Entwicklung neuartiger telemedizinischer Applikationen in der Ultraschallausbildung

Inaugural-Dissertation

zur Erlangung des Doktorgrades

der Hohen Medizinischen Fakultät

der Rheinischen Friedrich-Wilhelms-Universität

Bonn

Elena Höhne

aus Köln

2024

Angefertigt mit der Genehmigung
der Medizinischen Fakultät der Universität Bonn

1. Gutachter: PD Dr. med. MUDr. Valentin Sebastian Schäfer
2. Gutachter: Prof. Dr. Lorenz Grigull

Tag der Mündlichen Prüfung: 30.10.2023

Aus der Medizinische Klinik III - Rheumatologie und klinischen Immunologie
Direktor: Univ Prof. Dr. med. Peter Brossart

Inhaltsverzeichnis

Abkürzungsverzeichnis

FAST	Focused Assessment with Sonography for Trauma
POCUS	Point-of-Care-Ultraschall
MCQ	Multipe-Choice Fragen
OSAUS	Objective Structured Assessment of Ultrasound Skills
OSCE	Objective Structured Clinical Examination
DOPS	Direct Observation of Procedural Skills

1. Deutsche Zusammenfassung

1.1 Einleitung

Die Bedeutung von Ultraschall in der Lehre von Medizinstudierenden hat in Europa kontinuierlich an Relevanz gewonnen (Prosch et al. 2020). Dabei haben unterschiedliche Studien gezeigt, dass Ultraschall sowohl zur Verbesserung anatomischer Kenntnisse (Dreher et al. 2014), als auch zur Förderung schwer fassbarer Krankheitsbilder beitragen kann (So et al. 2017). Aktuell besteht kein einheitlicher Konsens hinsichtlich der Integration von Ultraschallunterricht in das herkömmliche Curriculum sowie bezüglich der anschließenden Methodik zur Bewertung der Kompetenzen. Dementsprechend bleibt es den medizinischen Fakultäten selbst überlassen, inwieweit die Eingliederung von Ultraschall in den Lernplan realisiert wird. Die Art und Qualität der Ausbildung hängt dabei von zahlreichen Faktoren ab, darunter verfügbare Ressourcen, Anforderungen des Curriculums, gewählte Lehrmethoden und Fähigkeiten der Lehrkräfte. Neben dem Fehlen standardisierter Leitlinien zur Etablierung eines konsistenten Ansatzes zur Integration des Ultraschalls in die medizinische Ausbildung, hat die weltweite COVID-19-Pandemie zusätzlich zu einer Umstrukturierung der medizinischen Lehrmethoden geführt und die progressiven Bemühungen um eine praxisnahe Ausbildung zurückgeworfen. Aufgrund der Einschränkungen des traditionellen Präsenzunterrichts in der medizinischen Grundausbildung während der vergangenen zwei Jahre wurden neue Unterrichtskonzepte implementiert. Infolgedessen wurden Studien durchgeführt, die die Lehre von Ultraschall mit mobile Geräten oder webbasierten Anwendungen getestet haben (Situ-LaCasse et al. 2021; Zhang et al. 2022). Trotz dieser technologischen Fortschritte, sowie dem wachsenden Interesse an Ultraschall, wurden bislang jedoch begrenzte Anstrengungen unternommen, teledidaktische Ultraschallkurse für Medizinstudierende zu entwickeln (Drake et al. 2021). In Publikation A wurde in einem systematischen Review die unterschiedlichen möglichen Prüfungsformate, die in der Ultraschallausbildung Anwendung finden, veranschaulicht und ihre Vor- und Nachteile gegenübergestellt. In Studie B wurde vor dem Hintergrund der COVID-19-Pandemie und der Abwendung von dem traditionellen Präsenzunterricht ein innovatives teledidaktisches Ultraschall-Curriculum entwickelt und durchgeführt. Publikation C bietet einen Überblick über die Anwendungsbereiche von Ultraschall in der Telemedizin und analysiert potenzielle Auswirkungen der zunehmenden Digitalisierung auf die Verbreitung von Tele-Ultraschall.

1.2 Material und Methoden

Eine systematische Übersichtsarbeit (Publikation A) wurde gemäß der PRISMA-Richtlinien (Page et al. 2021) erstellt. Publikationen zu der Bewertung und Analyse von Ultraschallkenntnissen wurden unter Bezugnahme der medizinischen Datenbanken PubMed, MEDLINE, EMBASE, Cochrane und Google Scholar untersucht. Die Titel sowie Abstracts wurden auf Einschlusskriterien untersucht und die Referenzlisten der identifizierten Artikel wurden auf weitere möglich relevante Artikel beleuchtet. Eingeschlossen wurden dabei sowohl prospektive als auch retrospektive Studien, Beobachtungs- oder Interventionsstudien sowie Studien, in denen verschiedene Bewertungsmethoden beschrieben werden. Ausschlusskriterien waren folgende: keine Angaben zur Bewertungsform oder nur deskriptive Daten, doppelte Artikel innerhalb oder zwischen Datenbanken, Reviews, Abstracts, Newsletter, Konferenzpräsentationen, Expertenmeinungen und Editorials. Die ausgewählten Schlüsselwörter lauteten Ultraschall oder Sonographie, Ausbildung, Medizin, Bewertung, Prüfung sowie Medizinstudierende. Die Schlüsselfragen wurden hierbei nach dem PICOS Format erarbeitet.

Begleitend zur Recherche für das systematische Review wurde ein teledidaktischer Ultraschallkurs am Universitätsklinikum Bonn durchgeführt (Publikation B). Medizinstudierende im Klinischen Abschnitt hatten die Möglichkeit den Kurs als Wahlfach zu belegen. Jeder Teilnehmer erhielt für die Dauer des Kurses ein mobiles ButterflyIQ-Gerät (Butterfly Network Inc, Delaware, USA) sowie die notwendige Ausstattung. Der Kurs setzte sich aus sieben wöchentlich stattfindenden 90-minütigen Modulen zusammen, die sich auf die Ultraschalluntersuchung des Abdomens, des Thorax und der Schilddrüse konzentrierten. Die sieben Module waren folgende: Einführung in die Ultraschalltechnik, Focused Assessment with Sonography for Trauma (FAST) (A), Lunge (B), Niere und Harnorgane (C), Aorta und Vena Cava (D), Schilddrüse (E) und Milz (F). Die Module wurden ausgewählt, um den Studierenden ein allgemeines Verständnis für die

Anwendung des Point-of-Care-Ultraschalls (POCUS) zu vermitteln (Hoppmann et al. 2022). Dabei wurde jedes Modul in einem Flipped-Classroom-Konzept in Zusammenarbeit mit der Amboss-Plattform angeboten (AMBOSS GmbH; Kapitel: Sonografie, Sektion: praktische Fähigkeiten). Flipped-Classroom heißt dabei, dass die Module neben Vorträgen aktive Anteile während des Unterrichts, sowie Aufgaben zur Vor- und Nachbereitung beinhalteten. Dieses ergänzende E-Learning-Angebot war optional und bot zusätzliche Kapitel zu jedem der Module, aus denen der Kurs bestand, sowie die Möglichkeit der Selbstüberprüfung durch die Beantwortung von Multiple-Choice-Fragen (MCQ). Außerdem begann jedes Modul mit einer Vorlesung, die die Handhabung der Ultraschallsonde während der Untersuchung erläuterte und typische Pathologien anhand von Ultraschallbildern zeigte. Durch diese Vorgehensweise sollte ein klinischer Bezug hergestellt werden, da die Studierenden sich gegenseitig oder Freunde zu Hause untersuchten, die in der Regel jung und gesund waren. Anschließend an die Vorlesung wurde die erforderliche Untersuchung live vorgeführt und erläutert. Während der Vorführung der Ultraschalluntersuchung wurde der Handybildschirm mit den Studierenden geteilt, um ihnen das Live-Ultraschallbild zu veranschaulichen. Durch die gleichzeitige Bildschirmübertragung von Ultraschall- und Kamerabildern sollten die Studierenden die Handhabung der Ultraschallsonde und die korrekte anatomische Darstellung der Organe nachvollziehen.

Abb. 1: Durchführung des teledidaktischen Ultraschallkurses

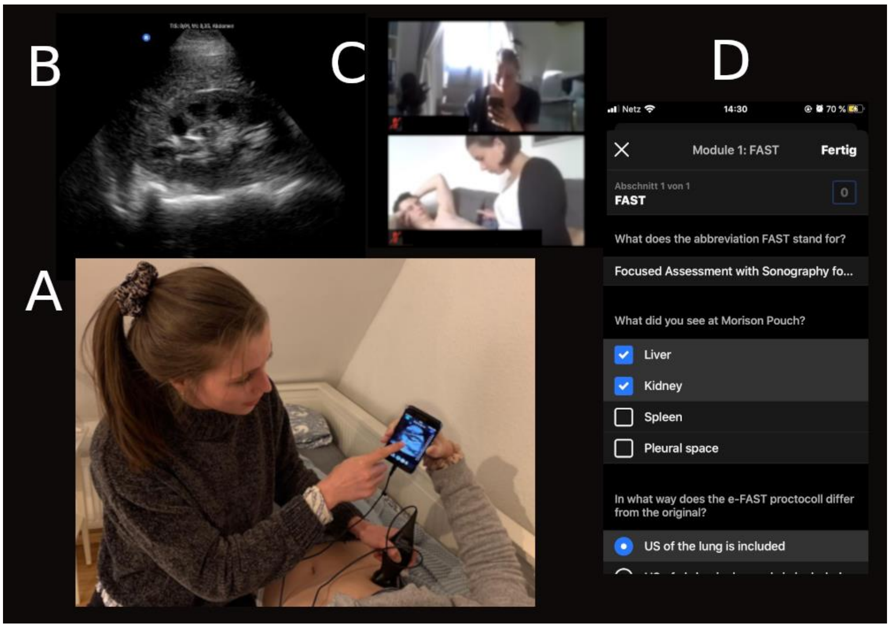


Abb. 1: Es wird die gleichzeitige Bildschirmübertragung von Ultraschall- und Kamerabildern gezeigt (Entnommen aus Publikation B, Seite 3, Textunterschrift übersetzt ins Deutsche).

A: Das Kamerabild des Peer-Tutors wird mit den Studierenden geteilt, während die Untersuchung demonstriert wird

B: Gleichzeitig wird der Bildschirm des Mobiltelefons des Tutors mit den Studierenden geteilt, um die Bildaufnahme zu visualisieren

C: Selbständiges Durchführen der Ultraschalluntersuchung durch die Studierenden zuhause

D: Beispiel für ein Arbeitsblatt, das innerhalb der App ausgefüllt werden musste und zusammen mit den aufgenommenen Ultraschallbildern in der Cloud gespeichert und bewertet wurde

Nach der Vorlesung und Demonstration der Untersuchung hatten die Studierenden Übungszeit, um die Untersuchung selbstständig durchzuführen. Am Ende jedes Moduls wurden die aufgenommenen Ultraschallbilder über die dazugehörige App in ein cloudbasiertes System hochgeladen und ein Arbeitsblatt mit organspezifischen Fragen musste ausgefüllt werden.
Alle, während des Kurses und der Prüfung aufgenommenen Bilder, wurden mit der Brightness Mode Quality Ultrasound Imaging Examination Technique (B-QUIET) (Bahner et al. 2011) bewertet und die erreichten Punktzahlen verglichen. B-QUIET wurde als Ansatz für eine standardisierte Ultraschall Bildinterpretation entwickelt und besteht aus Unterskalen zur Messung von Orientierung/Identifikation, technischen Aspekten und Bildanatomie. Des Weiteren wurde am Ende der Kursperiode mit jedem Teilnehmer eine digitale Objective Structured Assessment of Ultrasound Skills (OSAUS) als Abschlussprüfung durchgeführt (Tolsgaard et al. 2013). Die OSAUS-Skala enthält sieben Schlüsselelemente, die nachfolgend aufgezählt werden: Indikation der Untersuchung, Angewandte Kenntnisse über Ultraschallgeräte, Bildoptimierung, Systematische Untersuchung, Interpretation der Bilder, Dokumentation der Untersuchung und Medizinische Entscheidungsfindung. Dementsprechend ermöglicht die Anwendung des OSAUS-Protokolls die Untersuchung verschiedener Organe unter Verwendung

desselben Fragebogens, da die Bewertungsskala nicht spezifisch für den Ultraschall in einer bestimmten Fachrichtung oder Körperregion ist. Die OSAUS Prüfung wurde unter denselben Bedingungen wie der Kurs abgehalten. Die Studierenden legten die Prüfung von zu Hause aus ab und demonstrierten ihr Vorgehen über Kamera- und Bildschirmübertragung. Durch ein Fallbeispiel geführt, hatten die Teilnehmer insgesamt 30 Minuten Zeit, das heißt etwa fünf Minuten pro Aufgabe. Sowohl bei der praktischen Prüfung als auch bei der Bewertung der akquirierten Ultraschallbilder wurden die Medizinstudierenden von drei unabhängigen Beurteilern bewertet. Die anschließende statistische Auswertung der Ergebnisse wurde mit der Software R durchgeführt (Version i386 4.0.2). Mediane und Standardabweichungen wurden als deskriptive Parameter berechnet. Unterschiede wurden als statistisch signifikant gewertet, wenn $p < 0.05$ lag. Die Interrater Reliabilität der bewerteten Bilder mit B-QUIET sowie der Prüfungsprotokolle der OSAUS Prüfung wurde mithilfe des Intraklassen-Koeffizienten ermittelt (ICC2,1). Dabei kann der ICC nach Rosner folgendermaßen interpretiert werden: ICC <0.4 = schlechte Reliabilität, 0.4-07 = mittelmäßig, >0.75 = exzellent (Rosner 2011) .

1.3 Ergebnisse

In das Systematische Review (Publikation A) wurden nach Anwendung der Inklusions- und Exklusionskriterien insgesamt 101 von 247 Artikel eingeschlossen. Die Auswertung der einbezogenen Studien hat ergeben, dass die am häufigsten verwendeten Prüfungsformate Selbsteinschätzung oder Surveys, MCQ, Objective Structured Clinical Examination (OSCES), Direct Observation of Procedural Skills (DOPS), OSAUS, Bild- oder Fallbasierte Fragen, Fertigkeitsüberprüfung an Simulatoren und Rating der Ultraschallbilder waren. In Publikation A wurden dabei die verschiedenen Testverfahren aufgezeigt und die Vor- und Nachteile der unterschiedlichen Prüfungsformate ausführlich gegenübergestellt (Vgl. Publikation A, Seite 6, Tabelle 3).

Vor der Umsetzung der Studie B haben alle Studierende schriftlich ihr Einverständnis zur Teilnahme abgegeben und die Studie wurde von der Ethikkommission der Universität

Bonn genehmigt (129/29). Insgesamt haben 15 Medizinstudierende den Kurs absolviert. Der Altersdurchschnitt lag bei 24,7 Jahren (SD± 3,6 Jahre). 53 % der teilnehmenden Studierenden haben vor dem Kurs weniger als zehn mal selbstständig Ultraschall am Patienten durchgeführt und vier Studierende (27 %) haben vor dem Kurs noch nie selbst geschallt.

Die Kursteilnehmer wurden im Rahmen der OSAUS Prüfung fünf verschiedenen Aufgaben unterzogen. Dabei konnte bei jeder Aufgabe 35 Punkte erreicht werden und somit eine Gesamtpunktzahl von 175 Punkten. Die mittlere erreichte Punktzahl lag bei 154,5 (SD± 11,7) von 175 und somit wurden im Durchschnitt 88,29 % der Punkte erzielt. Die meisten Punkte wurden dabei in dem Modul Schilddrüse erreicht, mit einem Durchschnittsergebnis von 31,8 von 35 möglichen Punkten (SD± 2,6). Die niedrigste mittlere Punktzahl wurde in dem Modul Aorta und Vena cava erreicht, hier schafften die Studierenden eine Durchschnittspunktzahl von 30,1 (SD± 3,5).

Die Interrater-Reabilität der OSAUS Prüfung lag bei 0,874 (95 %-Konfidenzintervall 0,65 < ICC < 0,965), was nach Rosners Definition als exzellente Realibilität zu verstehen ist.

Bei der Bewertung der Ultraschallbilder anhand des B-QUIET Schematas konnten insgesamt maximal 44 Punkte pro Bild erreicht werden. Bilder aus dem Kurs und der Prüfung wurden für die jeweiligen Module bewertet und die Punktzahl verglichen. Während des Kurses wurden die meisten Punkte für die Bilder des Lungen Moduls vergeben, die Studierenden erreichten durchschnittlich 34,4 (SD± 3,2) von 44 möglichen Punkten. In der Prüfung hingegen haben die Bilder der Schilddrüse am besten abgeschnitten, mit durchschnittlich 35,0 Punkten (SD± 4,4). Die Bilder der Aorta und Cava haben sowohl im Kurs, als auch in der Prüfung im Vergleich zu den anderen Modulen am schlechtesten abeschnitten. Die generelle Durchschnittspunktzahl pro Bild hat im Kurs 31, 2 (SD± 3,8) betragen und in der Prüfung bei 32,3 (SD± 4,0) Punkten gelegen. Dementsprechend haben die Studierenden während der Prüfung eine Verbesserung von durchschnittlich 1,1 Punkten pro Bild erzielt. Der ICC (2,1) für die drei unabhängigen Prüfer der Bilder wurde berechnet und lag bei 0,895 (95 % Konfidenzintervall 0,858 < ICC < 0,924).

Es gab keine Korrelation zwischen der Gesamtpunktzahl in OSAUS und der Gesamt- oder Durchschnittspunktzahl pro Bild, dementsprechend hat der Studierende mit der höchsten Punktzahl in OSAUS nicht zwangsläufig die am höchsten gewerteten Bilder. Die höchste

mittlere Punktzahl in der OSAUS Prüfung erreichten die Studierenden jedoch im Modul Schilddrüse mit 31,8 (SD± 2,59) Punkten, was auch dem Modul mit der höchsten durchschnittlichen Punktzahl in der B-QUIET-Bewertung der Prüfungsbilder entspricht (35,03, SD± 4,41). Parallel dazu erhielten Studierende in dem Modul Aorta und Cava mit 30,13 (SD± 3,15) Punkten die niedrigste Punktzahl im OSAUS und die Bilder wurden mit einem Mittelwert von 30,6 (SD± 3,49) bewertet, was die niedrigste Punktzahl bei den Prüfungsbildern darstellt.
Außerdem bestand kein signifikanter Zusammenhang zwischen der Anzahl der vor dem Kurs durchgeführten Ultraschalluntersuchungen und der erreichten OSAUS-Punktzahl. Der Studierende, der mit einer mittleren Punktzahl von 171,5 von 175 Punkten die höchste OSAUS-Punktzahl erreichte, gab an, vorher noch nie selbstständig eine Ultraschalluntersuchung durchgeführt zu haben. Die nachverfolgten Daten des Flipped-Classroom-Formats von Amboss zeigen eine regelmäßige Nutzung des zusätzlichen, freiwilligen E-Learning-Angebots. Alle Studierenden haben mindestens ein Kapitel bearbeitet und vier Studenten (27 %) haben alle Kapitel bearbeitet. Deutlich mehr Studierende haben die MCQs bearbeitet (80 %) und 90 % der Fragen wurden hierbei korrekt beantwortet. Insbesondere nach der Einführung des E-Learning-Konzepts und kurz vor der Abschlussprüfung wurde eine hohe Anzahl von Zugriffen festgestellt.

1.4 Diskussion

Publikation B zeigt die Evaluation eines neu entwickelten, teledidaktischen Ultraschallkurses des Abdomens, der Schilddrüse und des Thorax mit einem modernen Handgerät. Aus vorherigen systematischen Überblicksarbeiten geht hervor, dass E-Learning eine wirksame Methode zur Lehre im Gesundheitswesen sein kann (Vaona et al. 2018; Tomlinson et al. 2013). Im Hinblick auf die medizinische Ausbildung erweitert die teledidaktische Ausbildung des Ultraschalls das Spektrum der Lehrmethoden, unsere Daten deuten darauf hin, dass es durch die Verwendung eines Flipped-Classroom-Konzepts in Kombination mit einem portablen Gerät möglich ist, einen umfassenden Ultraschallkurs zu konzipieren, um praktische Fertigkeiten entsprechend den didaktischen Anforderungen zu trainieren. Derzeitige Erkenntnisse deuten darauf hin, dass der "Flipped Classroom"-Ansatz in der Ausbildung von Gesundheitsberufen im Vergleich zu traditionellen Lehrmethoden zu einer deutlichen Verbesserung des Lernerfolgs der

Studierenden führt (Lien et al. 2023) und die Vorbereitungszeit für den Kurs ohne zusätzliche Kosten erheblich verkürzt (Tolks et al. 2016). In unserer Studie werden die ersten Ergebnisse vorgestellt, bei denen ein solches Konzept in Kombination mit dem Telelernen praktischer Fertigkeiten eingesetzt wird. Weitere Studien mit Kontrollgruppen, die Unterricht in Präsenz erhalten, sollten durchgeführt werden, um das Konzept mit traditionellem Frontalunterricht zu vergleichen. Wie die Covid-19 Pandemie gezeigt hat, ist die Ausweitung und Weiterentwicklung von Lernstrategien unerlässlich und es sollten aus den Erfahrungen Konsequenzen gezogen werden und ein zukunftsorientierter und wissenschaftlicher Ansatz priorisiert werden. Es empfiehlt sich, einheitliche Standards zu definieren, die festlegen, wie Ultraschall integriert werden sollte und welches Prüfungsformat zum Einsatz kommen soll. Da es sich bei Ultraschall um eine praktische Fertigkeit handelt, sollte die Prüfung idealerweise nicht nur theoretisches Wissen abfragen, sondern auch die Handhabung des Gerätes, Durchführung der Untersuchung und die resultierenden Bilder miteinbeziehen. Durch die Verwendung einer Kombination verschiedener Bewertungsmethoden können einige der Einschränkungen, die jedes Prüfungsformat hat, kompensiert werden und es können unterschiedliche Dimensionen der Fertigkeit getestet werden. Wie Publikation A zeigt, bleibt die Entscheidung, welche Bewertungsmethode oder welche Kombination sich am besten zur Messung der Ultraschallkompetenz eignet, eine anspruchsvolle Aufgabe für die Zukunft. Publikation C kommt zu dem Entschluss, dass die fortschreitende Digitalisierung voraussichtlich zu der Weiterentwicklung und Verbreitung von Tele-Ultraschallverfahren führen wird, insbesondere die Notfallversorgung sowie die Medizinversorgung in abgelegenen Gebieten könnte profitieren. Technologisch gesehen sind die Ultraschallgeräte mobiler geworden und die relativen Kosten sind gesunken, zudem werden auch Smartphones immer alltäglicher und verfügen über Apps, die als erschwingliche tragbare Telemedizinplattformen können (Britton et al. 2019). Die Unterrichtung von Studierenden oder auch Medizinern in strukturschwachen Gebieten im Umgang mit dieser strahlungsfreien Bildgebung durch Online-Methoden könnte mit vergleichsweise wenig Aufwand und kosteneffizient durchgeführt werden. Die digitale Umsetzung mit einem erschwinglichen, tragbaren POCUS-Gerät könnte eine große Chance sein, die Ultraschallausbildung global und über große Distanzen zu fördern.

1.5 Zusammenfassung

In Publikation A wurde anhand der PRISMA Guidelines ein systematisches Review erarbeitet, das sich mit den verschiedenen Bewertungsformaten beschäftigt, die bei der Ultraschallausbildung von Medizinstudierenden Anwendung finden. Dabei gibt es zum jetzigen Stand kein universal genutztes Bewertungsinstrument, sondern es kommt eine Fülle unterschiedlicher Formate zum Einsatz. Die meistbenutzten Prüfungsformat sind dabei Selbsteinschätzung oder Surveys, MCQ, OSCES, DOPS, OSAUS, Bild- oder Fallbasierte Fragen, Fertigkeitsüberprüfung an Simulatoren und Rating der Ultraschallbilder. Künftige Studien sollten dazu streben einen allgemeinen Ansatz für eine gleichwertige Ultraschallausbildung und Bewertung an verschiedenen Universitäten zu entwickeln, um zu einer geringeren Variabilität in der praktischen Ausbildung beizutragen.

In Publikation B wurde ein teledidaktischer Ultraschallkurs für Medizinstudierende im klinischen Abschnitt entwickelt. Hierbei wurde virtuell anhand von Video- und Handybildschirmübertragung Ultraschalluntersuchungen vorgeführt, die daraufhin von Studierenden zuhause nachgeahmt wurden. Anhand von sieben Kurs Modulen und Vorlesungen sowie darauf zugeschnittene Amboss Lern-Modulen wurde hierbei Wissen und praktische Fertigkeiten über die grundlegende Ultraschalluntersuchung von Thorax, Abdomen und Schilddrüse vermittelt. Die Studierenden haben während des Kurses vordefinierte Ultraschallbilder aufgenommen, die von drei unabhängigen Ratern bewertet wurden. Die Kursbilder wurden mit Bildern aus der Abschlussprüfung verglichen, die nach acht Wochen stattfand. Die Abschlussprüfung wurde dabei anhand des OSAUS Protokolls abgehalten und hat theoretische und praktische Fertigkeiten geprüft. Die Ergebnisse der OSAUS Prüfung wurden mit den Ergebnissen der Bilder aus Kurs sowie Prüfung verglichen. Dabei wurden im Bilderrating der Prüfungsbilder durchschnittliche 32,3 Punkte erreicht, was 73 % der möglichen Punktzahl entspricht. In der OSAUS Prüfung lag die mittlere erreichte Punktzahl bei 154,5 (SD ± 11.7) von 175 und somit wurden im Durchschnitt 88,29 % der Punkte erzielt. Diese Studie sollte als Proof-of-Concept Studie verstanden werden und zukünftig muss dieses teledidaktische Konzept durch weitere Forschung untersucht und bestätigt werden. Dieses Lehrkonzept könnte nicht nur helfen digitalen Unterricht voranzutreiben, sondern auch der Forschung im Gesundheitswesen entlegener Gebiete helfen. Wie wir in der aktuellen Pandemie gesehen haben, ist der Ausbau digitaler Lernmöglichkeiten nicht nur nötig, sondern unvermeidbar. Wie man in Zeiten der globalen Gesundheitskrise gesehen hat, ist es wichtig, sich auf fortschrittliche Ansätze zu konzentrieren, um die praktischen Bildungsstrategien zu erweitern.

1.6 Literaturverzeichnis der deutschen Zusammenfassung

AMBOSS GmbH; Kapitel: Sonografie, Sektion: praktische Fähigkeiten (2022). Online verfügbar unter https://www.amboss.com/de, zuletzt aktualisiert am 31.10.2022, zuletzt geprüft am 31.10.2022.

Bahner, David P.; Adkins, Eric J.; Nagel, Rollin; Way, David; Werman, Howard A.; Royall, Nelson A. (2011): Brightness mode quality ultrasound imaging examination technique (B-QUIET): quantifying quality in ultrasound imaging. In: *Journal of ultrasound in medicine : official journal of the American Institute of Ultrasound in Medicine* 30 (12), S. 1649–1655. DOI: 10.7863/jum.2011.30.12.1649.

Britton, Noel; Miller, Michael A.; Safadi, Sami; Siegel, Ariel; Levine, Andrea R.; McCurdy, Michael T. (2019): Tele-Ultrasound in Resource-Limited Settings: A Systematic Review. In: *Frontiers in public health* 7, S. 244. DOI: 10.3389/fpubh.2019.00244.

Butterfly Network Inc, Delaware, USA (2022). Online verfügbar unter https://www.butterflynetwork.com/, zuletzt aktualisiert am 31.10.2022, zuletzt geprüft am 31.10.2022.

Drake, Anne E.; Hy, Jonathan; MacDougall, Gordon A.; Holmes, Brendan; Icken, Lauren; Schrock, Jon W.; Jones, Robert A. (2021): Innovations with tele-ultrasound in education sonography: the use of tele-ultrasound to train novice scanners. In: *The ultrasound journal* 13 (1), S. 6. DOI: 10.1186/s13089-021-00210-0.

Dreher, Stephanie M.; DePhilip, Robert; Bahner, David (2014): Ultrasound exposure during gross anatomy. In: *The Journal of emergency medicine* 46 (2), S. 231–240. DOI: 10.1016/j.jemermed.2013.08.028.

Hoppmann, Richard A.; Mladenovic, Jeanette; Melniker, Lawrence; Badea, Radu; Blaivas, Michael; Montorfano, Miguel et al. (2022): International consensus conference recommendations on ultrasound education for undergraduate medical students. In: *The ultrasound journal* 14 (1), S. 31. DOI: 10.1186/s13089-022-00279-1.

Lien, Wan-Ching; Lin, Phone; Chang, Chih-Heng; Wu, Meng-Che; Wu, Cheng-Yi (2023): The effect of e-learning on point-of-care ultrasound education in novices. In: *Medical education online* 28 (1), S. 2152522. DOI: 10.1080/10872981.2022.2152522.

Page, Matthew J.; McKenzie, Joanne E.; Bossuyt, Patrick M.; Boutron, Isabelle; Hoffmann, Tammy C.; Mulrow, Cynthia D. et al. (2021): The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. In: *BMJ (Clinical research ed.)* 372, n71. DOI: 10.1136/bmj.n71.

Prosch, Helmut; Radzina, Maija; Dietrich, Christoph F.; Nielsen, Michael Bachmann; Baumann, Sven; Ewertsen, Caroline et al. (2020): Ultrasound Curricula of Student Education in Europe: Summary of the Experience. In: *Ultrasound international open* 6 (1), E25-E33. DOI: 10.1055/a-1183-3009.

Rosner, Bernard A. (2011): Fundamentals of biostatistics. 7th ed. Boston, MA: Brooks/Cole, Cengage Learning.

Situ-LaCasse, Elaine; Acuña, Josie; Huynh, Dang; Amini, Richard; Irving, Steven; Samsel, Kara et al. (2021): Can ultrasound novices develop image acquisition skills after reviewing online ultrasound modules? In: *BMC medical education* 21 (1), S. 175. DOI: 10.1186/s12909-021-02612-z.

So, Sokpoleak; Patel, Rita M.; Orebaugh, Steven L. (2017): Ultrasound imaging in medical student education: Impact on learning anatomy and physical diagnosis. In: *Anatomical sciences education* 10 (2), S. 176–189. DOI: 10.1002/ase.1630.

Tolks, Daniel; Schäfer, Christine; Raupach, Tobias; Kruse, Leona; Sarikas, Antonio; Gerhardt-Szép, Susanne et al. (2016): An Introduction to the Inverted/Flipped Classroom Model in Education and Advanced Training in Medicine and in the Healthcare Professions. In: *GMS Journal for Medical Education* 33 (3), Doc46. DOI: 10.3205/zma001045.

Tolsgaard, Martin G.; Todsen, Tobias; Sorensen, Jette L.; Ringsted, Charlotte; Lorentzen, Torben; Ottesen, Bent; Tabor, Ann (2013): International multispecialty consensus on how to evaluate ultrasound competence: a Delphi consensus survey. In: *PloS one* 8 (2), e57687. DOI: 10.1371/journal.pone.0057687.

Tomlinson, Jo; Shaw, Tim; Munro, Ana; Johnson, Ros; Madden, D. Lynne; Phillips, Rosemary; McGregor, Deborah (2013): How does tele-learning compare with other forms of education delivery? A systematic review of tele-learning educational outcomes for health professionals. In: *New South Wales public health bulletin* 24 (2), S. 70–75. DOI: 10.1071/NB12076.

Vaona, Alberto; Banzi, Rita; Kwag, Koren H.; Rigon, Giulio; Cereda, Danilo; Pecoraro, Valentina et al. (2018): E-learning for health professionals. In: *The Cochrane Database of Systematic Reviews* 1 (1), CD011736. DOI: 10.1002/14651858.CD011736.pub2.

Zhang, Yi; Li, Shenyi; Long, Xiangdang; Li, Xi (2022): A real-time video-based social network platform for online ultrasound education. In: *BMC Med Educ* 22 (1), S. 160. DOI: 10.1186/s12909-022-03220-1.

2. Veröffentlichung A

frontiers | Frontiers in Medicine

SYSTEMATIC REVIEW
published: 09 June 2022
doi: 10.3389/fmed.2022.871957

Assessment Methods in Medical Ultrasound Education

Elena Höhne[1†], *Florian Recker*[2*†], *Christoph Frank Dietrich*[3] and *Valentin Sebastian Schäfer*[1]

[1] *Clinic of Internal Medicine III, Oncology, Hematology, Rheumatology and Clinical Immunology, University Hospital Bonn, Bonn, Germany,* [2] *Department of Obstetrics and Prenatal Medicine, University Hospital Bonn, Bonn, Germany,* [3] *Department of Internal Medicine, Clinics Beau-Site, Salem, and Permanence, Bern, Switzerland*

Medical schools are increasingly incorporating ultrasound into undergraduate medical education. The global integration of ultrasound into teaching curricula and physical examination necessitates a strict evaluation of the technology's benefit and the reporting of results. Course structures and assessment instruments vary and there are no national or worldwide standards yet. This systematic literature review aims to provide an up-to-date overview of the various formats for assessing ultrasound skills. The key questions were framed in the PICO format (Population, Intervention, Comparator, and Outcome). A review of literature using Embase, PubMed, Medline, Cochrane and Google Scholar was performed up to May 2021, while keywords were predetermined by the authors. Inclusion criteria were as follows: prospective as well as retrospective studies, observational or intervention studies, and studies outlining how medical students learn ultrasound. In this study, 101 articles from the literature search matched the inclusion criteria and were investigated. The most frequently used methods were objective structured clinical examinations (OSCE), multiple choice questions, and self-assessments *via* questionnaires while frequently more than one assessment method was applied. Determining which assessment method or combination is ideal to measure ultrasound competency remains a difficult task for the future, as does the development of an equitable education approach leading to reduced heterogeneity in curriculum design and students attaining equivalent skills.

Keywords: medical education, assessment, ultrasound, undergraduate education, practical skills

OPEN ACCESS

Edited by:
Ahsan Sethi,
Qatar University, Qatar

Reviewed by:
Majed Wadi,
Qassim University, Saudi Arabia
David Resuehr,
University of Alabama at Birmingham, United States

Correspondence:
Florian Recker
florian.recker@ukbonn.de

†These authors have contributed equally to this work

Specialty section:
This article was submitted to Healthcare Professions Education, a section of the journal Frontiers in Medicine

Received: *23 February 2022*
Accepted: *11 May 2022*
Published: *09 June 2022*

Citation:
Höhne E, Recker F, Dietrich CF and Schäfer VS (2022) Assessment Methods in Medical Ultrasound Education. Front. Med. 9:871957. doi: 10.3389/fmed.2022.871957

INTRODUCTION

Ultrasound examinations and obtained images are highly dependent on the physician's competence. Integration of ultrasound training offers opportunities to provide instruction in the use of novel educational and clinical practice tools and there is wide support for the incorporation into undergraduate medical education. However, despite growing interest in ultrasound education, course structure and implementation in undergraduate medical education programs differ between universities and countries without national standards and guidelines (1). A critical difficulty in ultrasound training is allocating time and funds for training programs in overburdened curricula. Early analyses demonstrated that in small cohorts, medical students were able to develop the psychomotor and interpretative skills required for effective focused ultrasound. For example, 1st year medical students were able to successfully use portable ultrasound after following six 90-min sessions covering abdominal, cardiovascular, genitourinary, and musculoskeletal applications (2). Recently, the European Federation of Medical and Biological Ultrasound Societies (EFSUMB) and the World Federation for Ultrasound in Medicine and Biology (WFUMB) have promoted undergraduate medical ultrasound education within European medical faculties and have developed measures to accomplish this objective (3, 4). The use of ultrasound in medical education depends on curricular requirements as well as the type of equipment available, the selected educational approach and faculty skill sets. These determine the type and quality of training delivered to students. Selecting an appropriate assessment method is crucial given the need to closely align learning objectives, instructional methods and exams. Reliable methods to assess physician's skills in performing ultrasound are critical for training and to prove the curriculum's quality (5). The global integration of ultrasound into medical education will make a regulated assessment and report of the results essential (6) in order to estimate and compare the efficacy of different attempts to organize ultrasound courses in medical education (7). There are various goals of assessment, including the optimization of learning and direct feedback in order to protect patients from insufficiently educated doctors (8) and to re-certify individuals, whose skills may have declined over time (9). However, a standardized method to evaluate ultrasound knowledge or of higher importance to assess the examination performance does not exist yet (9–11).

It has been proposed that the practical examination should include assessment of accurate machine settings, probe handling, image acquisition as well as documentation (12).

To assess various examination formats used for ultrasound in medical education, a systematic literature review of the MEDLINE, EMBASE, Cochrane, PubMed, and Google Scholar Databases was conducted to identify published literature on ultrasound assessment in undergraduate or graduate medical training.

MATERIALS AND METHODS

Search Strategy

This systematic literature review was conducted according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (13).

Relevant medical databases, including PubMed, MEDLINE, EMBASE, Cochrane and Google Scholar were searched for publications related to the assessment of ultrasound skills up to May 2021, while keywords were predetermined by the authors (**Figure 1**). Titles and abstracts were analyzed for possible inclusion. In addition, reference lists of the identified articles were investigated for further potential inclusion. Agreement regarding potential relevance was reached by consensus and full text copies of relevant papers were obtained. The key questions of this systematic literature review were framed in the PICOS format (Population, Intervention, Comparator, Outcome, and Study design) as detailed in **Table 1**.

Inclusion Criteria

Articles meeting the following criteria were suitable for inclusion:

- Prospective as well as retrospective studies, observational or intervention studies, and studies outlining different assessment methods.
- The following keywords were combined: (ultrasound or sonography) and (education, medical) or (medical students) and (assessment) or (exam).

Exclusion criteria were:

- No data about the form of assessment or descriptive data only
- Duplicate articles within or between data bases
- Reviews
- Abstracts only
- Newsletters
- Conference presentations
- Expert opinions
- Editorials

The different assessment formats were structured in subclasses, which are the following: theoretical knowledge (written or online examination, multiple choice questions (MCQ) or essay questions), practical examination skills [e.g., US acquisition (US image rating), observed simulated clinical encounters (Objective Structured Clinical Examination (OSCEs), The Objective Structured Assessment of Ultrasound Skills (OSAUS), Direct Observation of Procedural Skills (DOPS))], and self-assessment (e.g., surveys regarding satisfaction and competence).

Data originated from full-text articles is presented in a structured table (**Table 2**) to illustrate the various assessment formats in ultrasound education and to give selected examples for the outlined evaluation methods.

RESULTS

The results section that follows should provide a general understanding of the various assessment forms utilized in the evaluation of ultrasound.

Self-Assessment

In many cases evaluation is based on self-assessment using surveys or questionnaires, sometimes in a pre-/post course design. Self-assessment can help to evaluate the student's thoughts and manners when learning and it can identify tactics that enhance better understanding and improvement of skills.

Further, students can rate their own competence, which might motivate them to improve their skills as they detect incongruity between present and wanted performance. According to one study, self-evaluation can help students improve their critical thinking skills (52) further it might encourage reflection on personal performance (53).

Creating surveys is time- and cost-effective and the evaluator does not essentially have to be a specialist. Since the evaluation is based on subjective data when using self-assessment, there is the threat of discrepancy between actual performance and answers given in the survey. Students might not rate their actual performance competence but the effort they put into the course (54).

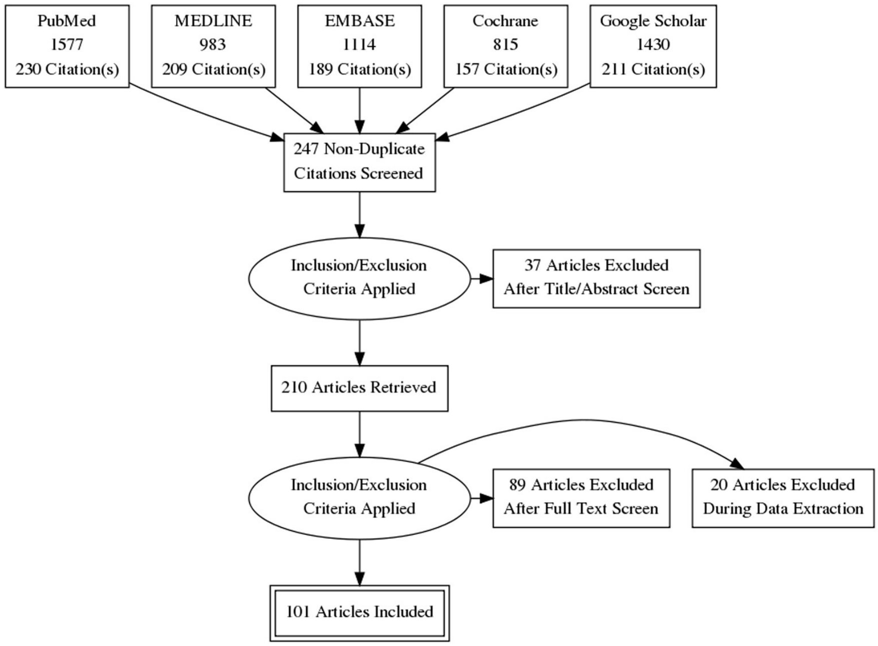


FIGURE 1 | This systematic literature review was conducted according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. The figure displays the review process, at the end 101 of 247 articles have been included.

TABLE 1 | Key questions of ultrasound methods and medical ultrasound education.

Population	Medical students, residents, physicians
Intervention	Ultrasound in education
Comparator	Different approaches to assess ultrasound skills
Outcome	Analysis of course structures and assessment instruments
Study Design	Prospective and retrospective studies, observational or interventional studies

There is no acquisition of genuine knowledge and competence in examination as no objective data is generated. Additionally, there is a risk of decreased validity by response bias which are prevalent in research involving participant's self-report. For example, the study results can be influenced by acquiescence bias, which belongs to response bias and describes that participants in a survey have the tendency to agree with the asked questions.

Objective Structured Clinical Examination (OSCE)

The objective structured clinical examination (OSCE) was developed by Harden and colleagues in 1975 (55). The idea is rotating through multiple stations in a simulated clinical setting. Each of these stations challenges the student to solve a special task in a pre-specified time in order to test clinical skill performance. While the students carry out the examination they are observed by one or two assessors who rate the student's performance using checklists which have been developed in advance.

OSCE has been widely accepted as an objective form of assessing clinical competences (56) and is used in various specializations and clinical tasks.

It allows the assessment of scanning technique and image interpretation in real time and combines the evaluation of technical skills and theoretical knowledge. Further, the possibility for direct feedback on the student's performance is provided and it aims to prepare students for daily clinical practice. There are different assessors with every station and the students should rotate so that they should all have the same time and tasks to bring fairness.

Within an OSCE, different forms of assessment can be combined since e.g., at one station case- based US images could be diagnosed while the next task requires the students to examine a patient to obtain own images to observe the student's probe handling and scanning technique.

In general, the checklist for ultrasound can include various aspects, which have been defined prior to the assessment. Items that are often included are e.g., positioning of the patient as well as interaction with the patient, positioning/handling/orientation of the ultrasound probe, image adjustment, and interpretation. A different OSCE station is needed for each organ as the protocols are individually tailored.

Therefore, the large number of stations and the various protocols to test different organs as well as the required educated

TABLE 2 | Example studies.

References	Study design	Study site	Number of participants	Assessment
Bernard et al. (14)	Prospective observational study	Loma Linda University School of Medicine	8	Post-instructional survey
Hammoudi et al. (15)	Prospective observational study	Faculty of Medicine Pierre et Marie Curie	348	Survey and open feedback
Hoyer et al. (16)	Single-center cross-sectional study	University of Arizona	55	Self-assessment by questionaire
Ivanusic et al. (17)	Prospective observational study	University of Melbourne	119	Survey and open feedback
Brown et al. (18)	Prospective observational study	University of Arizona	100	Survey and identification of US images
Keddis et al. (19)	Prospective observational study	Mayo Clinic Rochester, Minnesota	76	Pre- and post-survey
Rempell et al. (20)	Prospective observational study	Havard Medical School, Boston	176	Post-assessment survey
Swamy and Searle (21)	Prospective observational study	Durham University	215	Questionnaire
Teichgraber et al. (22)	Prospective observational study	Hannover Medical School	113	Questionnaire
Moscova et al. (23)	Prospective observational study	University of Sydney	901	Survey and open feedback
Dinh et al. (24)	Prospective observational study	Loma Linda University	163	Questionnaire, OSCE
Duanmu et al. (25)	Cross-sectional cohort study	Stanford University School of Medicine	29	OSCE
Hofer et al. (7)	Prospective observational study	H.-Heine University Düsseldorf	626	OSCE
Sisley et al. (5)	Prospective observational study	University of Arizona	82	OSCE
Knobe et al. (26)	Randomized controlled trial	RWTH Aachen University	151	OSCE, MCQ
Lozano-Lozano et al. (27)	Randomized controlled multicenter study	University of Granada	110	OSCE, MCQ, survey
Hofer et al. (28)	Longitudinal two cohort study	H.-Heine University Düsseldorf	2,485	OSCE
Gogalniceanu et al. (29)	Prospective observational study	Imperial College London	25	OSCE
Knobe et al. (30)	Randomized cross-over controlled trial	RWTH Aachen University	242	OSCE, MCQ
Bornemann (31)	Prospective observational study	University of South Carolina School of Medicine	17	OSCE, MCQ
Henwood et al. (32)	Prospective cohort study	Kigali, Rwanda	29	OSCE, image based assessment
Chuan et al. (33)	Prospective cohort study	Australian and New Zealand College of Anaesthestists	49	DOPS
Nilsson et al. (34)	Randomized controlled trial	University of Copenhagen	38	OSAUS
Royer et al. (35)	Prospective observational study	University of Colorado	32	Knowledge quiz, pre- and post-survey
Heinzow et al. (36)	Prospective observational study	University Hospital Münster	240	DOPS, pre- and post-survey
Hempel et al. (37)	Prospective observational study	Johann Wolfgang Goethe University Frankfurt	91	Questionaire to assess theoretical knowledge
Fox et al. (38)	Prospective controlled trial	University of California, Irvine School of Medicine	45	Image based test
Noble et al. (39)	Prospective cohort study	Massachusetts General Hospital	30	Image based test
Syperda et al. (40)	Prospective observational study	Lake Erie College of Osteopathic Medicine-Bradenton	5	Case based test
Madsen et al. (41)	Prospective observational study	University of Copenhagen	28	Assessment using virtual-reality ultrasound simulators
Yoo et al. (42)	Randomized controlled trial	University of Texas Southwestern Medical Center	28	Assessment using simulators and MCQ
Kobal et al. (43)	Prospective interventional study	University of California, Los Angeles	7	Comparison of findings between students and specialists
Mouratev et al. (44)	Prospective interventional study	University of South Carolina School of Medicine	14	Comparison of findings between students and specialists
Angtuaco et al. (45)	Prospective interventional study	University of Arkansas for Medical Sciences	24	Comparison of findings between students and specialists

(Continued)

TABLE 2 | Continued

References	Study design	Study site	Number of participants	Assessment
Arger et al. (46)	Prospective observational study	University of Pennsylvania School of Medicine	33	Image rating
Mullen et al. (47)	Prospective observational study	California Northstate University College of Medicine	28	Real-time image rating
Tshibwabwa and Groves (48)	Prospective observational study	McMaster University Medical Center	490	Real-time image rating
Wittich et al. (49)	Prospective observational study	Mayo Medical School	42	Image rating
Fernández-Frackelton et al. (50)	Prospective observational study	Harbor-UCLA Medical Center	31	Image rating, pre- and post-theoretical test
Shapiroa et al. (51)	Prospective observational study	Mount Sinai School of Medicine	5	Image rating

Data originated from full-text articles is presented in a table to illustrate the various assessment formats in ultrasound education and to give selected examples for the outlined evaluation methods.

assessors may exceed the available resources (36). OSCEs require staff, equipment, clinical laboratories as well as long preparations. Furthermore, to avoid bias, two assessors each station would be preferable, resulting in even higher cost- and time investment. OSCEs might not display a realistic hospital setting (57).

As the time allotted to each station is predetermined, students may become stressed and be unable to complete the task to their own expectations owing to time constraints. However, limited time may compel a higher level of training motivation and motivate students to practice more in order to achieve satisfactory outcomes (7).

Direct Observation of Procedural Skills (DOPS)

The concept of direct observation of procedural skills (DOPS) was developed by the Royal Medical College of England. The assessor observes the student during the clinical procedure on a real patient and gives feedback afterwards, it is a workplace-based assessment method.

Further, DOPS combines learning, supervision, rating and feedback (58) and can be both formative and summative (59).

Designing specific protocols for grading facilitates detailed feedback and fairness since the assessor has the same base to rate the different students.

The use of workplace-based assessment is useful since it determines not only the students' learning achievements but also their attempt to assume professional responsibilities (60). Scanning technique and image interpretation can be assessed in real time and therefore theoretical knowledge as well as examination technique can be rated. DOPS have been used for ultrasound assessment and seems to be a reliable and valid method (36) and requires less assessment stations and resources than an OSCE format. However, an educated assessor is necessary for the evaluation of the student and it would be even better to have two independent raters. Further, in comparison to OSCE, DOPS is not widely established in ultrasound assessment and there might be more studies required to show its efficacy and validity.

Objective Structured Assessment of Ultrasound Skills (OSAUS)

The Objective Structured Assessment of Ultrasound Skills (OSAUS) was developed as an approach to achieve international consensus across various specialities on an evaluation tool for ultrasound education (9). Based on a delphi-consensus seven key points have been identified and included in the protocol.

These key points are: (1) Indication for the examination, (2) Applied knowledge of ultrasound equipment, (3) Image optimization, (4) Systematic examination, (5) Interpretation of images, (6) Documentation of examination, and (7) Medical decision making.

OSAUS can be used to assess US competence in different clinical settings and disciplines. It is a time-effective method as the protocol should be used universally there is no need of developing a new protocol for various specializations/organs. However, OSAUS is measuring general aspects and is not procedure specific.

The student is asked, to state the indication for the examination, as well as how the examination could help in further decision making and treatment. Therefore, the student learns the importance of ultrasound and the practical applications of this imaging method.

Further studies are required to examine the value of the protocol to assess ultrasound competence in different fields and clinical settings.

Multiple Choice and Written Questions

Examinations in form of multiple choice (MCQ) or written questions are often used additionally to a direct observation of scanning technique (26, 27, 61).

Using MCQ is objective and the questions could be included in any existing examination.

Further, no educated assessor is required for the real-time assessment of skills.

Due to the absence of an ultrasound examination, evaluating scanning method and image optimization is not feasible. Whereas, ultrasound is a technical skill, the assessment with MCQ rather checks theoretical knowledge.

TABLE 3 | Ultrasound assessments in medical education.

Form of assessment	Positive aspects	Negative aspects
Self-assessment or surveys regarding satisfaction	• Easy to create and evaluate • No need of a specialist as assessor • Cost effective	• Only subjective elements are measured, no objective view • No direct feedback to the student • No information about actual knowledge or practical skills • Bias possible, depending on the question structure
OSCE	• Assessment of both scanning technique and image interpretation • Combines evaluation of technical skills and knowledge in real time • Direct feedback to the students • Can connect different assessment forms: case based questions e.g., could be incorporated • Widely used, not only for US but for the assessment of multiple practical skills	• Requires different stations and protocols if different organs/situations shall be presented • Requires assessor who is educated in US and assessment • Better even to have different assessors to prevent bias, therefore high cost- and time expenditure
DOPS	• Assessing skills in a workplace setting • Formative and summative, observing knowledge and skills • Direct feedback	• Requires assessor to rate student, better even more than one • Not widely established yet, might need more studies showing efficiency/validity
OSAUS	• Objective measurement tool • Protocol is applicable for different specializations and clinical situations • Not only focused on direct performance at scanning, further checks if the student has the needed knowledge to evaluate if the US examination is necessary and how it could help in the further treatment of the patient • Approach for global rating system –> delphi consensus • Rating system which has been developed for US only	• Since it should be applicaple for different specializations it is more general than e.g., osce protocols since not every special finding for the different organs are named • Experienced assessor needed, not widely established yet
multiple choice and written questions	• Objective • Can be incorporated into another exam (e.g., internal medicine) • No special educated assessor necessary	• If used alone no direct evaluation of scanning technique • Knowing what is shown on an US image or how a disease would show does not mean that the student is capable to obtain the image and detect the pathology • US is a technical skill while MCQ rather checks theoretical knowledge
Pictures and case based questions	• Objective • Has been shown to be a good learning strategy • No assessor necessary • Can be incorporated into another exam	• No information about how the students' competence in an examination would be • No information about students' probe handling/ image acquisition
Skill assessment on simulators	• No accidental findings which could be detected when scanning other students • Good training prior to examine a real patient, especially for rather advanced tasks	• No clinical setting • Better learning effect while scanning real humans • Might know the simulator from training and memorizes locations
Comparison of findings between students and specialists	• Examination of real patients • Clinical setting • Objective • No theoretical approach but students had to obtain images	• No direct feedback • No check on scanning technique, only results are compared
Rating of images	• Direct outcome is evaluated • Practical skills are assessed • Objective	• Examination itself is not evaluated, therefore no direct feedback on scanning technique • Theoretical knowledge is not evaluated and no globally accepted image rating system is existing yet

This overview depicts the various forms of evaluation, as well as the benefits and drawbacks of the various approaches in medical ultrasound teaching.

Images and Case-Based Questions

Including pictures and case-based assessments are more opportunities for the assessment of ultrasound knowledge. Here, students have to detect pathologic findings in US images and have to connect them to clinical cases and further clinical applications.

Short duration and case based presentations can increase the knowledge maintained after 2 weeks in learning (37).

Case based learning (CBL) is a teaching method which finds application in multiple medical fields using case vignettes to convey relevance and to connect theory to practice (62).

It is objective and does not require any special educated assessor. Just like MCQ, case-based questions can be incorporated into an already existing exam.

Since it is a cost- and time-effective tool it can be well-used when resources are limited.

However, probe handling, scanning technique and image adjustment cannot be evaluated with this method of assessment and would be necessary to further improve the students' competence.

Skills Assessment on Simulators

Several studies have shown that simulation-based ultrasound training can lead to better clinical performance not only regarding diagnostic accuracy, but further students seem to need less supervision (63). Ultrasound simulators are important for training in anesthesia and gynecology and can be used for the assessment of competence (41). They are used especially for rather advanced exercises e.g., for the incorporation of central venous catheters or practicing regional anesthesia (64) as they provide the possibility to practice complex tasks prior to the performance with patients. Simulators can offer standardized and valid measurement of skills that can be compared not only nationally but globally (41). The clinical setting is missing and the interaction with the patient cannot be evaluated. On the other hand, the assessment in a clinical setting requires expenditure not every university can afford.

When the number of simulators is limited, the assessment can be affected if the students memorized the correct position. Since anatomy differs, the learning effect when scanning patients might be different.

Comparison of Findings Between Students and Specialists

In this assessment format students as well as experts were asked to perform the same examination and results were compared afterwards.

One study trained students to measure the liver size using ultrasound. Experienced physicians were asked to measure liver span with standard examination methods. Afterwards the results were compared to the student's findings to evaluate if the course was effective (44). Another study compared the precision of cardiovascular diagnoses by medical students using a mobile ultrasound device with the findings of cardiologists which were using standard physical examinations (43). This assessment form provides a clinical setting and students get to perform examinations with real patients. Theoretical knowledge cannot be assessed neither can scanning technique or probe handling since only the resulting image is rated. In this case the students do not get direct feedback on their performance.

Rating of Images

In some studies US images of the students were rated by predetermined criteria. For example images from the pretraining scanning examination and the images from the post-training scanning examination were stored and then compared for improvement (46). In other studies the image quality was live-evaluated and students got a different score, depending on their ability to visualize the organ (47, 48).

There is no global accepted rating system of US images yet, even though the need for a standardized method to evaluate the quality of an US image is well-documented. The B-QUIET method for example represents such an approach to quantify the sonographer component of ultrasound images (65) (**Table 3**).

DISCUSSION AND CONCLUSION

Since assessment is a crucial part of medical education and plays a major role in the concept of constructive alignment, it should always be considered in curriculum development. Especially for practical skills such as ultrasound it plays a vital role and it is essential to ensure efficacious use of this specific technology (66). As ultrasound is a hands-on skill, the examination should ideally not only ask for theoretical knowledge, in addition it may be necessary to assess the resulting ultrasound images or the scanning technique. Furthermore, when testing, one should make sure that not only subjective outcomes are assessed to ensure that the study results can be used to compare different teaching methods in order to find the best educational approach. By using a combination of different assessment methods, some of the limitations that every examination format has can be compensated, learning objectives can be elaborated and inadequate performance can be detected (67). As seen by the numerous assessment forms presented, there is currently no internationally acknowledged assessment tool. Future studies should analyze and develop consensus on when and how ultrasound can be utilized effectively, as well as how ultrasound assessment should be incorporated into medical school education. Moreover, a general approach of an equal education in different universities and countries leading to less variability in the curriculum design is needed. There have already been attempts to develop a single general assessment tool that could be used to evaluate ultrasound skills across diverse specializations and contexts (9, 65). The decision which assessment method or which combination is best to measure ultrasound competency remains a challenging task for future trials. Besides, standards have to be defined as well as the frequency at which students should be tested.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

Material preparation, data collection, analysis were performed, and the first draft of the manuscript was written by EH, FR, and VS. CD and VS helped by manuscript editing. All authors contributed to the study conception and design, commented on previous versions of the manuscript, read, and approved the final manuscript.

REFERENCES

1. Tarique U, Tang B, Singh M, Kulasegaram KM, Ailon J. Ultrasound curricula in undergraduate medical education: a scoping review. *J Ultrasound Med.* (2018) 37:69–82. doi: 10.1002/jum.14333
2. Rao S, van Holsbeeck L, Musial JL, Parker A, Bouffard JA, Bridge P. A pilot study of comprehensive ultrasound education at the Wayne State University School of Medicine: a pioneer year review. *J. Ultrasound Med.* (2008) 27:745–9. doi: 10.7863/jum.2008.27.5.745
3. Cantisani V, Dietrich CF, Badea R, Dudea S, Prosch H, Cerezo E. EFSUMB statement on medical student education in ultrasound short version. *Ultraschall in der Medizin.* (2016) 37:100–2. doi: 10.1055/s-0035-1566959
4. Dietrich CF, Hoffmann B, Abramowicz J, Badea R, Braden B, Cantisani V. Medical student ultrasound education: a WFUMB position paper, part I. *Ultrasound Med Biol.* (2019) 45:271–81. doi: 10.1016/j.ultrasmedbio.2018.09.017
5. Sisley AC, Johnson SB, Erickson W, Fortune JB. Use of an Objective Structured Clinical Examination (OSCE) for the assessment of physician performance in the ultrasound evaluation of trauma. *J Trauma.* (1999) 47:627–31. doi: 10.1097/00005373-199910000-00004
6. Solomon SD, Saldana F. Point-of-care ultrasound in medical education — stop listening and look. *N Engl J Med.* (2014) 370:1081–3. doi: 10.1056/NEJMp1311944
7. Hofer M, Kamper L, Sadlo M, Sievers K, Heussen N. Evaluation of an OSCE assessment tool for abdominal ultrasound courses. *Ultraschall in der Medizin.* (2011) 32:184–90. doi: 10.1055/s-0029-1246049
8. Sultan SF, Iohom G, Saunders J, Shorten G. A clinical assessment tool for ultrasound-guided axillary brachial plexus block. *Acta Anaesthesiol Scand.* (2012) 56:616–23. doi: 10.1111/j.1399-6576.2012.02673.x
9. Tolsgaard MG, Todsen T, Sorensen JL, Ringsted C, Lorentzen T, Ottesen B. International multispecialty consensus on how to evaluate ultrasound competence: a Delphi consensus survey. *PLoS ONE.* (2013) 8:e57687. doi: 10.1371/journal.pone.0057687
10. Afonso N, Amponsah D, Yang J, Mendez J, Bridge P, Hays G. Adding new tools to the black bag–introduction of ultrasound into the physical diagnosis course. *J Gen Intern Med.* (2010) 25:1248–52. doi: 10.1007/s11606-010-1451-5
11. Bahner DP, Adkins EJ, Hughes D, Barrie M, Boulger CT, Royall NA. Integrated medical school ultrasound: development of an ultrasound vertical curriculum. *Crit Ultrasound J.* (2013) 5:6. doi: 10.1186/2036-7902-5-6
12. Akhtar S, Theodoro D, Gaspari R, Tayal V, Sierzenski P, Lamantia J. Resident training in emergency ultrasound: consensus recommendations from the 2008 Council of Emergency Medicine Residency Directors Conference. *Acad Emerg Med.* (2009) 16(Suppl.2):S32-6. doi: 10.1111/j.1553-2712.2009.00589.x
13. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. *BMJ.* (2009) 339:b2700). doi: 10.1136/bmj.b2700
14. Bernard S, Richardson C, Hamann CR, Lee S, Dinh V. Head and neck ultrasound education-a multimodal educational approach in the predoctoral setting: a pilot study. *J Ultrasound Med.* (2015) 34:1437–43. doi: 10.7863/ultra.34.8.1437
15. Hammoudi N, Arangalage D, Boubrit L, Renaud MC, Isnard R, Collet J, et al. Ultrasound-based teaching of cardiac anatomy and physiology to undergraduate medical students. *Archiv Cardiovasc Dis.* (2013) 106:487–91. doi: 10.1016/j.acvd.2013.06.002
16. Hoyer R, Means R, Robertson J, Rappaport D, Schmier C, Jones T. Ultrasound-guided procedures in medical education: a fresh look at cadavers. *Intern Emerg Med.* (2016) 11:431–6. doi: 10.1007/s11739-015-1292-7
17. Ivanusic J, Cowie B, Barrington M. Undergraduate student perceptions of the use of ultrasonography in the study of "living anatomy". *Anat Sci Educ.* (2010) 3:318–22. doi: 10.1002/ase.180
18. Brown B, Adhikari S, Marx J, Lander L, Todd GL. Introduction of ultrasound into gross anatomy curriculum: perceptions of medical students. *J Emerg Med.* (2012) 43:1098–102. doi: 10.1016/j.jemermed.2012.01.041
19. Keddis MT, Cullen MW, Reed DA, Halvorsen AJ, McDonald FS, Takahashi PY, et al. Effectiveness of an ultrasound training module for internal medicine residents. *BMC Med Educ.* (2011) 11:75. doi: 10.1186/1472-6920-11-75
20. Rempell JS, Saldana F, DiSalvo D, Kumar N, Stone MB, Chan W, et al. Pilot point-of-care ultrasound curriculum at harvard medical school: early experience. *West J Emerg Med.* (2016) 17:734–40. doi: 10.5811/westjem.2016.8.31387
21. Swamy M, Searle RF. Anatomy teaching with portable ultrasound to medical students. *BMC Med Educ.* (2012) 12:99. doi: 10.1186/1472-6920-12-99
22. Teichgraber UKM, Meyeq JMA, Poulsen Nautrup C, Berens von Rautenfeld D. Ultrasound anatomy: a practical teaching system in human gross anatomy. *Med Educ.* (1996) 30:296–8. doi: 10.1111/j.1365-2923.1996.tb00832.x
23. Moscova M, Bryce DA, Sindhusake D, Young N. Integration of medical imaging including ultrasound into a new clinical anatomy curriculum. *Anat Sci Educ.* (2015) 8:205–20. doi: 10.1002/ase.1481
24. Dinh V, Frederick J, Bartos R, Shankel TM, Werner L. Effects of ultrasound implementation on physical examination learning and teaching during the first year of medical education. *J Ultrasound Med.* (2015) 34:43–50. doi: 10.7863/ultra.34.1.43
25. Duanmu Y, Henwood PC, Takhar SS, Chan W, Rempell JS, Liteplo AS. Correlation of OSCE performance and point-of-care ultrasound scan numbers among a cohort of emergency medicine residents. *Ultrasound J.* (2019) 11:3. doi: 10.1186/s13089-019-0118-7
26. Knobe M, Münker R, Sellei RM, Holschen M, Mooij SC, Schmidt-Rohlfing B. Peer teaching: a randomised controlled trial using student-teachers to teach musculoskeletal ultrasound. *Med Educ.* (2010) 44:148–55. doi: 10.1111/j.1365-2923.2009.03557.x
27. Lozano-Lozano M, Galiano-Castillo N, Fernández-Lao C, Postigo-Martin P, Álvarez-Salvago F, Arroyo-Morales M. The ecofisio mobile app for assessment and diagnosis using ultrasound imaging for undergraduate health science students: multicenter randomized controlled trial. *J Med Internet Res.* (2020) 22:e16258. doi: 10.2196/16258
28. Hofer M, Schiebel B, Hartwig HG, Garten A, Mödder U. Innovative course concept for small group teaching in clinical methods. Results of a longitudinal, 2-cohort study in the setting of the medical didactic pilot project in Dusseldorf. *Dtsch Med Wochenschr.* (2000) 125:717–23. doi: 10.1055/s-2007-1024468
29. Gogalniceanu P, Sheena Y, Kashef E, Purkayastha S, Darzi A, Paraskeva P. Is basic emergency ultrasound training feasible as part of standard undergraduate medical education? *J Surg Educ.* (2010) 67:152–6. doi: 10.1016/j.jsurg.2010.02.008
30. Knobe M, Carow JB, Ruesseler M, Leu BM, Simon M, Beckers SK, et al. *Arthroscopy or Ultrasound in Undergraduate Anatomy Education: A Randomized Cross-Over Controlled Trial.* (2012). Available online at: https://bmcmededuc.biomedcentral.com/track/pdf/10.1186/1472-6920-12-85 (accessed April 16, 2020).
31. Bornemann P. Assessment of a novel point-of-care ultrasound curriculum's effect on competency measures in family medicine graduate medical education. *J Ultrasound Med.* (2017) 36:1205–11. doi: 10.7863/ultra.16.05002
32. Henwood PC, Mackenzie DC, Rempell JS, Douglass E, Dukundane D, Liteplo AS. Intensive point-of-care ultrasound training with long-term follow-up in a cohort of Rwandan physicians. *Trop Med Int Health.* (2016) 21:1531–8. doi: 10.1111/tmi.12780
33. Chuan A, Thillainathan S, Graham PL, Jolly B, Wong DM, Smith N. Reliability of the direct observation of procedural skills assessment tool for ultrasound-guided regional anaesthesia. *Anaesth Intensive Care.* (2016) 44:201–9. doi: 10.1177/0310057X16044 00206
34. Nilsson PM, Todsen T, Subhi Y, Graumann O, Nolsøe CP, Tolsgaard MG. Kosteneffizienz des App-basierten Selbststudiums im "Extended Focused Assessment with Sonography for Trauma" (eFAST): Eine randomisierte Studie. *Ultraschall in der Medizin.* (2017) 38:642–7. doi: 10.1055/s-0043-119354
35. Royer DF, Kessler R, Stowell JR. Evaluation of an innovative hands-on anatomy-centered ultrasound curriculum to supplement graduate gross anatomy education. *Anat Sci Educ.* (2017) 10:348–62. doi: 10.1002/ase.1670
36. Heinzow HS, Friederichs H, Lenz P, Schmedt A, Becker JC, Hengst K. *Teaching Ultrasound in a Curricular Course According to Certified EFSUMB Standards During Undergraduate Medical Education a Propective Study.* (2020). Available online at: https://theultrasoundjournal.springeropen.com/track/pdf/10.1007/s13089-011-0052-9 (accessed April 16, 2020).

37. Hempel D, Stenger T, Campo Dell' Orto M, Stenger D, Seibel A, Röhrig S, et al. Analysis of trainees' memory after classroom presentations of didactical ultrasound courses. *Crit Ultrasound J.* (2014) 6:10. doi: 10.1186/2036-7902-6-10
38. Fox JC, Cusick S, Scruggs W, Henson TW, Anderson CL, Barajas G. Educational assessment of medical student rotation in emergency ultrasound. *Western J Emerg Med.* (2007) 8:84–7.
39. Noble VE, Nelson BP, Sutingco AN, Marill KA, Cranmer H. Assessment of knowledge retention and the value of proctored ultrasound exams after the introduction of an emergency ultrasound curriculum. *BMC Med Educ.* (2007) 7:40. doi: 10.1186/1472-6920-7-40
40. Syperda VA, Trivedi PN, Melo LC, Freeman ML, Ledermann EJ, Smith TM. Ultrasonography in preclinical education: a pilot study. *J Am Osteopath Assoc.* (2007) 108:601–5. doi: 10.7556/jaoa.2008.108.10.601
41. Madsen ME, Konge L, Nørgaard LN, Tabor A, Ringsted C, Klemmensen AK. Assessment of performance measures and learning curves for use of a virtual-reality ultrasound simulator in transvaginal ultrasound examination. *Ultrasound Obstetr Gynecol.* (2014) 44:693–9. doi: 10.1002/uog.13400
42. Yoo MC, Villegas L, Jones DB. Basic ultrasound curriculum for medical students: validation of content and phantom. *J Laparoendosc Adv Surg Tech A.* (2004) 14:374–9. doi: 10.1089/lap.2004.14.374
43. Kobal SL, Trento L, Baharami S, Tolstrup K, Naqvi TZ, Cercek B. Comparison of effectiveness of hand-carried ultrasound to bedside cardiovascular physical examination. *Am J Cardiol.* (2005) 96:1002–6. doi: 10.1016/j.amjcard.2005.05.060
44. Mouratev G, Howe D, Hoppmann R, Poston MB, Reid R, Varnadoe J. Teaching medical students ultrasound to measure liver size: comparison with experienced clinicians using physical examination alone. *Teach Learn Med.* (2013) 25:84–8. doi: 10.1080/10401334.2012.741535
45. Angtuaco TL, Hopkins RH, DuBose TJ, Bursac Z, Angtuaco MJ, Ferris EJ. Sonographic physical diagnosis 101 teaching senior medical students basic ultrasound scanning skills using a compact ultrasound system. *Ultrasound Q.* (2007) 23:157–60. doi: 10.1097/01.ruq.0000263847.00185.28
46. Arger PH, Schultz SM, Sehgal CM, Cary TW, Aronchick J. Teaching medical students diagnostic sonography. *J Ultrasound Med.* (2005) 24:1365–9. doi: 10.7863/jum.2005.24.10.1365
47. Mullen A, Kim B, Puglisi J, Mason NL. An economical strategy for early medical education in ultrasound. *BMC Med Educ.* (2018) 18:169. doi: 10.1186/s12909-018-1275-2
48. Tshibwabwa ET, Groves HM. Integration of ultrasound in the education programme in anatomy. *Med Educ.* (2005) 39:1148. doi: 10.1111/j.1365-2929.2005.02288.x
49. Wittich CM, Samantha PC, Montgomery MS, Michelle A, Neben BS. *Teaching Cardiovascular Anatomy to Medical Students by Using a Handheld Ultrasound Device*. JAMA. (2002) 288:1062–3. doi: 10.1001/jama.288.9.1062
50. Fernández-Frackelton M, Peterson M, Lewis RJ, Pérez JE, Coates WCA. bedside ultrasound curriculum for medical students: prospective evaluation of skill acquisition. *Teach Learn Med.* (2007) 19:14–9. doi: 10.1080/10401330709336618
51. Shapiroa RS, Kob RP, Jacobson S. A pilot project to study the use of ultrasonography forteaching physical examination to medical students. *Comput Biol Med.* (2002) 32:403–9. doi: 10.1016/S0010-4825(02)00033-1
52. Austin Z, Gregory P, Chiu S. Use of reflection-in-action and self-assessment to promote critical thinking among pharmacy students. *Am J Pharm Educ.* (2008) 72:48. doi: 10.5688/aj720348
53. Sullivan K, Hall C. Introducing students to self-assessment. *Assess Eval High Educ.* (1997) 22:289–305. doi: 10.1080/0260293970220303
54. Evans AW, McKenna C, Oliver M. Self-assessment in medical practice. *J Royal Soc Med.* (2002) 95:511–3. doi: 10.1177/014107680209501013
55. Harden RM, Stevenson M, Downie WW, Wilson GM. Assessment of clinical competence using objective structured examination. *Br Med J.* (1975) 1:447–51. doi: 10.1136/bmj.1.5955.447
56. Onwudiegwu U. OSCE: design, development and deployment. *J West Afri Coll Surg.* (2018) 8:1–22.
57. Touchie C, Humphrey-Murto S, Varpio L. Teaching and Assessing Procedural Skills: A Qualitative Study. *BMC Med Educ.* (2013) 13:69. doi: 10.1186/1472-6920-13-69
58. Norcini JJ, McKinley DW. Assessment methods in medical education. *Teach Teacher Educ.* (2007) 23:239–50. doi: 10.1016/j.tate.2006.12.021
59. Wragg A, Wade W, Fuller G, Cowan G, Mills P. Assessing the performance of specialist registrars. *Clin Med.* (2003) 3:131–4. doi: 10.7861/clinmedicine.3-2-131
60. Farajpour A, Amini M, Pishbin E, Mostafavian Z, Akbari Farmad S. Using Modified Direct Observation of Procedural Skills (DOPS) to assess undergraduate medical students. *J Adv Med Educ Professional.* (2018) 6:130–6. doi: 10.30476/JAMP.2018.41025
61. Wright SA, Bell AL. Enhancement of undergraduate rheumatology teaching through the use of musculoskeletal ultrasound. *Rheumatology.* (2008) 47:1564–6. doi: 10.1093/rheumatology/ken324
62. McLean SF. Case-based learning and its application in medical and health-care fields: a review of worldwide literature. *J Med Educ Curricular Dev.* (2016) 3.:S20377 doi: 10.4137/JMECD.S20377
63. Tolsgaard MG, Chalouhi GE. Use of ultrasound simulators for assessment of trainee competence: trendy toys or valuable instruments? *Ultrasound Obstetr Gynecol.* (2018) 52:424–6. doi: 10.1002/uog.19071
64. Amini R, Stolz LA, Breshears E, Patanwala AE, Stea N, Hawbaker N. Assessment of ultrasound-guided procedures in preclinical years. *Intern Emerg Med.* (2017) 12:1025–31. doi: 10.1007/s11739-016-1525-4
65. Bahner DP, Adkins EJ, Nagel R, Way D, Werman HA, Royall NA. Brightness mode quality ultrasound imaging examination technique (B-QUIET): quantifying quality in ultrasound imaging. *J Ultrasound Med.* (2011) 30:1649–55. doi: 10.7863/jum.2011.30.12.1649
66. Moore CL, Copel JA. Point-of-care ultrasonography. *N Engl J Med.* (2011) 364:749–57. doi: 10.1056/NEJMra0909487
67. Epstein RM. Assessment in medical education. *N Engl J Med.* (2007) 356:387–96. doi: 10.1056/NEJMra054784

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

3. Veröffentlichung B

Original Article

Thieme

Conception and Feasibility of a Digital Tele-Guided Abdomen, Thorax, and Thyroid Gland Ultrasound Course for Medical Students (TELUS study)

Entwicklung und Durchführung eines digitalen telemedizinischen Abdomen-, Thorax- und Schilddrüsen- Ultraschallkurses für Medizinstudierende

Authors

Elena Höhne[1]*, Florian Recker[2]*, Erik Schmok[3], Peter Brossart[1], Tobias Raupach[4], Valentin Sebastian Schäfer[1]

Affiliations

1 Clinic of Internal Medicine III, Oncology, Hematology, Rheumatology and Clinical Immunology, University Hospital Bonn, Germany
2 Department of Obstetrics and Prenatal Medicine, University Hospital Bonn, Germany
3 Amboss, AMBOSS GmbH, Berlin, Germany
4 Institute for Medical Education, University Hospital Bonn, Germany

Key words

ultrasound education, tele-medicine, tele-ultrasound, course concept, medical students

received 17.01.2021
accepted 09.06.2021
published online 05.07.2021

Bibliography

Ultraschall in Med
DOI 10.1055/a-1528-1418
ISSN 0172-4614

Georg Thieme Verlag KG, Rüdigerstraße 14, 70469 Stuttgart, Germany

Correspondence

Dr. Valentin Sebastian Schäfer
Clinic of Internal Medicine III, Oncology, Hematology, Rheumatology and Clinical Immunology, University Hospital Bonn, Venusberg-Campus 1, 53127 Bonn, Germany
Tel.: +49/2 28/28 71 70 00
Fax: +49/2 28/28 79 08 00 52
valentin.s.schaefer@hotmail.de

ABSTRACT

Purpose Medical education has been transformed during the COVID-19 pandemic, creating challenges regarding adequate training in ultrasound (US). Due to the discontinuation of traditional classroom teaching, the need to expand digital learning opportunities is undeniable. The aim of our study is to develop a tele-guided US course for undergraduate medical students and test the feasibility and efficacy of this digital US teaching method.

Materials and Methods A tele-guided US course was established for medical students. Students underwent seven US organ modules. Each module took place in a flipped classroom concept via the Amboss platform, providing supplementary e-learning material that was optional and included information on each of the US modules. An objective structured assessment of US skills (OSAUS) was implemented as the final exam. US images of the course and exam were rated by the Brightness Mode Quality Ultrasound Imaging Examination Technique (B-QUIET). Achieved points in image rating were compared to the OSAUS exam.

Results A total of 15 medical students were enrolled. Students achieved an average score of 154.5 (SD ± 11.72) out of 175 points (88.29 %) in OSAUS, which corresponded to the image rating using B-QUIET. Interrater analysis of US images showed a favorable agreement with an ICC (2.1) of 0.895 (95 % confidence interval 0.858 < ICC < 0.924).

Conclusion US training via teleguidance should be considered in medical education. Our pilot study demonstrates the feasibility of a concept that can be used in the future to improve US training of medical students even during a pandemic.

ZUSAMMENFASSUNG

Ziel Das Ziel dieser Studie war die Konzeption eines telemedizinischen Ultraschall (US)-Kurses für Medizinstudierende zu Zeiten der COVID-19-Pandemie mit anschließender Evaluation praktischer Untersuchungskompetenzen.

Material und Methode Es wurde ein telemedizinischer Ultraschallkurs mit Medizinstudierenden durchgeführt. Die Studierenden absolvierten insgesamt 7 US-Module. Jedes Modul wurde in einem Flipped-Classroom-Konzept mit der Amboss-Plattform konzipiert, um den Studierenden die Möglichkeit zu geben, zusätzliches E-Learning-Material zu nutzen, das optional war und Informationen zu jedem der US-Module lieferte. Als Abschlussprüfung wurde eine objektive Bewertung der US-Kompetenzen (OSAUS) durchgeführt. Zusätzlich wurden die US-Bilder aus Kursstunden und Prüfung mit der B-QUIET-Rating-Methode bewertet und die dort

* Elena Höhne and Florian Recker contributed equally (first-shared authors).

erreichten Punkte mit den Ergebnissen der OSAUS-Prüfung verglichen.

Ergebnisse Insgesamt nahmen 15 Medizinstudierende teil. In OSAUS wurden durchschnittlich 154,5 (SD ± 11,72) von insgesamt 175 Punkten erreicht (88,29 %). Die OSAUS-Ergebnisse stimmen mit der Punktzahl aus der Bildbewertung mit B-QUIET überein. Die Interrater-Analyse der bewerteten US-Bilder zeigte eine gute Übereinstimmung mit einem ICC (2,1) von 0,895 (95 %-Konfidenzintervall 0,858–0,924).

Schlussfolgerungen Die US-Lehre mittels Teleguidance hat sich in dieser Pilotstudie als erfolgreiches Lehrkonzept erwiesen. Dieses zukunftsweisende Lehrkonzept ermöglicht zudem die US-Ausbildung von Medizinstudierenden in Zeiten der COVID-19-Pandemie, in denen Präsenzlehre nicht möglich ist.

Introduction

Traditionally, physicians have acquired ultrasound (US) skills during residency training. However, in recent decades, US has been introduced in undergraduate medical education [1]. Many authors [2–5] have described that US is not just limited to diagnostic imaging but can be used in teaching to support the understanding of complex anatomical structures. As a result, innovative training methods have been designed and implemented for medical students. Over the past few decades, technological advances in both US and the application of telemedicine have been made [6].

There have been attempts to implement distance learning of US skills with mobile devices [7] or web-based applications [8], including physicians and non-physician medical providers, which have been found to be effective. Tele-guided US is the latest technological innovation in the tele-ultrasound sector and hand-held US devices, such as the Butterfly IQ system [9], facilitate live teleguidance and enable the exchange of expertise at the bedside [10] by using the respective application software. The current COVID-19 pandemic resulted in the discontinuation of traditional classroom/presence teaching that is considered crucial in US education. Alternative teaching approaches as well as the expansion of digital learning opportunities became necessary to ensure adequate training of medical students.

The aim of our study is to examine the educational outcome of a newly designed digital tele-guided US course of the abdomen, thorax, and the thyroid gland with the implementation of a modern hand-held US device (the TELUS study), enabling a flipped classroom setting.

Materials and Methods

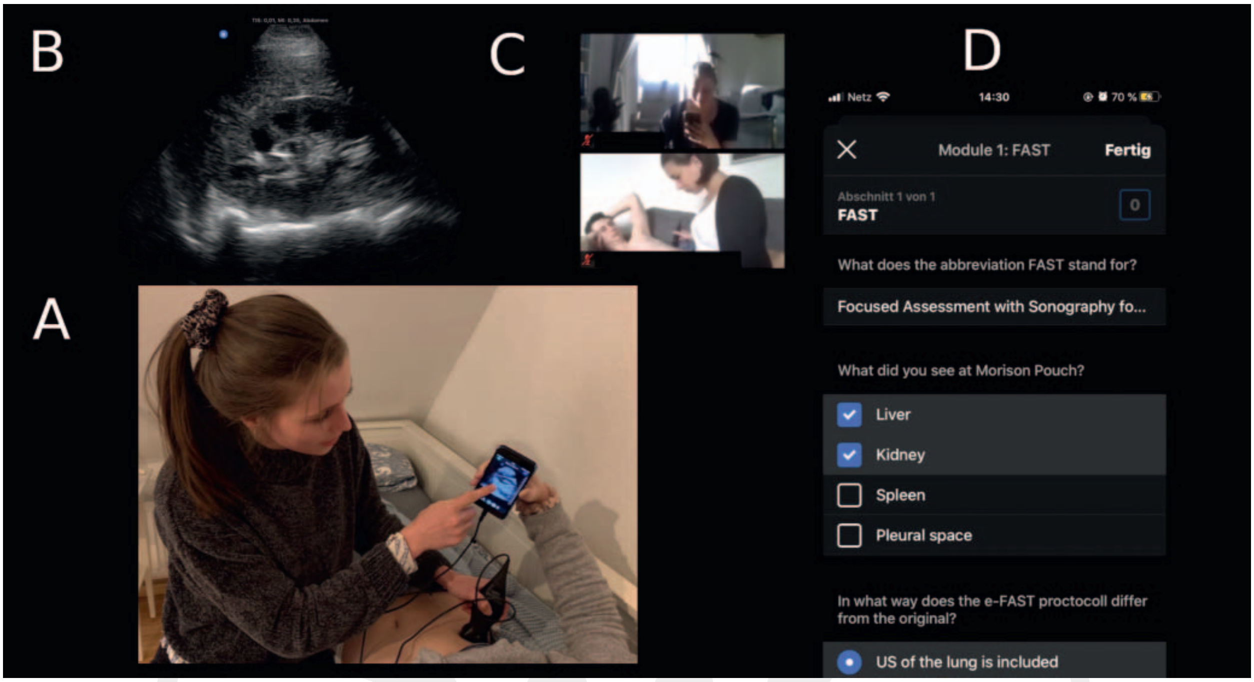
This study was conducted by two board-certified US specialists (one certified EFSUMB/DEGUM level I, the other level III) with longstanding experience in US. The participating students were enrolled in the fourth and fifth year of undergraduate medical education and they were given the opportunity to choose the US course as an elective subject. Each student had to provide an additional volunteer during the course and the exam acting as a US model for training at home. The participants received a mobile ButterflyIQ US device [9] for the course period with the necessary equipment and used exclusively an iPhone, version 7 or newer. The corresponding software ButterflyIQ version 1.25 facilitates the recording of live videos with simultaneous US and camera images as needed for tele-guidance transmission. In addition, the app allows saved images to be added to worksheets that are built by the tutors and can consist of various query types (e. g., multiple choice questions, free text answers) addressing the different organ modules.

Tele-ultrasound course structure

The course was composed of seven modules taking place weekly focusing on organs and structures of the abdomen, the thorax, and the thyroid gland. The organ modules were chosen based on the structure of the DEGUM basic US course of the abdomen. Since point-of-care US (POCUS) is of high importance in medicine, the different modules should provide the students with a general understanding of its applicability. Due to the technical equipment and resolution of the hand-held device, small vessels and bile ducts were not integrated into the course format.

Each module was designed using a flipped classroom concept [11] in cooperation with the Amboss platform [12], which is a German commercial learning platform developed for medical students. Flipped classroom approaches deviate from traditional classroom teaching and exchange transmissive lectures with active in-class tasks and pre-/post-class work at home [13]. Consequently, the participating students received a supplementary e-learning offer available at Amboss that was optional and provided chapters to each of the US organ modules. The information about organ anatomy, examination indication and procedure in the e-learning chapters included normal findings and images of typical pathologies. A chapter with videos demonstrating the correct US technique for each organ structure was also provided [14]. In addition, medical students were asked to answer multiple choice questions after reading the articles to enable self-testing. Students acquired theoretical and practical basics of a new module topic at their own pace by working on the chapters and questions. Thus, participants had more time to study independently during the course and the chance to receive individualized feedback from the tutors. Each course module started with a short lecture outlining the specific topics of the corresponding US module. All tutors gave basic information about the organs including anatomy and possible pathologies as well as instructions to simplify the probe handling needed to obtain the required US images. Typical pathologies were included in each lecture to facilitate student preparation for their first contact with difficult or emergent clinical situations, and to underline the diagnostic and therapeutic utility of each US module.

After the lecture was given, the required US examination was demonstrated by one of the tutors. The tutor's mobile phone screen as well as their camera image was shared with the students during the demonstration to visualize the best image acquisition



▶ **Fig. 1** Implementation of the digital ultrasound course concept. Classroom setting is displayed, demonstrating simultaneous screen transmission of ultrasound (US) and camera images. **A** The peer tutor's camera image is shared with the students while demonstrating the US examination, **B** At the same time the tutor's mobile phone screen is shared with the students in order to visualize the US image acquisition, **C** Students performing the US examination on their own, **D** Example of a worksheet, which had to be completed within the app and was stored along with the US images in the cloud.

technique. Accordingly, students were trained to obtain the predefined US images via simultaneous screen transmission of US and camera images showing probe position (▶ **Fig. 1**). Subsequently, the participants received time to perform the examination on their own and were advised to save images of each US section that was predetermined. In some cases, further modifications of the images were required (e. g., measuring of the organ size). During the active tasks, the tutors observed the students' cameras and the US images in order to assist in the handling of the probe, in case of difficulties, and to provide live guidance. At the end of each module, US images were uploaded to a cloud-based system and a worksheet containing specific questions for each module (identification of anatomical structures, multiple choice questions, or short written questions that aimed to test for obtained knowledge) had to be completed.

Assessment tools

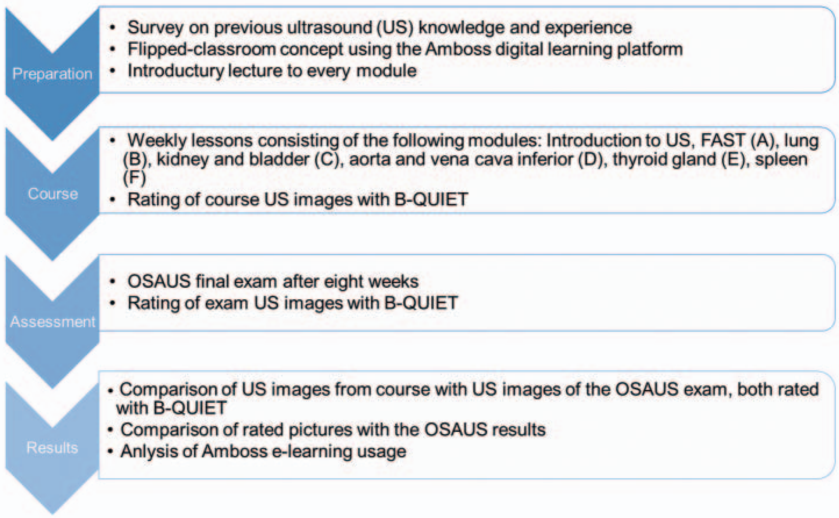
The didactic efficacy of the US course was measured with different tools (▶ **Fig. 2**).

A digital Objective Structured Assessment of Ultrasound Skills (OSAUS) [15] was completed as the final exam by each participant after attending all US course modules at eight weeks. The OSAUS scale contained seven key elements (▶ **Table 1**) and made it possible to evaluate student performance regarding different organs.

Independent raters assessed medical students (EFSUMB/DEGUM Level I and III and a peer tutor) via a practical case study that led the students through the examination. The peer tutor was a student at the same age and level as the participating students who was trained prior to the study to assist in lectures and US demonstrations during the course lessons as well as the student assessment. Each student had 30 minutes to complete the final exam, with approximately five minutes assigned to each task. The exam took place in the same setting as the course lessons and the students scanned a person of their choice at home while sharing their camera and mobile display with the raters. Students had to complete five tasks in the OSAUS, which corresponded to the course modules and included the following:

a) Focused Assessment with Sonography for Trauma (FAST) examination (demonstration of the spleen (F) was incorporated into this module)
b) US of the lungs (B- and M-mode)
c) US of the kidneys (including determination of size) and the bladder (including measurement of residual volume)
d) US of the aorta and vena cava (including measurement of diameter)
e) US of the thyroid gland (including determination of gland volume)

All images taken during the course and exam were rated using the Brightness Mode Quality Ultrasound Imaging Examination Technique (B-QUIET) [16]. B-QUIET has been developed as an approach to standardize US image interpretation (▶ **Table 1**). Images of the course were compared to images of the final OSAUS

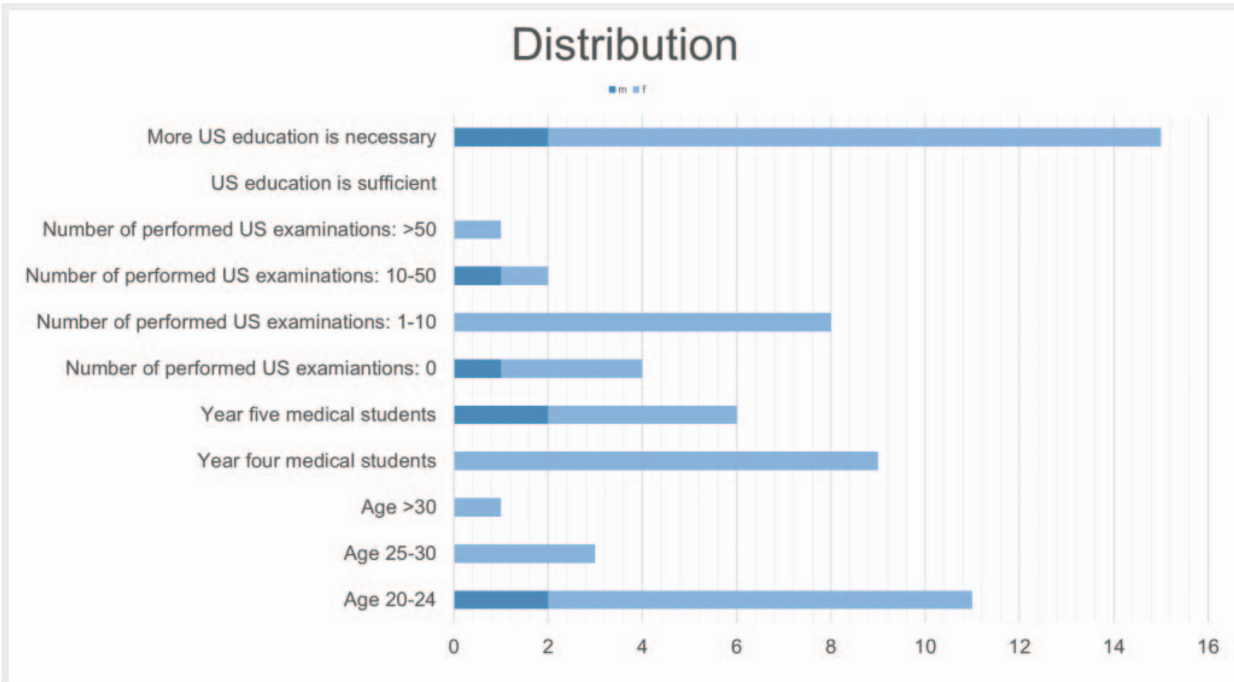


▶ **Fig. 2** Structure of the tele-guided ultrasound course. The course concept is displayed along with the different instruments to measure efficacy. OSAUS: Objective Structured Assessment of Ultrasound Skills, FAST: Focused Assessment with Sonography for Trauma, B-QUIET: Brightness Mode Quality Ultrasound Imaging Examination Technique, US: ultrasound.

▶ **Table 1** Evaluation criteria of Objective Structured Assessment of Ultrasound Skills (OSAUS) and Brightness Mode Quality Ultrasound Imaging Examination Technique (B-QUIET) score.

Objective Structured Assessment of Ultrasound Skills (OSAUS)	Brightness Mode Quality Ultrasound Imaging Examination Technique (B-QUIET)
1. indication for the examination	**identification/orientation**
reviewing patient history, indication	1.0 date/time
2. applied knowledge of ultrasound (US) equipment	1.1 patient name/MRN/sonographer
familiarity with equipment and functions	1.2 body marker
3. image optimization	1.3 comments (image title, labeled structures)
optimal image quality	**technical**
4. systematic examination	2.1 resolution – application/focal zone
systematic approach, presentation of relevant structures	2.2 depth – field of view
5. interpretation of images	2.3 gain (segmental, overall)
recognition of image pattern and interpretation	**image anatomy**
6. documentation of examination	3.1 near field (top of screen)
image recording and documentation	3.2 receding edge (right side)
7. medical decision making	3.3 far field (bottom of screen)
ability to integrate scan results into patient care	3.4 leading edge (left side)
5 points could be obtained within each category with a total of 35 points	within each category 4 points could be obtained and a total of 44 points

A digital Objective Structured Assessment of Ultrasound Skills (OSAUS) was completed as the final exam by each participant after attending all US course modules. Furthermore, US images of the course and exam were rated by the Brightness Mode Quality Ultrasound Imaging Examination Technique (B-QUIET). The different criteria for assessment are displayed.



► **Fig. 3** Student characteristics. Pre-course survey on ultrasound education and experience as well as year of study. US: ultrasound, m: male, f: female.

exam to determine whether the students' image quality improved, decreased, or remained constant. Students had approximately one hour to take images in each course module compared to the five minutes per task during the exam.

All images (n = 497) were evaluated by two raters (EFSUMB/DEGUM Level I and III), who likewise assessed student performance in the OSAUS exam. A total of 104 of these images were randomly chosen and rated by the peer tutor and an intraclass correlation coefficient was determined afterwards for the three independent raters. Raters were blinded to the images originating from the course and final exam. Within the OSAUS exam, theoretical knowledge and performance of physical examination were assessed. Thus, more than practical ability was evaluated, whereas the B-QUIET image rating considered image quality and therefore the direct outcome.

Statistical analysis

Statistical analysis was performed with R statistical software (version i386 4.0.2). Means and standard deviations were calculated as descriptive parameters. In case of correlations between OSAUS and image rating results, Spearman's rank-order correlations [17] were determined since no normal distribution could be assumed. Differences were considered statistically significant if p was < 0.05. Using the scientific B-QUIET score [16] for standardized US image interpretation, a total of 497 images were rated and inter-rater reliability was assessed. Inter-rater reliability of image ratings with B-QUIET and the OSAUS protocol was assessed separately according to the intraclass correlation coefficient (ICC) (2.1) [18]. The ICC can be interpreted according to Rosner [19]: ICC < 0.4 indicated poor reliability, $0.4 \leq$ ICC < 0.75 fair to good reliability, and ICC ≥ 0.75 excellent reliability.

The study was approved by the local ethics committee (no. 129/29) and all participants gave written informed consent to participate in the study.

Results

Participants characteristics

A total of 15 medical students (13 females (87 %), two males (13 %)) with a mean age of 24.7 years (SD± 3.6 years) were enrolled in the study. The number of study participants was based on the number of US probes available. Half of the students (53 %) had performed US on a patient on their own less than ten times and four students (27 %) had never performed US independently before (► **Fig. 3**). All students wished for more US education, as they felt that the amount offered by medical faculty was inadequate [20].

Objective Structured Assessment of Ultrasound Skills (OSAUS) results

Participants had to complete five different tasks in the OSAUS [15] exam. For each task, 35 points could be obtained for a total of 175 points. The average number of points achieved was 154.5 (SD ± 11.7) out of 175 points (88.29 %). The highest median number of points was scored in the thyroid gland module (E) with an average result of 31.8 points (SD± 2.6), while the lowest average score was obtained in the aorta and vena cava module (D) with 30.1 points (SD± 3.2). The three OSAUS raters showed an inter-rater reliability of 0.874 (95 % confidence interval 0.65 < ICC < 0.956).

Image analysis results using B-QUIET

The students' images were rated with the B-QUIET [16] method, where a maximum of 44 points could be obtained per image. Images from the course and the exam were evaluated for each module (▶ **Table 2**). The ICC (2.1) was determined for the three independent raters and the detected ICC (2.1) was 0.895 (95 % confidence interval 0.858 < ICC < 0.924).

The best rated US course images were observed in the lung (B) module with a mean score of 34.4 (SD± 3.2) points, whereas in the final exam, the highest mean score was achieved in the thyroid gland (E) module with a total of 35.0 (SD± 4.4) points. The images of the aorta and vena cava (D) achieved the lowest mean score in both the course and final exam. The mean score of the US course images was 31.2 (SD± 3.8) points, while the highest score reached was 39 points. The mean exam score of the US images was 32.3 (SD± 4.0). Therefore, students obtained one point more per image in the exam compared to the course modules before.

There was no substantial correlation between the total points in OSAUS and the total or average points per image rating in B-QUIET. However, the students reached the highest mean score in OSAUS in module E (thyroid) with 31.8 (SD± 2.6) points, which is also the module with the highest average points in the B-QUIET rating of images (35.0 SD± 4.4).

Similarly, in module D (aorta and cava), students received the lowest score in OSAUS with 30.1 (SD± 3.2) points, and the images were rated with a mean score of 30.6 (SD± 3.5), which is the lowest observed in the final exam (▶ **Fig. 4**).

Furthermore, there was no significant correlation between the number of performed US examinations before the course and the points achieved in OSAUS.

Tracked data e-learning results

The tracked data of the flipped classroom format offered by Amboss displays favorable use of the optional e-learning material, which consisted of chapters dealing with the corresponding module and a multiple choice question tool. The number of times students accessed the chapters and multiple-choice questions was analyzed and each time the material was accessed was registered corresponding to the weekly module sessions. All students accessed at least one chapter and four students (27 %) worked on all chapters. Twelve students (80 %) took part by answering the MCQ questions and answered more than 90 % correctly. The majority of online access to chapters and questions was documented shortly before the final OSAUS test. (▶ **Fig. 5**).

▶ **Table 2** Mean results of the OSAUS exam as well as the the course and exam B-QUIET image rating.

module	rating of US course images using B-QUIET	rating of final exam images using B-QUIET	OSAUS results
A (FAST)	30.2 ± 3.9 (68.6 %)	31.1 ± 4.0 (70.7 %)	31.0 ± 4.0 (88.6 %)
B (lung)	34.4 ± 3.3 (78.2 %)	34.5 ± 3.8 (78.4 %)	30.9 ± 2.4 (88.3 %)
C (kidney, bladder)	31.8 ± 3.6 (72.7 %)	33.1 ± 3.6 (75.2 %)	30.7 ± 3.1 (87.7 %)
D (aorta, vena cava)	30.1 ± 3.3 (68.4 %)	30.6 ± 3.5 (69.6 %)	30.1 ± 3.2 (86 %)
E (thyroid gland)	32.4 ± 3.2 (73.6 %)	35.0 ± 4.4 (79.6 %)	31.8 ± 2.6 (90.9 %)

The US images saved by students during the course and the exam were rated using B-QUIET and can be compared to the OSAUS final exam results. The mean score and standard deviation are displayed as well as the percentage of highest achievable score. OSAUS: Objective Structured Assessment of Ultrasound Skills, FAST: Focused Assessment with Sonography for Trauma, B-QUIET: Brightness Mode Quality Ultrasound Imaging Examination Technique.

Discussion

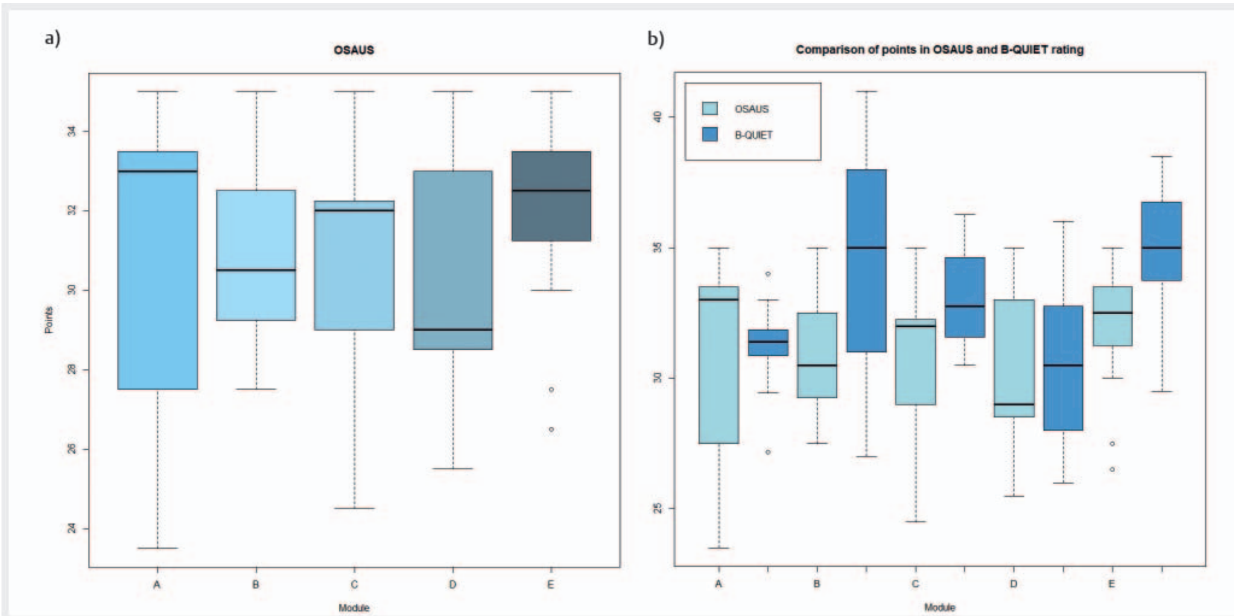
This is the first pilot study to investigate the learning outcome of German medical students in a newly developed, automated, tele-guided US course of the abdomen, the thyroid gland, and the thorax. In addition, it is the first study to test the use of the B-QUIET [16] image analysis method as well as the OSAUS [15] protocol in a digital tele-guided US course together.

US in medical education has been shown to be an achievable objective that is well-accepted by medical students. It has the potential to help medical students achieve basic competency in FAST US examination after only five hours of training. In addition, student assessment of their own performance shows high proficiency of the program [21]. The use of the Objective Structured Clinical Examination (OSCE) [22] has been investigated in many studies [23, 24], and Todsen et al. [25] demonstrated high reliability as well as evidence of construct validity of the OSAUS scale in an educational setting.

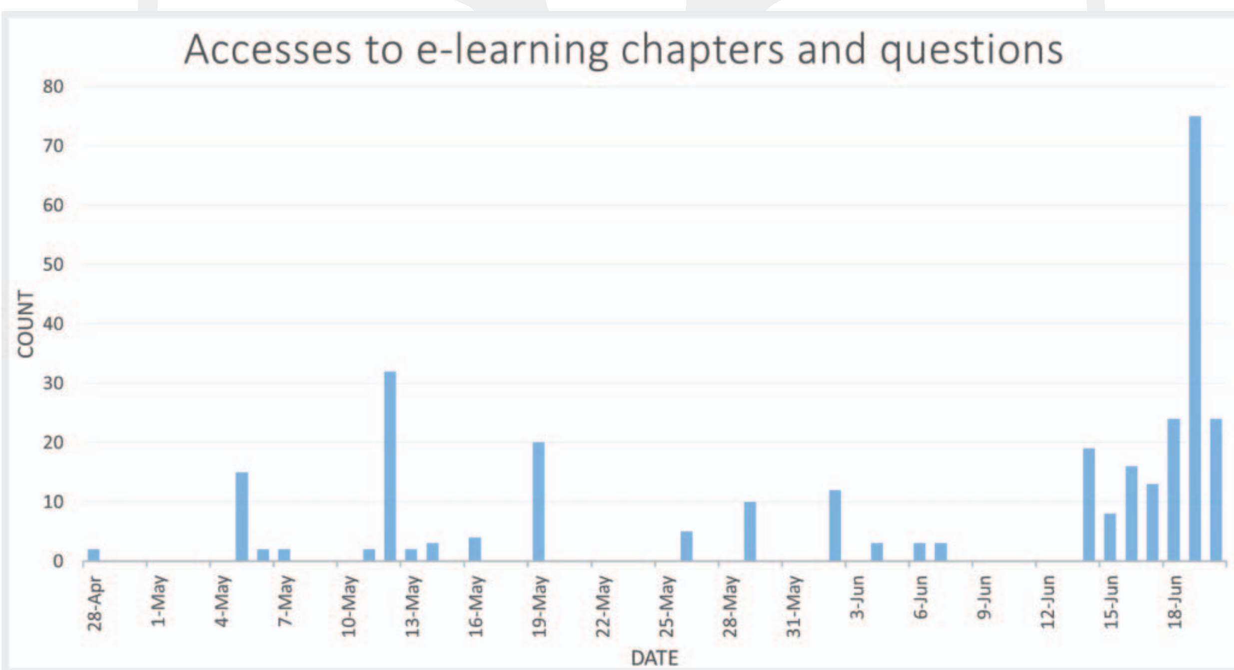
The existing literature indicates that e-learning can provide an effective method for improving educational outcomes [26] and manages to lead to similar results as traditional, face-to-face, teacher-centered courses [27]. To date, there has been no distance learning concept that has been tested for US in medical education.

Approximately one point more per image was achieved in the final exam compared to course images, which is remarkable since students had one hour to take images during each course module, while they only had roughly five minutes per task during the exam.

There was no substantial correlation between the total points in OSAUS and the total or average points per image rating in B-QUIET, indicating that the student with the highest number of points in OSAUS does not necessarily also have the best rated images. The missing correlation can be explained by the different sections that were tested with OSAUS. More than the practical



▶ **Fig. 4** Comparison of assessment methods. **a** Objective Structured Assessment of Ultrasound Skills (OSAUS) results of the final exam, **b** Comparison of achieved points in the OSAUS exam and image rating, using the B- QUIET method. A maximum of 35 points could be reached within each module in the OSAUS exam and 44 points could be achieved in image rating. A (Focused Assessment with Sonography for Trauma), B (lung), C (kidney, bladder), D (aorta and vena cava), E (thyroid gland) OSAUS: Objective Structured Assessment of Ultrasound Skills, B-QUIET: Brightness Mode Quality Ultrasound Imaging Examination Technique.



▶ **Fig. 5** Time course of the tracked flipped classroom concept using the Amboss platform. Tracked data regarding Students' use of the e-learning concept of the Amboss platform. The e-learning offer was used weekly before the course. The number of times students accessed the platform was highest prior to the final exam which was scheduled for the 20th of June.

ability was evaluated in the exam (indication and systematic examination, for example), whereas the B-QUIET image rating considered image quality and the direct outcome. Therefore, the two different assessment forms have different advantages. B-QUIET might be more objective, whereas OSAUS aims to measure not only image optimization but the ability to perform and explain the US examination.

Our study has several limitations, including the relatively small sample size which resulted from the limited number of hand-held US devices. However, the feasibility of the course would be difficult with a larger number of participants since the tutor must be accessible for the students at all times [28]. Therefore, conducting a power analysis would be essential for future studies. Due to the prevailing contact restrictions, it was not possible to compare the results to a group that underwent direct hands-on teaching on a live patient. Thus, the lack of a control group is a major limitation of our study. Additionally, US scanning was performed on young and healthy volunteers and none of the models had abnormal findings or were obese. As the students could not witness unusual findings, images and videos of typical pathologies were incorporated in the lectures and e-learning chapters. In the future, US pathologies could be taught using low-cost models (e. g., 3D printing), depending on the application area. Long-term retention of both functional and theoretical information was not evaluated in the course. Selection bias cannot be excluded, as more motivated students may have participated. Since students had their equipment at home during the whole course time, it is not clear whether the examination outcome results only from the course or is affected by self-practice. Our study should be seen as a proof-of-concept study, demonstrating the feasibility of tele-US teaching. A power analysis as well as additional studies including control groups should be performed in the future to allow a comparison to hands-on teaching. In the future, these concepts could be used not only to organize digital teaching but also to strengthen health services research and US training in remote areas. Turning a smartphone into a US machine with a hand-held US device like the ButterflyIQ system is more affordable for medical education and could be an incredible opportunity to expedite US training worldwide. Especially in times of a nationwide medical crisis such as COVID-19, it is essential that medical faculties draw the right conclusions from their experience and focus on an advanced approach to expand practical teaching strategies.

Conclusion

The TELUS study demonstrates the feasibility of a tele-guided US course concept using a hand-held US device that can be easily transported anywhere for practice. Consequently teleguided US training should be considered in future medical education. As can be seen in the current pandemic situation, the expansion of digital learning opportunities is not only necessary, but unavoidable.

Conflict of interest

Erik Schmok is an employee of Amboss.

Acknowledgements

The research team would like to thank the participants who generously shared their time.

References

[1] Prosch H, Radzina M, Dietrich CF et al. Ultrasound Curricula of Student Education in Europe: Summary of the Experience. Ultrasound Int Open 2020; 6: E25–E33. doi:10.1055/a-1183-3009

[2] Dreher SM, DePhilip R, Bahner D. Ultrasound exposure during gross anatomy. J Emerg Med 2014; 46: 231–240. doi:10.1016/j.jemermed.2013.08.028

[3] Stringer MD, Duncan LJ, Samalia L. Using real-time ultrasound to teach living anatomy: an alternative model for large classes. N Z Med J 2012; 125: 37–45

[4] Brown B, Adhikari S, Marx J et al. Introduction of ultrasound into gross anatomy curriculum: perceptions of medical students. J Emerg Med 2012; 43: 1098–1102. doi:10.1016/j.jemermed.2012.01.041

[5] So S, Patel RM, Orebaugh SL. Ultrasound imaging in medical student education: Impact on learning anatomy and physical diagnosis. Anat Sci Educ 2017; 10: 176–189. doi:10.1002/ase.1630

[6] Law J, Macbeth PB. Ultrasound: from Earth to space. Mcgill J Med 2011; 13: 59

[7] Levine AR, Buchner JA, Verceles AC et al. Ultrasound images transmitted via FaceTime are non-inferior to images on the ultrasound machine. J Crit Care 2016; 33: 51–55. doi:10.1016/j.jcrc.2016.02.019

[8] Yoo SK, Kim DK, Jung SM et al. Performance of a web-based, realtime, tele-ultrasound consultation system over high-speed commercial telecommunication lines. J Telemed Telecare 2004; 10: 175–179. doi:10.1258/135763304323070841

[9] Butterfly Network, Inc. Retrieved from: https://www.butterflynetwork.com

[10] Gibson LE, Low SA, Bittner EA et al. Ultrasound Teleguidance to Reduce Healthcare Worker Exposure to Coronavirus Disease 2019. Crit Care Explor 2020; 2: e0146 doi:10.1097/CCE.0000000000000146

[11] Bergmann J, Overmyer J, Wilie B. The Flipped Class: Myths vs. Reality -Retrieved from the daily riff – Be Smarter. About Education 2011 Jul

[12] Quast A, Weiss J. Die Miamed-Gründungsgeschichte: Für eine bessere Medizin weltweit. In: Bungard P, Hrsg. CSR und Geschäftsmodelle. Auf dem Weg zum zeitgemäßen Wirtschaften. Management-Reihe Corporate Social Responsibility. Berlin: Springer Gabler; 2018: 247–261. doi:10.1007/978-3-662-52882-2_15

[13] Abeysekera L, Dawson P. Motivation and cognitive load in the flipped classroom: definition, rationale and a call for research. High Educ Res Dev 2015; 34: 1–14. doi:10.1080/07294360.2014.934336

[14] Amboss GmbH. Sonografie-Videos und Standardschnitte (05.04.2019). Retrieved from (cited: 05.03.2021): https://next.amboss.com/de/article/Cq0q0h

[15] Tolsgaard MG, Todsen T, Sorensen JL et al. International multispecialty consensus on how to evaluate ultrasound competence: a Delphi consensus survey. PLoS One 2013; 8: e57687 doi:10.1371/journal.pone.0057687

[16] Bahner DP, Adkins EJ, Nagel R et al. Brightness mode quality ultrasound imaging examination technique (B-QUIET): quantifying quality in ultrasound imaging. J Ultrasound Med 2011; 30: 1649–1655. doi:10.7863/jum.2011.30.12.1649

[17] Spearman C. The proof and measurement of association between two things. Int J Epidemiol 2010; 39: 1137–1150. doi:10.1093/ije/dyq191

[18] Shrout PE, Fleiss JL. Intraclass correlations: Uses in assessing rater reliability. Psychol Bull 1979; 86: 420–428. doi:10.1037//0033-2909.86.2.420

[19] Rosner B. Fundamentals of biostatistics. 3rd ed. Boston, Mass.: PWS-Kent Publ. Co; 1990

[20] Wolf R, Geuthel N, Gnatzy F et al. Undergraduate ultrasound education at German-speaking medical faculties: a survey. GMS J Med Educ 2019; 36: Doc34 doi:10.3205/zma001242

[21] Gogalniceanu P, Sheena Y, Kashef E et al. Is basic emergency ultrasound training feasible as part of standard undergraduate medical education? J Surg Educ 2010; 67: 152–156. doi:10.1016/j.jsurg.2010.02.008

[22] Harden RM, Stevenson M, Downie WW et al. Assessment of clinical competence using objective structured examination. Br Med J 1975; 1: 447–451. doi:10.1136/bmj.1.5955.447

[23] am Dinh V, Dukes WS, Prigge J et al. Ultrasound Integration in Undergraduate Medical Education: Comparison of Ultrasound Proficiency Between Trained and Untrained Medical Students. J Ultrasound Med 2015; 34: 1819–1824. doi:10.7863/ultra.14.12045

[24] Hofer M, Kamper L, Sadlo M et al. Evaluation of an OSCE assessment tool for abdominal ultrasound courses. Ultraschall in Med 2011; 32: 184–190. doi:10.1055/s-0029-1246049

[25] Todsen T, Tolsgaard MG, Olsen BH et al. Reliable and valid assessment of point-of-care ultrasonography. Ann Surg 2015; 261: 309–315. doi:10.1097/SLA.0000000000000552

[26] Vaona A, Banzi R, Kwag KH et al. E-learning for health professionals. Cochrane Database Syst Rev 2018; 1: CD011736 doi:10.1002/14651858.CD011736.pub2

[27] Tomlinson J, Shaw T, Munro A et al. How does tele-learning compare with other forms of education delivery? A systematic review of tele-learning educational outcomes for health professionals. N S W Public Health Bull 2013; 24: 70–75. doi:10.1071/NB12076

[28] Steinert Y. Student perceptions of effective small group teaching. Med Educ 2004; 38: 286–293. doi:10.1046/j.1365-2923.2004.01772.x

4. Veröffentlichung C

applied sciences

MDPI

Review

Ultrasound in Telemedicine: A Brief Overview

Florian Recker [1,*], Elena Höhne [2], Domagoj Damjanovic [3] and Valentin S. Schäfer [2]

1 Department for Obstetrics and Gynecology, University Hospital Bonn, Venusberg Campus 1, 53127 Bonn, Germany
2 Clinic of Internal Medicine III, Oncology, Hematology, Rheumatology and Clinical Immunology, University Hospital Bonn, 53127 Bonn, Germany; elena.ho@outlook.de (E.H.); valentin.s.schaefer@hotmail.de (V.S.S.)
3 Department of Cardiovascular Surgery, University Hospital Freiburg, Medical Faculty of the Albert-Ludwigs-University Freiburg, 79106 Freiburg, Germany; domagoj.damjanovic@uniklinik-freiburg.de
* Correspondence: florian.recker@ukbonn.de; Tel.: +49-0228-2871-5449

Abstract: The delivery of healthcare from a distance, also known as telemedicine, has evolved over the past 50 years, changing the way healthcare is delivered globally. Its integration into numerous domains has permitted high-quality care that transcends the obstacles of geographic distance, lack of access to health care providers, and cost. Ultrasound is an effective diagnostic tool and its application within telemedicine has advanced substantially in recent years, particularly in high-income settings and low-resource areas. The literature in Pubmed from 1960–2020 was assessed with the keywords "ultrasound", "telemedicine", "ultrasound remote", and "tele-ultrasound" to conduct a SWOT analysis (strengths, weaknesses, opportunities, and threats). In addressing strengths and opportunities, we emphasized practical aspects, such as the usefulness of tele-ultrasound and the cost efficiency of it. Furthermore, aspects of medical education in tele-ultrasound were considered. When it came to weaknesses and threats, we focused on issues that may not be solved immediately, and that require careful consideration or further development, such as new software that is not yet available commercially.

Keywords: ultrasound; telemedicine; eHealth; tele-ultrasound

Citation: Recker, F.; Höhne, E.; Damjanovic, D.; Schäfer, V.S. Ultrasound in Telemedicine: A Brief Overview. *Appl. Sci.* **2022**, *12*, 958. https://doi.org/10.3390/app12030958

Academic Editor: Alessandro Ramalli

Received: 17 December 2021
Accepted: 14 January 2022
Published: 18 January 2022

1. Introduction

The term telemedicine was coined in the 1970s to describe the practice of delivering health care services through the use of information and communications technology, whereby geographic distance is not as constraining, as in the case of traditional medical practice. Telemedicine is not only used to exchange valid information for the diagnosis, treatment, and prevention of disease and injuries and research and evaluation, but also for the continuing the education of healthcare providers to advance individual and community health [1,2].

Telemedicine has been shown to improve access to healthcare and reduce costs, especially in areas with a limited healthcare infrastructure due to geographical barriers [3]. Recently, increased digitalization and the development of telehealth applications have finally reached the field of medical imaging. As telemedicine has evolved over the last few decades, ultrasound technology matured in parallel [4]. Ultrasound became a bedside tool in the 1990s that physicians, such as those who work in the emergency department, could use regularly because it is a fast, robust, and reliable way of determining a patient's status at the outset of treatment. Tele-ultrasound is defined as the use of ultrasound with telecommunications and/or an additional instructor who is telemedically connected to the process. The utilization of tele-ultrasound has been rapidly increasing worldwide since the 1990s and is commonly used for emergency, abdominal, and obstetrical ultrasound by general practitioners in remote areas worldwide. One of the beneficiaries of this is other doctors, but in a broader sense, it benefits patients as well. Moreover, it can be a cost-saving measure as it eliminates both long transportation times and extra doctor visits. A lack of access to ultrasound doctors, despite technological advancements and mobile devices with high bandwidth that allow for seamless live-image transmission, is a concern in both low-income and high-income countries. Moreover, the main challenge in telemedicine remains an organizational one, knowing how and when to take advantage of the technology.

Tele-Ultrasound in a Historical Context

According to the World Health Organization (WHO), in clinical situations, medical imaging is needed to make a diagnosis in 20–30% of cases, and ultrasound and/or conventional radiography are sufficient for 80–90% of those cases. However, two thirds of the world population does not have any access to medical imaging [5].

The beginnings of tele-ultrasound date back to the era of space exploration in the 1960s, when the first remote ultrasound scans were carried out on astronauts with remote guidance from experts in the Mission Control Center [6] (Figure 1). Those ultrasound systems were capable of high-definition sonographic imaging for the cardiac, vascular, general, abdominal, thoracic, and musculoskeletal systems, among others (Ashot 2006).

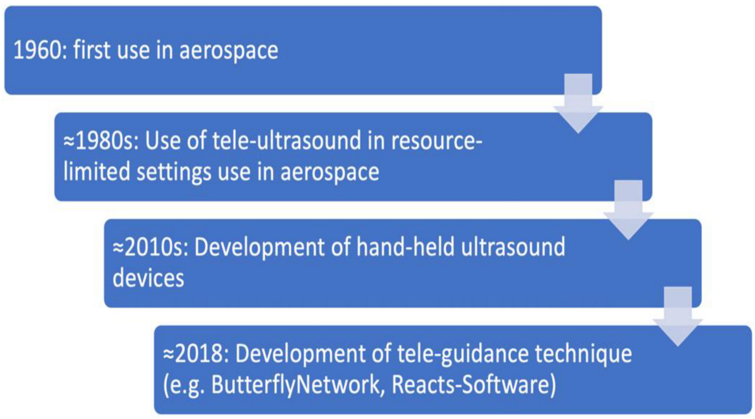


Figure 1. Timeline of use of tele-ultrasound.

The technology remains relevant in aeronautics and recently several studies have assessed the use of ultrasound by non-physician crew members at the International Space Station, which entailed prior training in ultrasound [6–10].

From space, the focus has shifted to earth. Here, especially in remote areas in New Zealand and Sub-Saharan Africa, tele-ultrasound has proven successful. Focusing mainly on emergency ultrasound [11] and Point-Of-Care Ultrasound (POCUS), it has been shown that remotely-guided Focused Assessment with Sonography for Trauma (FAST) ultrasound examinations with minimally trained health care workers are possible and effective [12,13]. In obstetrics and gynecology, several successful prenatal tele-ultrasound projects have been described in literature [14,15]. Many countries harbor only a small number of qualified fetal-medicine specialists who are capable of pre-natal ultrasound imaging, which does not adequately cover demand, but which is highly significant in diagnosing and preventing potential birth defects. Studies, mainly from remote areas such as rural Australia, have tried to identify the need for fetal therapy [16].

Tele-ultrasound performed in resource-limited settings can produce satisfactory images of diagnostic relevance which have an impact on medical treatment and outcomes [17].

2. Materials and Methods

A systematic review of the literature was conducted. The databases searched were Medline (1950 to October 2020) and Embase (1980 to October 2020), the Cochrane Library, all sections, and the Web of Science with Conference Proceedings (1970 to 2020). The searches were not limited by language. Auto-alerts in Medline were also run during the course of the review. Reference lists of relevant articles were also checked.

All relevant randomized controlled trials (RCTs) or quasi-RCTs were included. Due to the small number of RCTs, we also included nonrandomized studies (NRSs). Prospective oservational studies with controls, retrospective matched-pair studies, and comparative studies from well-defined registries/databases were also includes.

The terms to be examined were "ultrasound", "telemedicine", "ultrasound remote", and "tele-ultrasound", which helped to complete a SWOT (strengths, weaknesses, opportunities, threats) analysis (Figure 2).

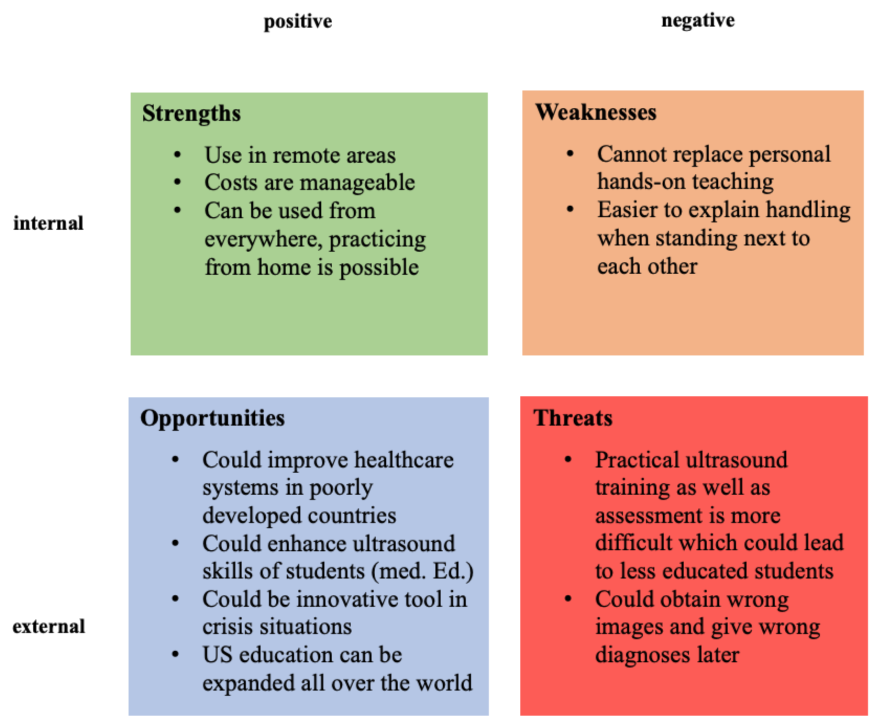


Figure 2. SWOT analysis of the use of tele-ultrasound.

Strengths and opportunities were considered based on practical aspects such as the practicality of using tele-ultrasound and cost efficiency. Additionally, aspects of medical educauon related to tele-ultrasounds were discussed.

When we analyzed weaknesses and threats, we focused on issues that are unlikely to be resolved immediately and which may require thorough consideration or further development, such as new software that has not yet been commercially released. All articles were screened for positive statements on approval by a local ethics committee, adherence to guidelines for animal care, and/or obtaining informed consent.

The present study is a review of previously published studies, and institutional review board approval and patient consent were not necessary. Only human studies with a full text in English were assessed for inclusion. Studies without detailed methods and results sections were excluded.

3. Results

3.1. Practicality of Use

Tele-ultrasound can be used in urban as well as in rural areas. It can improve the healthcare system and patient outcomes, especially in under-resourced areas [17]. From the point of view of medical education, it can enhance ultrasound skills and establish a basic knowledge of ultrasound. By expanding this method with tele-applications, practical ultrasound could be taught anywhere in the world.

In times of pandemics, such as COVID-19, with social distancing regulations and isolation measures, it can help to ease the pressure on healthcare systems by providin diagnostic alternatives. Rapid technical development and competition in the field of medical software engineering have made the cost of tele-ultrasound manageable. Even low-cost, readily available tools such as web interfaces or commercial messenger tools can be used for tele-supported ultrasound, with the advantage of being independent of any special setting and providing the flexibility to perform ultrasound when and wherever it may be necessary [18]. Recently, new software applications have been introduced that support the teaching of knobology and handling of the probe. Thus, one can even practice at home, independently of any course sessions (Figure 3).

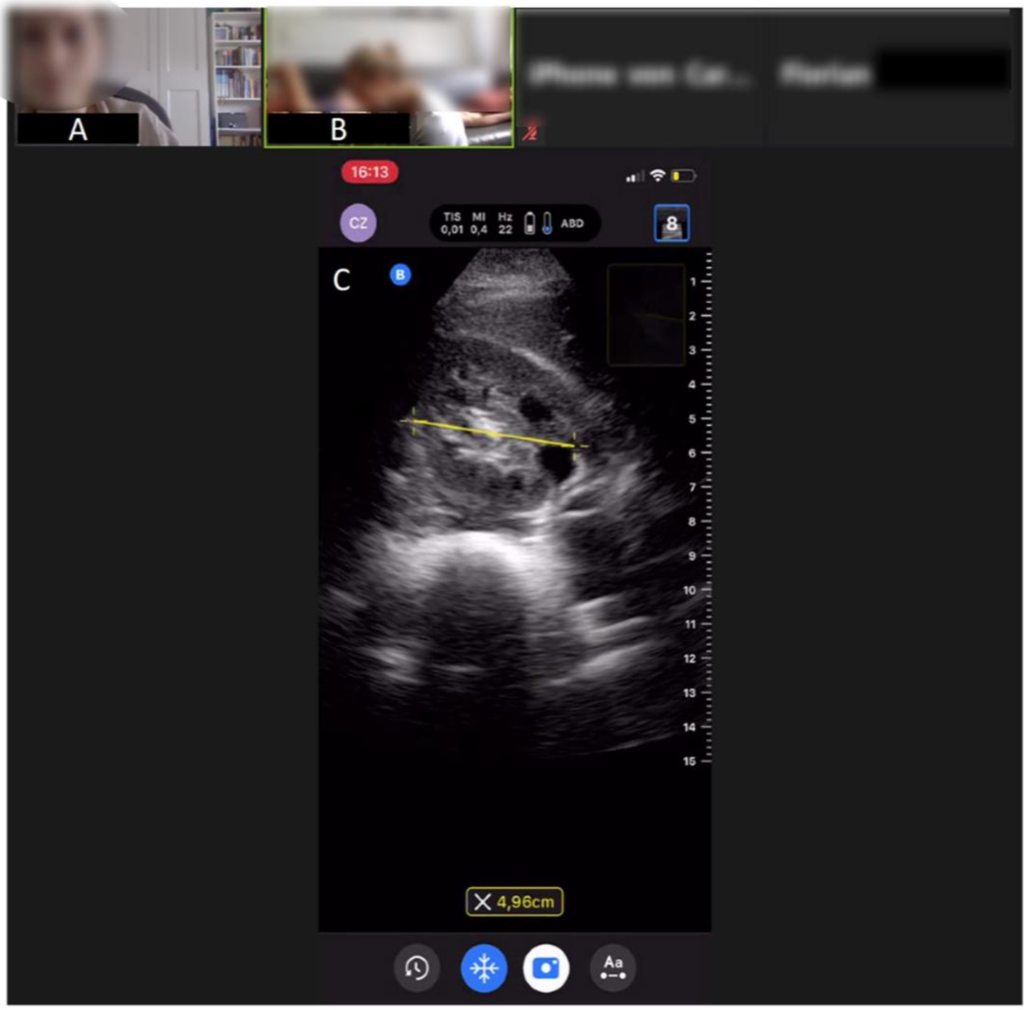


Figure 3. Ultrasound image from a tele-didactic ultrasound teaching study on abdominal ultrasound from the medical faculty of the University of Bonn, Germany. (**A**) Peer tutor, (**B**) student exercising ultrasound on another student, (**C**) ultrasound image of the right kidney, which will be improved via tele-guidance by the peer tutor. An experienced ultrasonographer is also online in order to assist if any questions arise.

3.2. Cost Efficiency

In the scenario of real-time tele-ultrasound consultations and tele-education, savings in the conventional costs of patient transfer (e.g., transfer from GP to clinic) and human resources (e.g., clinical specialist in remote areas) need to be balanced against accruing telecommunication costs. An Australian study demonstrated that tele-ultrasound can result in a net saving of AUD 6340 and, at the same time, enabled almost four times the number of consultations than if the service had not been available [19]. In this study, a real-time fetal tele-ultrasound consultation service had been implemented and integrated into the daily clinical practice. Patients in Townsville could be assessed by subspecialists in Brisbane, 1500 km away, using the service. Ninety percent of the babies born during the 90 tele-ultrasound consultations for the first 71 patients showed good outcome data. The existence of all key anomalies and diagnoses was established in this study. Without telemedicine, 24 of the 71 patients would have been physically referred to Brisbane. Thus, this study underlined the cost effectiveness of the practice in a rural region.

As technology improves, wireless networks and cell phone access become more reliable, and companies such as Apple, Skype and many start-ups provide commercially available real-time audiovisual software in compliance with patient protection laws such as the American HIPAA ("Health Insurance Portability and Accountability Act"), making tele-ultrasound a feasible proposition.

Cost is a commonly expressed concern regarding tele-ultrasound with a special emphasis on the need for affordable tele-ultrasound platforms to make its use feasible. In the literature, numerous studies have used telemedicine platforms with open-source, low-cost, commercially available software such as over-the-counter hardware and low-cost portable ultrasound machines to minimize costs. Two studies explored the issue from the patients' perspective and found that the introduction of tele-ultrasound was associated with lower out-of-pocket costs for the patient due to a reduced need for travel to larger medical centers with formal imaging capacity [15,20]. In another study, e-learning was found to be more effective than conventional education and superior to self-learning for enhancing novice learners' ultrasound technical skills without increasing their workload [21].

3.3. Medical Education

In terms of medical education, e-learning can serve as both a self-study tool, as well as a teaching device, when used in conjunction with colleagues or supervisors. With the emergence of faster network technology (5G/6G) and mobile app platforms for live interaction and handheld ultrasound devices, tele-ultrasound and new fields of applications in pre-clinical settings and outpatient areas such as midwifery, geriatric facilities, and therapeutic use will be enabled with these developments [22].

The existing literature indicates that e-learning can provide an effective way of improving educational outcomes for healthcare professionals. Several studies have shown that tele-learning methods lead to similar results to traditional, face-to-face, teacher-centered instruction [23]. Especially when it comes to the field of tele-ultrasound, didactic concepts are particularly important. Theoretical ultrasound knowledge can be learned using a "flipped classroom", a didactic format of blended learning, whereby students acquire knowledge at home and put it into practice during classes. In the past, attempts to offer targeted, individualized learning environments were abandoned due to the excessive expenditure of money. Nowadays, software-based, highly individualized learning is the norm rather than the exception and has shifted the paradigm. In this ongoing educational evolution, tele-ultrasound devices have several crucial advantages over traditional stationary ultrasound systems. Tele-ultrasound devices are connected to the internet, and interaction between every active participant is made easier, which simplifies communication and ideally speeds up the learning process. The internet, of course, provides access to a plethora of teaching and learning software. The combination of being continuously interconnected, elaborate software, and sufficient computing power has paved the way towards a personalized learning experience. The latest applications and web-based learning platforms can observe and track user profiles. In this way, individual learning behavior can be analyzed and optimized. Especially, theoretical ultrasound knowledge and knobology can be taught in this manner.

However, practical tele-guided ultrasound teaching and assessment comes with costs and challenges. In addition to purchasing the ultrasound equipment, the teacher and student need a video-based platform to show and see the student's performance and the position of the transducer. Furthermore, the real-time sonogram must be streamed in order to give the student instructions during the training. However, the limited evidence base of this relatively new field of medical education demands further research to corroborate its efficacy in comparison with conventional teaching methods (Table 1).

Table 1. Virtual ultrasound education requirements.

Dimension	Requirement	Remarks
	Theoretical teaching	
Propaedeutics, sonoanatomy, knobology, image optimization	Teaching material available and accessible -live -on demand Theoretical lectures, how-to videos, annotated image material with physiological variants and pathological findings Interactive elements, questionnaires, quizzes In live (real-time) formats, sufficient internet bandwidth required	Availability via videoconferencing platforms, video repositories, or learning management systems (LMS) preferred Especially in videoclips (cine-loops), smooth display during online lectures often limited by internet connectivity and bandwidth issues
	Practical teaching	
Image acquisition	Storage capability for still images, clips for asynchronous review Annotations possible Two-way communication between learner and educator Video-based real time instructions Artificial intelligence elements (optional) Augmented reality elements (optional)	Multiple communication pathways for two or more learners, collaborative learning optional (videoconference) Availability of probands limited, self-scanning possible in some pocus modalities
Image interpretation	Annotated image material with physiological variants and pathological findings for pattern recognition Active expert review of images Structured feedback In patient cases, corresponding other imaging/diagnostic modalities for confirmation and cross-reference of ultrasound findings	
Tracking and assessment of learning pathway	Ongoing quality assurance Structured assessment of learning progress Tracking capabilities in learning system	
Miscellaneous	Data protection regulations followed	

The most common components such as the handling and orientation of the probe, as well as image adjustments, may be evaluated with video footage that is recorded and reviewed afterwards or via a live stream.

These applications can be upgraded by augmented reality devices and experimental visual guidance tools that enhance the tele-guided experience and enable a more realistic method of learning [24]. Visual guidance is a computer-assisted method of demonstrating to an examiner the movement of the ultrasound probe as it is manipulated over a patient's body toward a desired anatomical location.

The latest technical advancement in the field of tele-ultrasound is tele-guided ultrasound, which enhances and enables tele-educational tools in a more precise way. Tele-guided ultrasound means that someone is controlling the ultrasound probe and has access to all device settings remotely. For assessing not only image quality, but also the proficiency of the tele-mentored ultrasound image acquisition some studies have combined different tools.

Furthermore, progress is being made in educational tele-guidance tools. These serve as image quality indicators that provide real-time feedback from the physician on the healthcare worker's scan technique. These tools aim to improve the quality and speed of the captured images. Thus, education in medical ultrasound can be expanded in remote areas if basic equipment (US machine, Internet, and telemedicine software) is available.

As an example of the use of tele-ultrasound in medical teaching, a tele-didactic ultrasound course was designed by Höhne et al. [25] in light of the current COVID-19 pandemic and the end of classical classroom teaching, which was previously considered vital in ultrasound training. The purpose of the study was to determine if online ultrasound teaching was effective. It also aimed to identify a suitable evaluation approach for evaluating US skills from afar. This pilot study demonstrated the effectiveness of online lectures in the context of ultrasound medical education. Furthermore, it illustrates that teleguided ultrasound training is feasible and should be addressed in medical schools, as well as the learning possibilities of tele-digital ultrasound.

3.4. Weaknesses and Threats

As far as weaknesses and threats are concerned, we analyzed issues that might need further development or deep consideration, such as new software that is not yet commercially available in comparison to traditional ultrasound (Table 2). Generally, in a tele-scenario with a remote expert, securing the multidimensional problem of "transducer angles", "transducer position", "patient body posture", and "patient breathing state" may be difficult. Furthermore, the device settings, device type, and transducer type all have an impact on whether or not a representation is useful. As a result, the use of tele-ultrasound may be contingent not only on the technological infrastructure and individual abilities of the two linked examiners, but also on the capacity of the two remote persons to interact successfully as a team.

Table 2. Advantages and disadvantages of conventional ultrasound versus tele-ultrasound.

-	Traditional Ultrasound Teaching	Tele-Ultrasound Teaching
Image acquisition	Trained provider	Untrained provider with real-time remote expert supervision
Image optimization	Directly possible by expert provider/educator, including manual intervention and correction of probe movements	Indirectly possible via verbal commands by expert provider/educator
Operation of complex ultrasound applications/functions/measurements	Direct	Not possible or indirect
Image interpretation	Clinical context known by local provider, supported by personal impression, direct correlation possible	Clinical context must be communicated, personal impression limited, correlation limited
Situational perception	Physical presence of supervisor	Tele-presence, perception reduced to 2D visual and audio
Integration into patient management	Direct interaction of provider with team (e.g., when pausing chest compressions during CPR)	Indirect interaction
Availability in austere settings	Reduced in terms of equipment, providers, experts and educators. Sometimes unavailable.	Enhanced by technology
Availability of experts	Lower Limiting factor in education. Need travel, accommodation, time.	Higher Low threshold, no travel time.
Equipment requirement	Ultrasound device	Ultrasound device and transmission technology Network capability
Additional expenses	Expert funding, travel, accommodation	No travel and accommodation costs
Geographical distance	Device with patient and diagnostician confined in very local space	Distance between tele-medicine sites only limited by data transfer range
Time lag	None	Ranges between none and significant
Data transfer	Normally wired and a data transfer rate in the gigabit range	Wireless or wired, with mega or gigabit per second speeds.
Data security	Local storage, general data protection considerations	Special considerations required, especially in case of transmission and processing of health-related personal data across different legislative spaces and IT-solutions
Legal framework, liability	Local framework applies	Special considerations required, as provider and supervisor may operate under different legislations

3.5. Image Quality

A quality assessment tool was developed a few years ago to standardize sonographic B-images [26]. As an important feature, it attempts to quantify the sonographer's influence with regard to the final image quality. This method can also be adopted for tele-ultrasound. Furthermore, the examiner's skill, as well as the patient's current state and cooperation, are all known to influence ultrasound imaging. Gallstones, for example, may only be scanned when the patient is in a precise inspiratory position and with extremely specific transducer angles and placements. As a result, even in the absence of tele-transmission, the imaging result is not always consistent. When two examiners look at the same patient, they will almost always produce different visuals and, in some situations, diagnoses. This general weakness naturally also has an influence on the use of ultrasound in telemedicine and must always be taken into account in all applications.

The latest developments in the field of telecommunication have paved the way for several attempts to test tele-ultrasound with mobile device application [22] or via web-based applications [27]. These studies have shown that commercially available video chat software can transmit high-quality and clinically useful ultrasound images. For nearly every anatomic location assessed in these studies, images obtained by means of this method were non-inferior to images obtained directly from a stationary ultrasound machine. There were also mobile ultrasound apps that went beyond simply projecting live images, with built-in tools to grade the images that study participants took and determined whether they passed or failed.

Data transfer rates have come a long way since the early stages of telemedicine two decades ago, when devices with a bandwidth of 2 Mbit/s were used successfully for obstetric tele-ultrasound [15]. Nowadays, the transmission of real-time ultrasound video footage to a remote iPhone using inexpensive technology is feasible, as shown in the literature. It can be accomplished without the loss of image quality and a minimal delay and works even with 3G mobile connection [28].

3.6. Safety of Data

As the value of personalized data increases and cheap data storage is abundantly available, telemedicine companies can record and analyze a complete set of parameters longitudinally in real-time, which is an unprecedented feat in the history of medicine. However, patients' access to and control over these stored data are not always guaranteed. In Western societies, where people are wary of privacy violations, these developments should spark an intense public discourse, which seems to lag behind the staggering pace of the technological advancement.

In a tele-guided setting, there are several ways to document the obtained images and results. There are various ultrasound documentation programs on portable devices and guidelines on how to appropriately document an ultrasound examination [29]. Moreover, there are cloud-based monitoring systems that do not require bedside supervision and documentation, which may enhance the ability of physicians to study and document ultrasound images [30]. Data protection is an important issue related to these cloud-based documentation applications. Although recent cloud-based products comply with EU regulations regarding data privacy and protection, this remains a hot topic.

4. Artificial Intelligence and Tele-Ultrasound

Excellent-quality ultrasound images serve as the foundation for expert interpretation. Artificial intelligence (AI) is emerging to provide a means for autonomously gathering images, even for the uninitiated. Obstetricians have perfected the art of capturing and evaluating fetal images for pregnancy monitoring. Startup enterprises in the United States and Europe have acquired regulatory approval to advise inexperienced clinicians to take images for clinical purposes using AI guidance. The ultrasound probe is put on the patient after entering information such as the patient's height, weight, and gender. The clinician is then instructed on how to move the probe (clockwise, counterclockwise, up, or down), and the picture is autocaptured as soon as the best image is detected.

There is still a scarcity of validation data for high-quality images acquired using this method. According to trials conducted by nurses with no previous echocardiography experience who used this equipment on hundreds of patients, high-quality video photographs may be obtained well over 90% of the time. That result holds true for images of organs that are not constantly moving, such as the heart, and should be more suited for AI algorithmic direction. Researchers are collecting massive amounts of ultrasound images from a range of patients to assist and drive algorithm development even further. These images will be linked to ground-truth diagnoses and verified clinical results. The implications of AI-assisted ultrasound guiding may be crucial for all practitioners in the future. For example, an emergency room doctor may snap a photograph of any region of a patient's body and then send the video loop to a radiologist for interpretation. Deep learning algorithms for exact ultrasound interpretations are being investigated in the meantime; however, they are still in the early phases of development [31]. The advantages might be extended to rural regions, as well as middle- and low-income nations, where worker capacity or skill in image capture may be limited or non-existent, democratizing imaging technology. More widespread clinical use of smartphone ultrasonography has begun in rural Africa and India, and AI guidance for image capture may be adopted soon. In the COVID-19 outbreak, new uses of AI guidance have lately been seen [32]. Researchers are using deep learning approaches to develop algorithms for automating acquisition and severity evaluations to help in real-time clinical decision-making. If fully confirmed, the easily available objective image data might assist in the diagnosis, triage, and surveillance of seriously sick patients. In the future, a patient with heart failure may transmit to their doctor a clinical grade echo of their heart, whereas a person with acute stomach discomfort might obtain targeted photographs that indicated a kidney stone.

5. Discussion

The rapidly evolving technology will likely promote the widespread implementation of tele-ultrasound procedures, especially in remote areas and in the first-responder setting. Further investigation of real-time image transfer and communication paradigms in prehospital scenarios and practical applications is warranted. Pocket and other portable ultrasound machines are the most commonly used ultrasound devices for tele-ultrasound. The potential impact of tele-ultrasound is substantial when considering both the scope of clinical fields of application (e.g., respiratory failure, hemodynamic compromise, procedural guidance) and the number of stakeholders (e.g., patients, providers, health systems). Technologically speaking, ultrasound machines have become smaller, more portable, and durable, and the relative cost has decreased dramatically. Smartphones are ubiquitous, and dozens of software applications run seamlessly on them simultaneously. Therefore, smartphones are capable of functioning as affordable handheld telemedicine platforms. Finally, global connectivity is steadily increasing, particularly wireless cellular and internet access. These advances have made tele-ultrasound feasible and have given it a durable competitive advantage compared to conventional ultrasound, which will boost its application in the near future.

Nevertheless, tele-guided ultrasound education also carries some weaknesses and risks. No tele-ultrasound module can fully replace real hands-on learning experiences. Although one can try to teach the handling of the probe via tele-guidance, it is easier to do this physically next to a student. The digital distance, which provides some benefits, appears as a barrier that cannot be eradicated when using tele-ultrasound. Therefore, tele-ultrasound is an option for remote or poorly developed areas, as well as an innovative tool in crisis situations.

The practical usefulness of tele-ultrasound has become more entrenched and advanced in the medical setting in recent years. A distinction must be made between tele-ultrasound and the pure transmission of ultrasound images, which does not have the aspects of real-time data transmission with a corresponding second examiner. Particularly in the field of medical teaching, there is a specific difference between these two modalities.

Tele-ultrasound is on the advance, especially in the next few years, due to further progress in digitalization and technical miniaturization. Global pandemics, such as the current COVID-19 pandemic, have particularly marked and shaped this use of technology.

Author Contributions: Conceptualization, F.R. and V.S.S.; methodology, F.R.; software; investigation, F.R. and E.H.; resources, F.R., E.H. and D.D.; data curation, F.R., E.H. and V.S.S.; writing—original draft preparation, F.R.; writing—review and editing, E.H. and D.D.; visualization, F.R. and D.D.; supervision, V.S.S.; project administration, F.R. and V.S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. WHO. *A Health Telematics Policy in Support of WHO's Health-For-All Strategy for Global Health Development-Report of the WHO Group Consultation on Health Telematics*; World Health Organization: Geneva, Switzerland, 1997.
2. Strehle, E.M.; Shabde, N. One hundred years of telemedicine: Does this new technology have a place in paediatrics? *Arch. Dis. Child.* **2006**, *91*, 956–959. [CrossRef]
3. Bashshur, R.L. Telemedicine effects: Cost, quality, and access. *J. Med. Syst.* **1995**, *19*, 81–91. [CrossRef] [PubMed]
4. Wootton, R. Recent advances: Telemedicine. *BMJ* **2001**, *323*, 557–560. [CrossRef] [PubMed]
5. Smith, P.; Brebner, E. Tele-Ultrasound for Remote Areas. *J. Telemed. Telecare* **2002**, *8*, 80–81. [CrossRef] [PubMed]
6. Sargsyan, A.E.; Hamilton, D.R.; Jones, J.A.; Melton, S.; Whitson, P.A.; Kirkpatrick, A.W.; Martin, D.; Dulchavsky, S.A. FAST at MACH 20: Clinical Ultrasound Aboard the International Space Station. *J. Trauma Inj. Infect. Crit. Care* **2005**, *58*, 35–39. [CrossRef] [PubMed]
7. Ashot, E. *The International Space Station Ultrasound Imaging Capability Overview for Prospective Users*; NASA: Houston, TX, USA, 2006.
8. Kwon, D.; Bouffard, J.A.; van Holsbeeck, M.; Sargsyan, A.E.; Hamilton, D.R.; Melton, S.L.; Dulchavsky, S.A. Battling fire and ice: Remote guidance ultrasound to diagnose injury on the International Space Station and the ice rink. *Am. J. Surg.* **2007**, *193*, 417–420. [CrossRef] [PubMed]
9. Law, J.; Macbeth, P.B. Ultrasound: From Earth to Space. *McGill J. Med.* **2011**, 13. [CrossRef]
10. Marshburn, T.H.; Hadfield, C.A.; Sargsyan, A.E.; Garcia, K.; Ebert, D.; Dulchavsky, S.A. New Heights in Ultrasound: First Report of Spinal Ultrasound from the International Space Station. *J. Emerg. Med.* **2014**, *46*, 61–70. [CrossRef]
11. Su, M.-J.; Ma, H.-M.; Ko, C.-I.; Chiang, W.-C.; Yang, C.-W.; Chen, S.-J.; Chen, R.; Chen, H.-S. Application of Tele-Ultrasound in Emergency Medical Services. *Telemed. e-Health* **2008**, *14*, 816–824. [CrossRef]
12. Boniface, K.S.; Shokoohi, H.; Smith, E.R.; Scantlebury, K. Tele-ultrasound and paramedics: Real-time remote physician guidance of the Focused Assessment With Sonography for Trauma examination. *Am. J. Emerg. Med.* **2010**, *29*, 477–481. [CrossRef]
13. Douglas, T.M.; Levine, A.R.; Olivieri, P.; McCurdy, M.T.; Papali, A.; Zubrow, M.T.; Rodick, K.M.; Hurley, J.M.; Verceles, A.C. Brief training increases nurses' comfort using tele-ultrasound: A feasibility study. *Intensiv. Crit. Care Nurs.* **2018**, *51*, 45–49. [CrossRef]
14. Ferlin, R.M.; Vaz-Oliani, D.M.; Ferreira, A.C.; Tristão, E.G.; Oliani, A.H. Tele-obstetric ultrasound: Analysis of first-trimester ultrasound images transmitted in realtime. *J. Telemed. Telecare* **2012**, *18*, 54–58. [CrossRef]
15. Chan, F.Y.; Whitehall, J.; Hayes, L.; Taylor, A.; Soong, B.; Lessing, K.; Cincotta, R.; Cooper, D.; Stone, M.; Lee-Tannock, A.; et al. Minimum requirements for remote realtime fetal tele-ultrasound consultation. *J. Telemed. Telecare* **1999**, *5*, 171–176. [CrossRef]
16. Soong, B.; Chan, F.Y.; Bloomfield, S.; Smith, M.; Watson, D. The fetal tele-ultrasound project in Queensland. *Aust. Heal. Rev.* **2002**, *25*, 67–73. [CrossRef]
17. Britton, N.; Miller, M.A.; Safadi, S.; Siegel, A.; Levine, A.R.; McCurdy, M.T. Tele-Ultrasound in Resource-Limited Settings: A Systematic Review. *Front. Public Health* **2019**, *7*, 244. [CrossRef] [PubMed]
18. Robertson, T.E.; Levine, A.R.; Verceles, A.C.; Buchner, J.A.; Lantry, J.H.; Papali, A.; Zubrow, M.T.; Colas, L.N.; Augustin, M.E.; McCurdy, M.T. Remote tele-mentored ultrasound for non-physician learners using FaceTime: A feasibility study in a low-income country. *J. Crit. Care* **2017**, *40*, 145–148. [CrossRef] [PubMed]
19. Chan, F.Y.; Soong, B.; Watson, D.; Whitehall, J. Realtime fetal ultrasound by telemedicine in Queensland. A successful venture? *J. Telemed. Telecare* **2001**, *7*, 7–11. [CrossRef] [PubMed]
20. Adambounou, K.; Adjenou, V.; Salam, A.P.; Farin, F.; N'Dakena, K.G.; Gbeassor, M.; Arbeille, P.; N'dakena, K.G. A Low-Cost Tele-Imaging Platform for Developing Countries. *Front. Public Health* **2014**, *2*, 135. [CrossRef]

21. Suzuki, R.; Hui, J.; Loftsgard, T.O.; Riley, W.; Bushman, M.S. Does Tele-Education Work. In *Point-Of-Care Ultrasound Training? A 3-Arm Randomized Trial Comparing Tele-Education, Conventional Education, And Self-Learning Methods*; ATS Journals: New York, NY, USA, 2017; Volume 195, Available online: https://www.atsjournals.org/doi/abs/10.1164/ajrccm-conference.2017.195.1_MeetingAbstracts.A7295 (accessed on 17 December 2021).
22. Levine, A.R.; Buchner, J.A.; Verceles, A.C.; Zubrow, M.T.; Mallemat, H.A.; Papali, A.; McCurdy, M.T. Ultrasound images transmitted via FaceTime are non-inferior to images on the ultrasound machine. *J. Crit. Care* **2016**, *33*, 51–55. [CrossRef]
23. Tomlinson, J.; Shaw, T.; Munro, A.; Johnson, R.; Madden, D.L.; Phillips, R.; McGregor, D. How does tele-learning compare with other forms of education delivery? A systematic review of tele-learning educational outcomes for health professionals. *N. South. Wales Public Health Bull.* **2013**, *24*, 70–75. [CrossRef] [PubMed]
24. Sheehan, F.H.; Ricci, M.A.; Murtagh, C.; Clark, H.; Bolson, E.L. Expert visual guidance of ultrasound for telemedicine. *J. Telemed. Telecare* **2010**, *16*, 77–82. [CrossRef]
25. Höhne, E.; Recker, F.; Schmok, E.; Brossart, P.; Raupach, T.; Schäfer, V.S. Conception and Feasibility of a Digital Tele-Guided Abdomen, Thorax, and Thyroid Gland Ultrasound Course for Medical Students (TELUS study). *Ultraschall Med. -Eur. J. Ultrasound* **2021**. [CrossRef] [PubMed]
26. Bahner, D.P.; Adkins, E.J.; Nagel, R.; Way, D.; Werman, H.A.; Royall, N.A. Brightness Mode Quality Ultrasound Imaging Examination Technique (B-QUIET): Quantifying Quality in Ultrasound Imaging. *J. Ultrasound Med.* **2011**, *30*, 1649–1655. [CrossRef]
27. Yoo, S.K.; Kim, D.K.; Jung, S.M.; Kim, E.-K.; Lim, J.S.; Kim, J.H. Performance of a Web-based, realtime, tele-ultrasound consultation system over high-speed commercial telecommunication lines. *J. Telemed. Telecare* **2004**, *10*, 175–179. [CrossRef] [PubMed]
28. Liteplo, A.S.; Noble, V.E.; Attwood, B. Real-time video transmission of ultrasound images to an iPhone. *Crit. Ultrasound J.* **2010**, *1*, 105–110. [CrossRef]
29. Dormagen, J.B.; Gaarder, M.; Drolsum, A. Standardized cine-loop documentation in abdominal ultrasound facilitates offline image interpretation. *Acta Radiol.* **2015**, *56*, 3–9. [CrossRef] [PubMed]
30. Canty, D.J.; Vijayakumar, R.; Royse, C.F. Cloud-based supervision of training in focused cardiac ultrasound-A scalable solution? *Australas. J. Ultrasound Med.* **2019**, *22*, 40–44. [CrossRef] [PubMed]
31. Komatsu, M.; Sakai, A.; Dozen, A.; Shozu, K.; Yasutomi, S.; Machino, H.; Asada, K.; Kaneko, S.; Hamamoto, R. Towards Clinical Application of Artificial Intelligence in Ultrasound Imaging. *Biomedicines* **2021**, *9*, 720. [CrossRef] [PubMed]
32. Cheema, B.S.; Walter, J.; Narang, A.; Thomas, J.D. Artificial intelligence–enabled POCUS in the COVID-19 ICU: A new spin on cardiac ultrasound. *Case Rep.* **2021**, *3*, 258–263.

5. Danksagung

Mein besonderer Dank gilt meinem Doktorvater Herrn PD Dr. med. MUDr. Valentin Sebastian Schäfer. Vielen Dank für die ausgezeichnete Betreuung und enorme Unterstützung während dieser Arbeiten, sowie auch für das Herausfordern, was mich auf meinem wissenschaftlichen Weg definitiv nach vorne gebracht hat.

Zudem möchte ich meinem Betreuer Dr. med. Florian Recker danken. Ohne deine unerschöpflichen Ideen sowie Unterstützung wäre diese Arbeit niemals zustande gekommen, insbesondere nicht mit diesem Outcome. Danke für die zahlreichen Gespräche auf persönlicher und wissenschaftlicher Ebene, die mich stets motiviert und bestärkt haben. Ich habe durch deine Betreuung sehr viel lernen dürfen und hoffe in der Zukunft auf weitere konstruktive Zusammenarbeit.

Zuletzt danke ich meiner Familie und meinen Freunden für ihre Geduld und Förderung während des Studiums und der Arbeit an dieser Dissertation. Insbesondere Lukas, für das Ermutigen während all dieser Phasen.