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Review Article

A systematic review and utilization study of digital stethoscopes for cardiopulmonary assessments

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ABSTRACT

Objectives: The demand for cardiopulmonary assessment via real-time live streaming is prevalent in remote communities of British Columbia, Canada. Digital stethoscopes enable remote assessments, but the difference in quality compared to conventional assessments is unknown.

Objectives were to explore published literature for real-time remote audio and video streaming of cardiopulmonary assessments via digital stethoscopes, and evaluate the quality of digital stethoscopes for remote cardiopulmonary assessments as compared to conventional stethoscopes in a Cardiac Virtual health Assessments (CaViAs) project.

Material and Methods: CaViAs included evaluation of quality and utility of three digital stethoscope devices, three digital platforms/applications, three noise-cancelling headsets, and two Internet-enabled devices with one technical operator and one evaluator.

A comprehensive search for "digital stethoscope*" was conducted in PubMed, Science Direct, CINAHL, TRIP, Open Grey and ClinicalTrials.gov in February 2021 for relevant peer reviewed studies. Studies were screened for eligibility and inclusion based on population, intervention, comparator, outcome and study design criteria and utilizing Preferred Reporting Items for Systematic reviews and Meta-Analysis, and assessed for methodological quality using Critical Appraisal Skills Programme for Randomized Controlled Trials.

Studies were eligible if they included adult humans undergoing cardiopulmonary assessment with digital stethoscopes compared to conventional stethoscopes to test the audio quality and ease of use of digital stethoscopes via real-time remote audio and video streaming across a distance.

Results: Of 238 articles identified, only one study of poor methodological quality was found that fulfilled all inclusion criteria. This study rated the quality of digital stethoscopes as good or very good. In the CaViAs project, the Eko Duo digital stethoscope in combination with the Eko ECG application, streamed between two Cisco DX 80 devices, and using the Plantronics Voyager 8200 performed the best.

Limitations included having only one reviewer for title and abstract screening and data extraction; hearing is subjective; a validated tool for quality testing was not used; and auscultation in general has several limitations.

Conclusion: There is a gap in literature to help inform decision-making in choosing digital stethoscopes that are best for real-time virtual remote outreach for cardiopulmonary assessments. For best results, digital stethoscopes should be used in conjunction with equipment that optimize audio and ease of use.

Keywords: digital stethoscope, utility, remote cardiopulmonary assessment, systematic literature review

INTRODUCTION

Heart disease is the leading cause of death globally, accounting for 16% of the world total deaths.[1] Early identification and treatment of heart disease, requires accurate diagnostic tools.[2] Assessment of cardiac health or disease, using a stethoscope has been the cornerstone of cardiac diagnostics for the last 200 years.[2-4] These once simple acoustic devices have evolved into technological masterpieces, allowing clinicians and patients to connect digitally to each other through wireless technologies. Digital stethoscopes are a subset of electronic stethoscopes. These devices take the electronic stethoscope capability of amplifying and filtering sound, and enhance it by converting audio signals into digital ones that can be shared in real-time.[2,5-8] This advanced connectivity allows clinicians to connect several devices and link to applications in real-time, displaying visual sound and electrical waves in addition to the audio feed to enhance and improve diagnostic accuracy.[8,9] This wireless connection between clinician and patient using digital devices has bridged the geographical access barriers that are often experienced in health systems.[5,7,8,10] These innovative solutions have shifted traditional health care practice into the realm of virtual health and telemedicine. Telemedicine broadly refers to care delivery using medical devices that either transmit or record health information.[11] Over the last decade, a number of new digital devices have become commercially available.[2,7,9,11] During the COVID-19 pandemic, the uptake and rapid adoption of remote options like telemedicine has increased.

The demand for cardiopulmonary assessment via real-time live streaming is most prevalent in the remote communities of British Columbia, Canada. These populations have limited access to cardiac specialists due to geographical and seasonal barriers. During COVID-19, the demand and potential for remote outreach to these populations was further compounded when the government of British Columbia restricted non-urgent in-person healthcare visits for several months. Real-time, unlike pre-recorded audio, has the ability to reduce time to care and treatment, and combined with video feed, provide simultaneous assessment of the physical presentation of the patient. New technologies can bridge the gaps to care in rural and remote settings; expediting timely cardiovascular assessment and promote early initiation of appropriate treatments.[12] In an attempt to increase access to quality care, Fraser Health Authority implemented a virtual first approach to care with the goal of keeping patients healthy at home. This necessitated integration of virtual health strategies. The utilization of digital stethoscopes enables real-time streaming of audio and video cardiopulmonary assessments of patients living in remote areas. It is well documented that audio quality is degraded when transmitted via the Internet.[13-16] To ensure that these remote assessments were of a similar quality and comparable to assessments conducted at the bedside with a conventional stethoscope, and to inform decisions about digital stethoscope procurement, quality and ease of use, assessment of different digital stethoscopes were conducted in a Cardiac Virtual health Assessments (CaViAs) project. To inform this quality assessment, a systematic review of the literature was conducted to evaluate available published knowledge regarding digital stethoscope testing via real-time streaming.

MATERIAL AND METHODS

Literature review

A review of the literature was performed in accordance with a rigorous, systematic process[17] in February 2021 to identify and assess the methodological quality of published studies that compared the quality of real-time audio and video streaming using digital stethoscopes to conventional stethoscopes used at the bedside. PubMed, Science Direct, CINAHL, TRIP and Open Grey databases, as well as ClincialTrials.gov were searched using broad search terms "digital stethoscope*" to ensure the search was as comprehensive as possible. To improve the relevancy of the articles returned, a more focused approach was followed in Pubmed and Science Direct by adding "cardio*" to the search terms, filtering by article type, and limiting by year (2000-present in Science Direct only). More details about the search are provided in Table 1. Additionally, relevant digital health journals were searched using the words "digital stethoscope," websites of digital stethoscope manufacturers were searched, and hand searches were conducted.

PICOS (Population, Intervention, Comparator, Outcome, Study Design) criteria were used to guide inclusion/exclusion criteria [Table 2]. Briefly, only studies involving human adults undergoing cardiopulmonary assessments in trials or meta-analysis were of interest. The justification for excluding pediatric patients is because the systems tested in the utilization study are meant to be used on adult patients with cardiovascular disease. Additionally, only studies that tested the quality of digital stethoscopes in a setting of real-time remote monitoring and transmitting audio and video over a distance were of interest. Quality deteriorates significantly when audio is transmitted over Wi-Fi/Internet, as opposed to audio recordings made at the bedside for review later. Trials were excluded if they compared digital and conventional stethoscopes, but the assessor was in the same location as the patient for both digital and conventional stethoscope assessments. This was a requirement to ensure study conditions of publications resembled the conditions under which the digital stethoscopes were tested in the current study. Additionally, clinical trials without available

Table 1: Search strategy

Database and date searched	Dates	Search terms	Filters	Number retrieved	Number excluded after title and abstract review
PubMed 19 Feb 2021	Inception to present	"digital stethoscope*" AND cardio*	Clinical trials, reviews and systematic reviews	6	0
Science Direct 19 Feb 2021	Inception to present	"digital stethoscope*" AND cardio*	None	9	9
Science Direct 19 Feb 2021	2000-present	(digital stethoscope) AND cardio	Research articles, review articles, product reviews	32	32
CINAHL/EBSCO 19 Feb 2021	Inception to present	"digital stethoscope"	None	0	0
TRIP 22 Feb 2021	Inception to present	"digital stethoscope"	None	153	147
Open Grey 19 Feb 2021	Inception to present	digital stethoscope	None	2	2
Clinicaltrials.gov	Inception to present	digital stethoscope	None	6	6

Table 2: PICOS

Population	Human adults undergoing cardiopulmonary assessment
Intervention	Digital stethoscope/Prototype
Comparator	Classic/Conventional/Acoustic stethoscope
Outcome	Audio and video quality, ease of use, extra equipment required (utility) for real-time audio and video streaming between different locations with digital stethoscopes
Study design	Meta-analysis, randomized controlled trial, other comparative trials

published full-text articles, articles not in English, and studies without a comparator were also excluded. The outcomes of interest were quality and ease of use of digital stethoscopes for real-time audio and video streaming between different locations in comparison to cardiopulmonary auscultation with conventional stethoscopes and methods.

One reviewer (AL) excluded articles based on title and abstract review, and two reviewers (AL, CK) excluded articles after full-text review. Reviewers were in consensus, and a third adjudicating party was not needed to resolve disagreement. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were followed [Figure 1].[18] Methodological quality was assessed using the Critical Appraisal Skills Programme (CASP) for Randomized Controlled Trials (RCTs).[19] Data were extracted by a single reviewer (AL) into a table [Table 3], including information about design, setting, population, intervention, comparator, outcome, findings, and quality.

CaViAs

Clinical testing of the equipment was carried out to compare the published findings to the clinical test findings. Exhaustive testing of various digital stethoscopes and other required equipment was undertaken to ensure that Fraser Health was adopting the best digital stethoscope set up, and maximizing the audio and video experience for both provider and remote receiver of care. The control comparator was a conventional, non-electronic, non-digital stethoscope: America Diagnostic Corporation (ADC) Adscope 615 Clinical Stethoscope. The primary purpose was to test the equipment's quality and capability to preserve audio and video integrity when transmitted via real-time streaming. The secondary purpose was to test the ease of utility of the devices and connections from a human factors standpoint, including setting up the equipment, connecting the devices, and initiating the real-time stream. All simulation and testing was conducted with the digital stethoscope directly on the subject's skin.

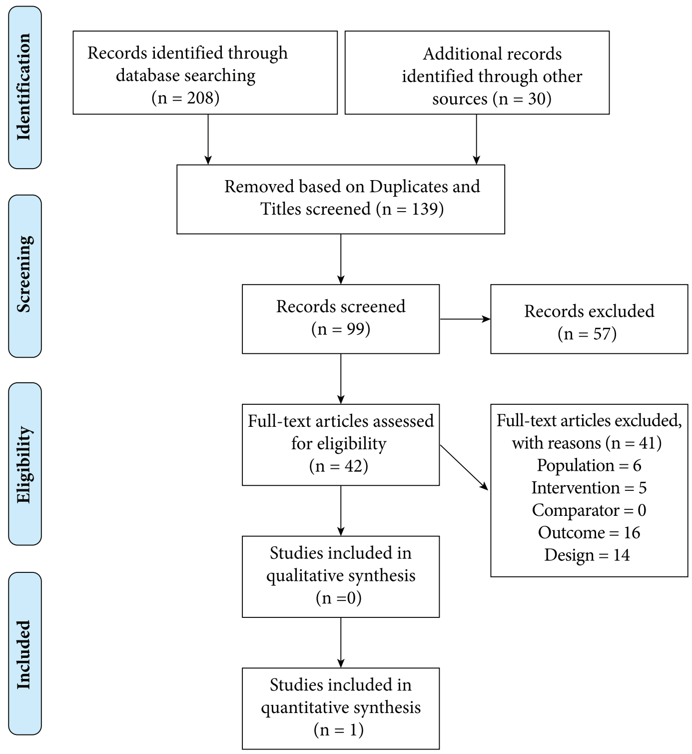

Figure 1: PRISMA flow chart.

Table 3: Data extraction.

Study	Foche-Perez et al. 2012(20)
Design	Stethoscope development with clinical validation using a randomized trial
Setting	Spain bedside and remote telematic auscultation through the hospital intranet, no facilities specified Peru: Santa Clotilde Health Center and Loreto Regional Hospital 180 km apart
Sample/ Population	Spain: 12 in the preliminary study, then 40 in a larger follow-up trial Peru: not specified Both countries: Very limited information provided about participants and no demographic details
Intervention	Digital stethoscope prototype with real-time and videoconferencing capabilities costing US$170 and using free open-source software
Comparator	Conventional Classic-II Littman
Outcomes	Acoustic quality Inter- and intra-observer agreement Exam-time
Findings	Acoustic quality: Good to very good quality reported with digital stethoscope Intra-observer: Mostly good to very good, but poor for some murmurs Inter-observer: Agreement in 8/12 patients for respiratory and cardiac sounds Exam time Digital: 191 seconds; Conventional: 110 seconds
Quality	This was a prototype design study with enough detail to build a similar prototype. However, the clinical validation part of the prototype was poorly described. No patient demographic details were provided and the detail about the randomization process is limited and results brief and not detailed. Evaluating methodological quality using CASP for RCTs found “yes” was applicable to only 2 items, “no” to 5 items and “can’t tell” to 6 items. A future publication was planned, but has not been found.

The subject and the stethoscope was situated in a different location to where the listener to the heart and lung sounds was situated; sending a transmission to a location remote from where the stethoscope was receiving the sounds. All, but the final test, involved the same operator of the equipment and the same listener of the real-time feed. The equipment operator has 16 years of experience in computer programming and technical leadership, and the listener and evaluator has 18 years of clinical practice in cardiopulmonary assessments. The final test included an independent operator and listener to verify the results obtained in all prior tests. The project was named CaViAs: Cardiac Virtual Health Assessments. CaViAs and included evaluation of quality and utility of three digital stethoscope devices, three digital platforms/applications, three noise-cancelling headsets, and two Internet-enabled devices [Table 4]. Each digital stethoscope was tested with the selection of platforms, headsets, and Internet-enabled devices as outlined in the methods. Each digital stethoscope was optimized to maximum potential in consultation with the device developer or vendor specialist. Scores were assigned from 1 (low) to 10 (high) for quality (audio and video) and ease of use in setting up the equipment and establishing a real-time connection. The equipment choice was based on availability from Canadian vendors.

No ethical clearance was required for the literature review or for the CaViAs project because no patients were involved.

RESULTS

Literature review

The literature search generated 238 articles, of which 139 were duplicates or were excluded based on title. The remaining 99 abstracts were screened and 57 were excluded, leaving 42 articles that underwent full-text review. Of these, 41 were excluded based on PICOS criteria [Figure 1]. Fifteen articles were found through various hand searches, but all were ultimately excluded. Only one study was found that compared the quality of a digital stethoscope (real-time live audio and video streaming over several kilometers) to the quality of using a conventional stethoscope at the bedside.[20]

Table 4: CaViAs project test equipment.

Digital stethoscopes	Internet-enabled devices	Platforms	Headsets
Thinklabs One	Cisco DX80 Video Conference Equipment	Zoom	Plantronics Blackwire 8225
Eko Duo ECG	Lenovo ThinkPad Laptop	TeleSensi	Jabra Evolve 65
Littman 3200 Bluetooth		Eko ECG Application	Plantronics Voyager 8200 UC

* This table provides a list of equipment tested, not the combinations in which it were tested

The methodological quality (using CASP criteria) of the clinical validation of the stethoscope in this study was relatively poor [Table 3]. The authors rated the acoustic quality of the digital stethoscope as good to very good; intra-observer agreement was mostly good to very good, but poor for some murmurs; there was inter-observer agreement in 8 of 12 patients for respiratory and cardiac sounds; and exam time with the digital stethoscope was 191 seconds compared to 110 seconds with the conventional stethoscope (Classic-II Littman).[20] Limitations of this study are that it was mainly about the design of the digital stethoscope with only a small section addressing the clinical validation in a group of patients. However, no patient demographic details were provided, the details about the comparative process were limited, and the reported results were not comprehensive.[20] An additional test was conducted with the digital stethoscope prototype described in this study in Peru over a 180 km distance, and a couple of cardiologists and pulmonologists were satisfied with the digital stethoscope when they tested it in this real-time telemedicine scenario.[20] Due to the lack of high quality published literature, this systematic literature review could not inform the CaViAs Project, but it highlighted the need for equipment testing in this particular type of setting.

CaViAs testing

Digital stethoscopes that were tested are presented in Table 5. Various combinations of selected equipment were evaluated. Each digital stethoscope device was tested with the Cisco DX80 and Lenovo Laptop, the three headsets, and Zoom. The DX80 has videoconference capability used for video and audio feed. Additional tests of the platforms were limited to device capability and developer recommendations. The Eko ECG App is compatible with the Eko Duo device. The Littman 3200 Bluetooth is the preferred device for the TeleSensi platform.

Table 5: Digital stethoscopes tested in the CaViAs project as illustrated by the manufacturers.

Eko Duo ECG	Thinklabs One	Littmann 3200
		

The CaViAs test results revealed that the best quality of audio, video, and ease of use for all parties was the Eko Duo digital stethoscope in combination with the Eko ECG application, streamed between two Cisco DX80 devices, using the Plantronics Voyager 8200 on the receiver end. This combination scored 9.5 out of 10 for audio quality when compared to the conventional stethoscope. The video quality of the subject and the application video feed was superior to other combinations, and compared to other device setups, ease of use and initiation of the video session was superior to others.[9-10] The addition of the Eko ECG app provided confirmation of audio signal with visual sound waves (phonocardiography) and a one-lead electrical tracing [Figure 2]. This feature added significant value to the experience that was not matched with the other devices. The Eko Duo used without the Eko ECG application reduced the audio quality to 5 out of 10 due to volume issues, even with all sounds setting optimized. However, not using the Eko ECG app increased the ease of use to 10 out of 10 because using the Eko ECG app adds steps to the user process.

Testing audio quality showed that the Thinklabs One device was comparable to the Eko Duo, however the set up and settings on the device itself were technically challenging. The Littman sound quality, even when paired with the TeleSensi platform that is intended to enhance the experience, was suboptimal and introduced static and suboptimal lung sounds. The Eko Duo was the easiest digital stethoscope to set up and connect to other devices, with no settings on the device itself that would require manipulation, and minimal interference when moving the device over the skin. When comparing the Eko ECG app to TeleSensi and Zoom, the steps to activate the Eko ECG app were significantly less. The Eko ECG app is the only platform that has visual representation of both the sound and electrical cardiac waves. The TeleSensi platform provides audio visualizations of the sound waves (phonocardiography), however, in tests, the audio quality was suboptimal and the steps to connect the digital stethoscope to the platform were cumbersome, necessitating session codes, and on several occasions, connections were not made on the first attempt. TeleSensi does not allow for video streaming of the subject during the session, required a separate connection via Zoom to see the subject under assessment. Zoom used alone lacked the ability to transmit the visual representation of the audio sounds, but provided video streaming of the subject and audio streaming of the stethoscope sound. Zoom setup includes a series of steps including meeting codes and accepting invitations to sessions, which decreased ease of use. The DX80 device was the best option for Internet-based real time streaming of audio and video. The DX80 is a touch screen video conference-enabled device that allows for very easy connecting between DX80 devices. The steps to activate a call are simple and allow very little room for error, and the screen layout is also customizable to the viewer's preference. Compared to the Lenovo laptop, which needs to be used in conjunction with Zoom for video, the steps with the DX80 were significantly reduced, and user experience and video quality of the DX80 was substantially better. The Plantronics Voyager 8200 headset was the best option for listening remotely to the real-time feed in a different location. This over-ear headset was significantly better at noise cancelling and was more comfortable than the comparators. The addition of Bluetooth connectivity to the Internet-enabled device and the auto on/off feature that is triggered when placing/removing the device from the ear, improved ease of use.

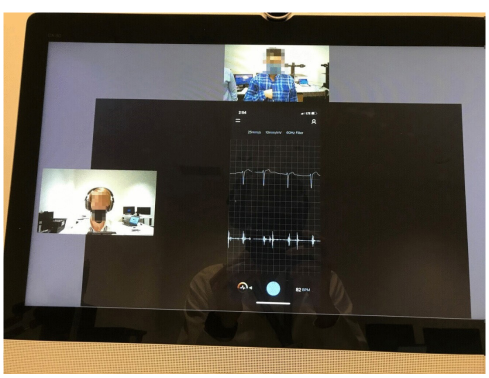

Figure 2: Cisco DX80 showing visual tracing of the Eko ECG application on a shared screen in the CaViAs project.

Utilization and adoption of a new practice can be affected by the ease of use. These include factors related to how easy it is to handle the stethoscope, additional settings that need to be manipulated, and ease in connecting the stethoscope to other devices. The ideal set up outlined in the CaViAs project took two steps, compared to the least ideal set up that included more than 10 steps. The best-case set up for each digital stethoscope was utilized to maximize audio and video quality and ease of use. As illustrated in Figure 3, the Eko Duo was ranked the best with an overall score of 18.5 out of 20; the Thinklabs was ranked 15.5 out of 20 and lost points for ease of use; and the Littman was ranked 7 out of 20 and lost points for both audio quality and ease of use. More details can be found in Table 6 outlining the various combinations of devices tested and the strengths and challenges encountered in the CaViAs project test scenarios.

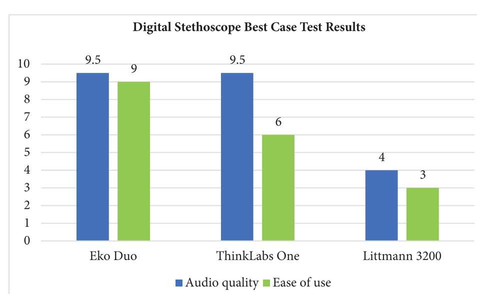

Figure 3: Best-case scenario of digital stethoscope performance, audio quality, and ease of use.

Table 6: CaViAs test results.

Digital stethoscope	Internet device	Platform	Extra equipment	Audio quality	Ease of use	Comments
Eko Duo with ECG app	DX80	DX80	Portable device for Eko Duo ECG app visual. Used iPhone for the test. Eko Duo connected via Bluetooth to DX80.	9.5/10	9/10 Two steps to connect VC to VC: touch call button; share screen button when ready; very simple set up Share screen is easy with DX80s (touch screen), two extra steps in working the iPAD, activating the Eko App, and keeping the stethoscope still to see visual ECG tracing.	May need Privacy and security approval to use Eko app in health settings. Experience greatly enhanced with 1 lead ECG and audio tracing. Audio clear, clear S1S2, no static. Ensure that Eko duo app volume boost is turned OFF. Audio best when patient side. DX80 is muted. Cannot select which lead is displayed on ECG app visual.
Eko duo without ECG app	DX80	DX80		5/10	10/10	Sound too soft even on full volume settings. More value and better sound with the ECG visual. Easy connect between DX80s. No extra steps involved if not using the app.
Thinklabs	DX80	DX80	3.5 mm stethoscope audio jack Headset for optimum noise cancelling	9.5/10	6/10	Clear audio, two steps to make VC to VC call between DX80s. Thinklabs non-Bluetooth option was difficult to set up with 3.5 mm cable, which allowed for error and reduced ease of use. Audio best when patient side DX80 is muted.
Thinklabs	DX80	Zoom	3.5 mm stethoscope audio jack Zoom invite and screen share	8/10	5/10 due to Zoom: multiple steps on both sender and receiver sides to initiate connection	Audio clear, no static, clear S1S2. Lung sounds not as clear but audible.
Eko Duo with ECG app	DX80	Zoom	Eko Duo Application on external device (iPhone) Connect app via Bluetooth Value add ECG one lead wave feature on app.	9/10 with app Too soft without app 2/10	5/10 due to Zoom: multiple steps on both physician and patient side to initiate connection	Added visual value with Eko ECG App.

(Continued)

Table 6: (Contd.)

Digital Stethoscope	Internet device	Platform	Extra equipment	Audio quality	Ease of use	Comments
Thinklabs	Laptop	Zoom	Need USB to 3.5 mm connection for laptop to Thinklabs Changes need to Zoom settings: disable audio cancelling	5/10 9/10 Quality improved dramatically with change in USB and turning 3.5 mm cable around – too many variables that can affect quality	4/10 due to Zoom: multiple steps on both sender and receiver side to initiate connection Also room for error on 3.5 mm cable	Need to switch microphone device between stethoscope and headset. Unable to hear signal sent out; need another cable to hear both audio and stethoscope.
Eko Duo	Laptop	Zoom	Cannot use app	2/10 Unable to use app	5/10 due to Zoom: multiple steps on both sender and receiver side to initiate connection	Volume too soft without app.
Littman 3200	Laptop	TeleSensi	Download driver for Littman and plug in extension for Google chrome License for TeleSensi app with monthly fee	4/10 Audio too soft and major static	3/10 due to TeleSensi generated pin to join session. Bluetooth connection difficult at times. Needs troubleshooting. Need to split screen with video and TeleSensi platform, requiring additional video call steps.	No audio chat feature between provider and receiver, only use written chat feature. Took more than 10 steps to connect to the platform and add a video call component. Audio adjusted in several places: on stethoscope, on platform, and on computer device. Big disadvantage not having video. Video can be added via Zoom but required extra window and steps.
Thinklabs	Laptop	TeleSensi	License for TeleSensi app with monthly fee	6/10	3/10 As above	Static on every heartbeat. Volume good, but too much interference.
Eko Duo	Laptop	TeleSensi	License for TeleSensi app with monthly fee	7/10	3/10 As above	Less static and audio better quality than Littman and Thinklabs in combination with TeleSensi

DISCUSSION

The literature review found only one study[20] conducted under similar circumstances as was used for the CaViAs equipment testing. Although this study provided sufficient detail regarding the design of the digital stethoscope prototype, very few details were provided about the clinical validation of the digital stethoscope with patients and assessors in separate locations.[20] Overall, the acoustic quality of this prototype was rated as good to very good.[20] More time was needed to conduct an examination using the digital stethoscope compared to the conventional stethoscope.[20] Several studies were identified during the systematic literature review (but did not fulfill inclusion criteria) that compared digital or electronic stethoscopes to conventional/acoustic stethoscopes, Computed Tomography

(CT) or Echocardiography.[21-33] In general, these studies found similar or improved quality with digital or electronic stethoscopes compared to conventional stethoscopes,[28,33] but lower sensitivity and specificity of cardiac auscultation with a stethoscope (89.5% and 57.5%, respectively) compared to gold standards such as echocardiography or CT angiography (96% and 86%, respectively).[27,30]

Published literature showed little comparison to the tests conducted in the CaViAs project. Only one review article presented sample case scenarios using similar devices, and transmitting the audio and video assessments in real-time to remote locations.[11] In this article, the authors briefly mention using Cisco software, similar to the DX 80 used in the CaViAs project, as well as the Eko Duo device.[11] The CaViAs project test results found that the digital stethoscope used on its own is suboptimal to its use in conjunction with other devices. The importance of confirming the audio transmission of heart and lung sounds with a visual representation (phonocardiography and/or single lead ECG tracing) is of significant importance. This feature has the ability to improve identification of abnormalities in cardio-pulmonary function. Visual representations of the audio signal have been shown to enhance and improve sensitivity of cardiac structural heart disease diagnosis.[34-36] While the audio quality of the digital stethoscopes can be greatly enhanced by pairing it with additional devices, the ease of use in setting up and connecting to the real-time session appears to be a barrier in utility and varies greatly between devices. The ease of use of the devices is greatly impacted by the amount of steps needed to set up, connect the device, and connect to the real-time video call. Reducing these steps greatly improves the experience and reduces the risk of error in connecting, time to make the connection, and sustainability of the process.

The cost of digital stethoscopes also deserves a mention. Some commercially available digital stethoscopes can cost up to US$500.[22] As these stethoscopes are relatively new to the Canadian market, prices are higher than in other markets, and substantially higher than traditional non-electronic stethoscopes. Stethoscope prices at the time of publication were: Eko Duo: $480, Thinklabs One: $871, and Littman 3200: $531, these quotes are based on Bluetooth versions and Canadian dollars including tax and shipping. In contrast, the digital stethoscope prototype can be built for US$170(20) or less, and there are several publications that describe how to build a digital stethoscope system at a reduced cost.[22,37-39] Health systems with limited financial means to implement remote cardiopulmonary auscultation, may find it helpful to improvise.

A limitation of the current study is that the systematic literature review was not registered and a protocol was not published.[18] Only one reviewer reviewed all the titles and abstracts for inclusion/exclusion, and only one reviewer extracted the data of the included study. It is recommended that two independent reviewers are involved in these processes when conducting systematic literature reviews.[17] Additionally, a validated tool to assess the quality of equipment was not used in the CaViAs project. There are a few publications that may inform future testing,[40,41] but the authors were not able to find the abstract or full-text article published by Ertel et al. in 1969.[40] The validated tool published by Lam et al. in 2005[41] may be an option to consider in future studies. The tests conducted in the CaViAs project were based on hearing ability, which is subjective. There is other equipment that can be tested, but it was not feasible to test in the CaViAs project due to limited resources. There is also concern that the accuracy of auscultation with stethoscopes can be poor. Accuracy of cardiac auscultation skills among medical professionals have been assessed in several countries (Britain, Canada, USA) and found to be poor (mean scores ≤42%, ≤58%, ≤58%) and consistently inaccurate.[42,43] Studies from other countries (Australia, New Zealand, Norway, Singapore, UK) had similar findings.[25,41] This poor performance may be improved with better training,[31] and adding visual feedback to audio and utilizing digital stethoscopes in combination with hand-held echocardiography, or with the addition of artificial intelligence algorithms.[21-23,29,30,44-46] Future steps may include using a validated tool to rate various digital stethoscopes and comparing real-time remote digital stethoscopes to conventional stethoscopes on patients in a clinical setting, and using a gold standard such as echocardiograms to improve the objectivity of findings.

CONCLUSION

There is a gap in literature to help inform decision-making in choosing digital stethoscopes that are best for real-time virtual remote outreach for cardiopulmonary assessments. The CaViAs project test results found that digital stethoscopes used on their own are suboptimal to their use in conjunction with other devices. In the CaViAs assessment, the Eko Duo digital stethoscope used in conjunction with the Eko ECG app, the Cisco DX80, and Plantronics Voyager 8200 noise cancellation headset provided the best quality audio and video, and ease of use with visual features that improve experience and accuracy.

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Declaration of patient consent

Patient’s consent not required as patients identity is not disclosed or compromised.

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Conflicts of interest

AL has no conflict of interests to declare. CK is an employee of Fraser Health Authority but has no conflicts of interest to declare.

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