is a greater trend toward the use of POCUS among emergency and intensive care physicians, that includes training in the performance of basic thoracic and abdominal ultrasound examinations[1], as well as guided procedures, with better accuracy and reduction of complications when compared to unguided tests[4,43].

Ultrasonography in medical undergraduate school

The remarkable incorporation of ultrasound imaging in medical practice has spread to training in fellowships and residencies, and now also involves undergraduate medical education[34]. Should the physical examination include, in addition to inspection, palpation, percussion, and auscultation, the element of insonation?[3] What would be the ideal ultrasonography curriculum from the perspective of the training of the general practitioner and what is the ideal way to carry out this practice?

For physicians to be able to perform the exams, it is necessary that medical schools have incorporated the teaching of ultrasonography into their undergraduate curricula. *"Ultrasonography in medical education: listening to the echoes of the past to form a vision for the future",* is the title of an article carried out at the University of Irvine in California. POCUS in medical education is growing. Subspecialties should recognize each other's expertise and come together as a cohesive unit to keep up with the educational needs of future generations of physicians[60].

Regardless of at which point in the curriculum ultrasound teaching is incorporated, skills in using the equipment buttons ("basic knobology"), must be acquired before practical classes, as they may represent an excessive cognitive load for students[32].

Ultrasonography, especially when introduced at the beginning of the curriculum, can allow the student to better understand the importance of teaching basic sciences. As future physicians, students must learn to interpret the results of clinical investigations from the early stage of their learning, and the integration of methods such as ultrasonography since the beginning of the medical school provides students with a significant foundation[20].

The American Academy of Emergency Medicine and the American Institute of Ultrasound in Medicine advocate for the integration of US training into the core curriculum of medical schools. In 2013, at the 2nd World Congress on Ultrasonography in Medical Education, more than 85 medical schools met to discuss the topic. The implementation of US in the curriculum improves the learning of basic concepts, improves the understanding of the physical examination, involves students in active learning, and is seen as useful and enjoyable by students[61].

Similarly, the European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) recommends

that ultrasound be used as an educational tool in the curriculum of modern medical schools[62].

Ultrasound imaging is used in preclinical education at most medical schools in the United States (76%) and students are trained to perform practical ultrasonography exams at half of the colleges (49%). However, only a minority of institutions offer an elective internship in POCUS (14%) (63). The learning objectives vary according to the curricular year. The highest workload occurs in the third (penultimate) medical year[56].

Physicians who participated in training during undergraduate school seek more hours of training and perform more exams after graduation, reporting greater proficiency in the use of ultrasound for clinical decision-making, in emergency scenarios, and use of new techniques[64]. The most commonly used environments for teaching ultrasound are anatomy laboratories and simulation laboratories, being guided by non-radiologists with experience in point-of-care ultrasound, at an instructor:student ratio of 1:4[65]. It has also been proposed 1 instructor for every 8 students, and, in this other study, most of the teachers who dedicated time to this activity had training in the area of medical emergencies, followed by family medicine and radiology[66].

Limiting factors for the implementation of an undergraduate ultrasound curriculum include the lack of people with adequate training of knowledge related to the diagnostic accuracy of ultrasonography in the hands of undergraduates, and relative absence of legal frameworks on the subject. The duration of the learning process for image acquisition competence, as well as its interpretation are also variable, extending from only the assessment of the normal to integration within a clinical context[6,67]. Other challenges encountered in the practice of ultrasound teaching include the need for people to be examined, with the possibility of finding a pathology about which a volunteer was unaware[20], as well as the development of instruments to assess ultrasound, as it includes not only the interpretation of the image, but also its acquisition, which requires manual skills with the use of the transducer[68], lack of space in the curriculum and low financial support[56]. Nonetheless, although the current curricula have little space for additional content, classes, and teaching, it seems important to include the basics of ultrasonography in the undergraduate medical curriculum[7].

Care must be taken to avoid assigning a workload below the minimum necessary for learning. An increase in confidence reported by students regarding anatomical knowledge has already been observed, but without significant impact on assessments, making the risk associated with limited exposure questionable, which increases confidence without increasing skills, showing the possibility that the *in vivo* imaging may not be effective when used as a short auxiliary teaching tool[19].

More focused learning objectives demonstrate good learning among first-year medical students, correlated to normal anatomy and physiology: 1. basic physics of ultrasound, instrumentation, and equipment use; 2. Focused cardiac ultrasonography, including anatomy, assessment of global contractility and pericardial effusion; 3. focused thoracic ultrasonography, including anatomy, normal ultrasonographic artifacts, and evaluation of the pleura (for pulmonary edema) and diaphragm (for pleural effusion); 4. focused abdominal ultrasonography, including gallbladder anatomy, appearance of stones, and ultrasonographic evaluation of Murphy's sign, as well as aortic anatomy and abdominal aortic aneurysm evaluation[35].

Regarding the technical aspects, the teaching of ultrasonography can be performed with real equipment (which allows both live models and *phantoms* to be insonated) or through computerized simulators, equipped with transducers similar to the real ones, which show images recorded from the movement that the student makes with the transducer in relation to the body of the simulator (69). Students rate the instructor-led teaching and practice on live volunteers (including transducer selection, knobology, and image adjustment) as superior to teaching by ultrasound simulator (notebooks with simulated ultrasound transducers, which allow the student to manipulate images on the screen in real time).[69]

Studies with remote teaching of ultrasonography have also been published, such as an e-learning program for lung ultrasound. The students in the e-learning group scored similarly to the classroom training in relation to knowledge gain and retention[70], but despite this, the e-learning does not allow the training of the manual skill of handling the device and the patient's insonation for image acquisition. The face-to-face practical moment seems to be the most important for learning, and it has already been demonstrated that there is no significant difference between groups that had previous theoretical classes and those that went directly to the practical class with the ultrasound device. [71].

Ultrasonography is able to integrate form and function dynamically, as well as highlight to students future clinical applications of the basic sciences. This clinical contextualization is important because students can understand why anatomy, physiology, or pathology are important[20]. The prevailing opinion among anatomists, as well as among physicians assisting in the teaching of anatomy and semiology, is that ultrasonography has significant potential to improve anatomical understanding, increase physical examination, and provide a necessary link between the teaching of anatomy during the preclinical years and actual application of clinical

anatomy in patients, subsequently in medical education, for diagnosis and treatment of the disease[34].

The term "living anatomy" was introduced in 1996 at the University of Hannover, in Germany. The authors observed that ultrasonography can bring benefits to first-year medical students such as: correlation of classical topographic anatomy with the living situation, accurate determination of organ sizes, better understanding of sectional anatomy and three-dimensional reasoning, as well as better visualization of anatomical relationships between vessels and organs taking into account physiological phenomena such as, for example, variations in the caliber of veins during breathing. Moreover, a strict separation between basic and clinical sciences is inadequate today, where students need to process more and more knowledge in less time, and quickly forget most of the information as long as they don't see the facts applied to clinical problems. Ultrasonography can be a connection between basic and clinical sciences and, in this way, the inclusion of the ultrasonographic method from the beginning of the course also generates the students' greater motivation due to the possibility of performing clinical correlations[11].

Several medical schools have introduced ultrasonography in the teaching of anatomy and physiology[36,37,39]. Ultrasound allows students to understand characteristics of different tissues and anatomy in several planes, something unattainable in a dissection room or physiology theoretical class[20]. Students consider that anatomy classes using ultrasonography can be used to improve their understanding of anatomy[16,17,18], stimulate the learning of clinical anatomy, and improve clinical reasoning skills.[13] With appropriate and well-planned use, ultrasound can be the key to involving students in the teaching-learning process, promoting the development of deeper approaches to learning through the clinical application of knowledge[20,34].

The use of portable ultrasound equipment in learning cardiac anatomy allows students to contemplate aspects such as the dynamic nature of heart anatomy and physiology in real time,[23] such as the opening and closing of heart valves, blood flow through color Doppler, aspects not visible in conventional cadaveric anatomy.[12] The dynamic correlation between ultrasound, auscultation, and electrocardiogram is also possible.[22,24]

After brief echocardiographic training using a portable ultrasound equipment to detect valvular disease and left ventricular alterations (systolic dysfunction, increased dimensions, and hypertrophy), medical students' diagnostic accuracy was superior to that of experienced cardiologists performing only clinical cardiological examination.[26]

The use of ultrasonography has shown to be useful in the teaching of hepatic semiology, improving the accuracy of the examination, especially in the identification of the edges of the liver for the performance of hepatimetry.[27,31] Learning to diagnose liver diseases at the point of care has also been demonstrated.[25] Ultrasound examination also had advantages over physical examination in the evaluation of the gallbladder and aorta, but it is emphasized that more training is necessary in cases of patient obesity.[27] On the one hand, during the initial phase of learning the clinical abdominal examination, ultrasonography does not provide benefits as an aid method, but for students who have already mastered the basic semiological maneuvers, ultrasonography has proven to be effective in improving the physical examination technique.[28]

It has also been observed that training related to musculoskeletal, abdominal, and cardiac ultrasonography were more successful in retaining relevant anatomical information when compared to the cervical region and eyeball.[21] The use of ultrasonography as a facilitator to understand diseases in rheumatology had good results, despite the small number of students who made up the study group.[29] A study on ultrasonography applied to the anatomical evaluation of the shoulder and knee by medical students has also been conducted, but few anatomical structures have been evaluated in each region.[38]

One of the studies with the largest sample evaluated 307 students after training in semiology, who participated in cardiovascular and abdominal ultrasound activities, initially observing exams and then practicing in standardized patients. The structures most easily identified with ultrasonography by the students were the internal jugular vein and the abdominal aorta. As for the identification of the gallbladder, the heart and structures related to Eco-FAST, it was more challenging, which is related to the different learning curves required for each anatomical structure.[30]

Ultrasonography influenced the correction of thyroid palpation and pulmonary percussion (lower limit of the lung) in a study conducted with 104 medical students.[31]

Previous ultrasound training improves the students' ability to palpate the femoral pulse, but ultrasound had no influence on improving the correct estimation of the anatomical location of the femoral vein.[33]

Medical students who received POCUS training did not show significant differences in mean scores in theoretical assessments but performed better in clinical ability assessments by OSCE (40).

Ultrasound training with tutors and peer instruction provided to 110 students during an emergency medicine internship was very well accepted by the students, with an overwhelming majority stating that they would feel more confident to obtain abdominal ultrasound and FAST visualizations after the course.[41]

A POCUS ultrasound examination performed by medical students and reviewed by an emergency physician, including 482 patients, resulted in a change in management in 17.3% of the exams performed, detected a new diagnosis in 12.4% and reduced the time to discharge by 33.5%. Due to the tests, the physicians avoided requesting an additional imaging study for 53.0% of patients.[42]

Regarding invasive procedures, the use of ultrasonography to guide venous punctures did not reduce the number of attempts required to achieve venous access, but it was observed that vein cannulation is easier when ultrasound is used.[44]

As for the jugular vein, the use of ultrasonography to guide the passage of the jugular central venous catheter by students with little experience in this type of puncture significantly reduced inadvertent arterial puncture, an essential result to improve patient safety.[43]

Literature review on the teaching of ultrasonography in undergraduate medical courses

Researchers from the University of Toronto, Canada, conducted a literature review on the teaching of ultrasonography in undergraduate medical courses. Initially, 328 articles were obtained, of which 128 remained after the application of the inclusion criteria.[72]

Authors from the University of Galway, Ireland, conducted a literature review on the teaching of ultrasonography in undergraduate medical courses. After applying the inclusion and exclusion criteria, 128 articles remained. The authors grouped the data into categories according to the part of the curriculum where the teaching of ultrasonography was anchored: in the teaching of anatomy ("living anatomy"), physiology, physical examination, invasive procedures (in cadavers or in simulated models), as a learning stimulator (including events on social media and competitions), simulation (including ultrasound simulators with a simulated transducer and a non-human model with an image bank, which links real-time changes in the image visible on the screen with hand movements, as well as the insonation of phantoms with real ultrasound equipment), e-learning and online teaching, new teaching techniques (role play, patient simulated by the students themselves, podcasts) or peer tutoring by students from later school years.[73]

In the same year, researchers from the Thomas Jefferson University School of Medicine also conducted a review on the evidence of educational outcomes associated with teaching sonography to medical students. A total of 95 articles were included. The main data observed were that students like and want more training in US. They generally have a positive evaluation, including in the preclinical years, and can learn basic ultrasonography knowledge and skills in relatively short trainings; however, continuous practice is necessary for skill retention. Educators should continue to use expert input to determine the optimal flow and timing for the inclusion of ultrasonography in medical education, as high-quality outcome data remain elusive. The authors suggest that future research should focus less on student perceptions and the ability to learn ultrasonography, but rather on determining where trainings fit best into the undergraduate curriculum to optimize student and patient outcomes.[74]

A study published by the University of Manitoba, Canada, conducted a review on POCUS in cardiology, including the different approaches adopted by various medical training programs regarding the duration of training, knowledge prerequisites, and teaching methodologies (including e-learning, practical training, and simulation). The authors also described issues related to the need for competency assessment and the limitations of the technology itself, and pointed out the role of cardiac ultrasonography as a tool for teaching other knowledges (such as for teaching anatomy) and as a diagnostic skill are different educational pathways. Considering that evidence, that suggests that there is a decrease in the acquired skills in time, it may be necessary to standardize tools for continuous performance evaluation during undergraduate school.[67]

A review was also carried out by researchers from the University of Auckland, in New Zealand, on ultrasonography for the teaching of anatomy. From an initial total of 76 results, 20 were selected to be analyzed. The authors highlight the need for medical students to develop skills in the interpretation and use of ultrasonography due to its importance in clinical practice, predicting a future where a good foundation in the use of ultrasound and image interpretation will be needed for physicians from different areas of expertise.[75]

A group of researchers from the universities of Catania, Milan, Bologna and Parma, in Italy, conducted a literature review with the aim of evaluating whether the integration of ultrasonography classes into the curriculum of medical students improves the learning of the physical examination and improves their skills when performing it. The authors comment that the integration of ultrasound into the undergraduate medical curriculum, whether in a short-term or long-term intervention, seems to improve students' skills and confidence to perform physical examinations, with significant student satisfaction, probably due to the possibility of immediate feedback with the image, allowing the correlation of the position of internal organs with the body surface in real time, helping the student to know whether they are examining the patient correctly, which improves the accuracy

and understanding of the physical examination, especially for palpation and percussion.[76]

CONCLUSIONS

Ultrasonography has been increasingly incorporated into undergraduate medical curricula. It is a method that can help in the teaching of other disciplines such as anatomy, physiology, and semiology, as well as constitute a method of diagnostic aid at the bedside. For its implementation in medical curricula, it is necessary to consider the competencies to be acquired from the perspective of the training of general practitioners. It is necessary to invest in quality equipment and in the training of teachers to achieve the learning objectives.

AUTHORS' CONTRIBUTIONS

Eduardo Antônio Andrade dos Santos contributed to the study conception, literature review and writing of the manuscript. Patricia Carla Zanelatto Gonçalves, Patricia Zen Tempski, Ipojucan Calixto Fraiz contributed to the critical review of the manuscript. Milton Arruda Martins contributed with the study orientation.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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