Review Article

Digital stethoscopes in paediatric medicine

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Short title: Digital stethoscopes

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Abstract

**Aim:** To explore, synthesise and discuss currently available digital stethoscopes (DS) and the evidence for their use in paediatric medicine. **Methods:** Systematic review and narrative synthesis of digital stethoscope use in paediatrics following searches of OVID Medline, Embase, Scopus, PubMed and Google Scholar databases. **Results:** Six digital stethoscope makes were identified to have been used in paediatric focused studies so far. A total of 25 studies of DS use in paediatrics were included. We discuss the use of digital stethoscope technology in current paediatric medicine, comment on the technical properties of the available devices, the effectiveness and limitations of this technology, and potential uses in the fields of paediatrics and neonatology, from telemedicine to computer aided diagnostics. **Conclusion:** Further validation and testing of available DS devices is required. Comparison studies between different types of DS would be useful in identifying strengths and flaws of each DS as well as identifying clinical situations for which each may be most appropriately suited.

**Key Notes**

1. Auscultation devices are undergoing technological advances evident through the introduction of digital stethoscopes.
2. Digital stethoscopes offer potential development to diagnostic devices without listener subjectivity constraints as in traditional auscultation techniques.
3. Potential uses of digital stethoscope technology include: telemedicine for increasing specialist access; computer aided diagnostic programs/algorithms for accurate clinical diagnosis based on auscultation; home-based monitoring of cardiorespiratory conditions; clinical teaching.

**Keywords**

Infant; Newborn; Telemedicine; Signal processing; Computer-Assisted Phonocardiography

**Introduction**
Rene Theophile Hyacinthe Laënnec invented the stethoscope in 1816 to aid physicians in listening to the workings of the internal body in a professionally appropriate manner (1, 2). More than 200 years later, the stethoscope is arguably the most iconic symbol of the medical profession. Although basic design changes have taken place over this time, the inherent acoustic properties of the stethoscope remained unchanged until the digital revolution, which has brought with it the introduction of the digital stethoscope. In this review article, we discuss the evolution of the stethoscope to this modern form, review the current range of electronic stethoscopes available, describe the utilisation of this technology in paediatric as well as neonatal medicine, and outline potential uses in future practice.

The Acoustic Stethoscope

The binaural acoustic stethoscope is the iteration of the stethoscope used most abundantly by medical practitioners currently. It functions simplistically on the transmission of sound waves captured through vibrations of the diaphragm of the chest piece contacting the surface of the skin. The sound is transmitted via the hollow tubing connecting the head of the stethoscope to the earpieces. Most acoustic stethoscopes will comprise of a diaphragm and bell chest piece, which operate to transmit different frequency ranges of heart and lung sounds (3).

Variations in acoustic stethoscope composition can alter the sound quality to some degree, for example through alterations in tubing length and material, presence of single or double tubing, and the depth and diameter of the diaphragm and bell components of the device. In some studies, double tubing was associated with greater sound transmission, with single-tubed stethoscopes producing irregular frequency responses (4). Other studies found no significant practical advantage of a double tubed device compared to a single tube (3). There is general consensus however that for traditional binaural stethoscopes, a properly sealed acoustic pathway is vitally important for optimising sound quality and frequency ranges transmitted (3-5).

Nevertheless, regardless of design, acoustic stethoscopes display a loss or alteration of high frequency tones. These are not only important in localisation of sounds and harmonics (4), but may also be associated with specific murmurs or respiratory pathologies (4, 6). Compromise of these frequency ranges in auscultation could therefore result in pathological sounds going unheard and undiagnosed. The incidence of failing to hear pathological high frequency sounds may be increased by presbycusis (7).

The Digital Stethoscope

Digital stethoscopes (DS) are generally superior to acoustic stethoscopes in their ability to convey a wide spectrum of sound waves. They do this by capturing sounds obtained from the diaphragm and
transmitting them electronically, rather than through acoustic vibrations. This electronic process enables the sound to be amplified and/or filtered before being converted back to sound waves for transmission to the clinician’s ears. In addition, visual displays of the sound can be generated on a smartphone, tablet or computer. These are commonly phonocardiographic or spectrographic in nature, and can be offered in “real-time”, meaning the clinician receives them at the time of auscultation with the consequent ability to make auscultation technique adjustments in response.

DS have many useful applications in medical practice. They may be used in lieu of binaural stethoscopes in daily patient care and can facilitate academic teaching in paediatrics (8). They have been successfully employed in medical research and have telehealth applications (9). They can also be augmented by computer software to increase diagnostic capability, although accurate diagnosis based on signal processing and/or deep learning algorithms is not currently available (10).

Digital phonocardiograms recorded via DS were an effective means of increasing auscultatory skills of paediatric clinicians (11). Telemedicine is an important and innovative area with the immense potential for operation in rural and isolated locations, or low resource settings where access to specialised medical care such as paediatric cardiologists or respiratory physicians may not be easily accessible. Telemedicine use in the paediatric population with cardiac auscultation recordings from electronic stethoscopes has already been shown to be feasible and effective for online diagnosis without the presence of the specialist at the bedside (12, 13), and has been expanded for use in teaching medical students cardiovascular examination remotely (8). In one study, telemedicine consultations for the monitoring of children with asthma via DS achieved comparable levels of satisfaction and outcomes in terms of asthma control when compared with in-person consultations (14). In the near future, the DS may become a device able to aid the diagnosis of pneumonia in children in low resource settings, through the development of advanced computer algorithms (which is already underway) (15).

A key drawcard of an electronic stethoscope is its amplification and sound filtering capabilities. This capability has been tested in in-flight medical evacuation, an environment with immense background sound interference (16, 17). This is an environment in which medical care frequently is necessary, but auscultation is almost impossible due to the noise of the helicopter or aircraft. In this setting, electronic stethoscopes were shown to be capable of enhancing the emergency clinician’s ability to auscultate both heart (16, 17) and respiratory (16) sounds, through ambient noise reduction and amplification of relevant sounds.

Despite this, as with the conventional acoustic stethoscope, the interpretation of clinician-received sounds from digital stethoscopes remains subjective in nature, as diagnosis is still dependent on the
listener’s ability to correlate sounds with medical conditions. This longstanding limitation of stethoscopes may be overcome when high-quality digital sound capture can be coupled with accurate computerised algorithms, facilitating non-invasive, cost-effective and reliable diagnosis.

Types of Digital Stethoscope

A variety of DS are currently available. As an emerging technology, it is likely that the capability and availability of different devices will change significantly over time. Two authors (AR, LZ) systematically searched the following databases: OVID Medline, Embase, Scopus, PubMed and Google Scholar to identify relevant studies utilising DS. We used the search terms: digital stethoscope OR electronic stethoscope; AND newborn OR neonate OR infant OR paediatric OR children. The search criteria used resulted in a total of 76 studies. 49 articles were excluded after close review as they were either published in a language other than English, utilised a non-commercially available recording apparatus, were computer or sound engineering based (and not clinical), or were animal studies. The main commercially available DS that have been studied in published literature have been briefly discussed below (Table 1):

3M Littman Electronic Model 3200/4000

The Littman Model 3200 (3M, Maplewood, Minnesota, USA) stethoscope is probably the most well-known and purchased electronic stethoscope worldwide (18).

The diagnostic capabilities of student doctors when equipped with a standard acoustic stethoscope and a Littman 3200 DS were compared, and found convincing improvements in diagnostic accuracy in the students using the Littman digital stethoscope (19). The Littman 3200 in conjunction with computer algorithms has been used effectively for diagnosis in clinical studies to define pathology in the pulmonary artery (20, 21), specify cardiac murmurs (22) and detect adventitious respiratory sounds in paediatric patients (23). The Littman DS was also used in the newborn to assess gut motility patterns (24).

Thinklabs Digital Stethoscope

The Thinklabs One Digital Stethoscope (Thinklabs, Centennial, Colorado, USA) was designed as a small, portable, tube-free device for clinicians (25).

The Thinklabs DS has been used in trials investigating the accuracy of cardiac murmur detection and diagnosis in children made by specialists via telemedicine (13). In the respiratory field, this stethoscope has effectively been implemented to describe the frequency characteristics of normal pulmonary sounds in the paediatric population, and was successful in describing a difference in
sound characteristics between various parameters such as age, height and weight (26). Further to this it has been used in the detection of pneumonia (27). Features associated with swallowing in newborns has also been described (28). Interestingly, this DS has also been used antenatally, to record and characterise abdominal sounds of pregnant women across multiple gestations (29).

**Clinicloud Digital Stethoscope**

The Clinicloud Digital Stethoscope (Clinicloud, Melbourne, Australia) is a Melbourne-designed and manufactured product that was created with the intention of being a low-cost user-friendly device targeted at the parent demographic, with the purpose of enabling parents to easily record heart and lung sounds of their child (30).

The Clinicloud DS has recently been used in clinical trials in tertiary hospitals in Melbourne, Australia. It proved to be an accurate and feasible apparatus for detecting abnormal lung sounds in children and for determining heart rate in newborns (31-33).

**ViScope Digital Stethoscope**

The ViScope Digital Stethoscope (HD Medical, Silicon Valley, California, USA) has a unique inbuilt phonocardiogram visual display, allowing for dynamic auscultation (34).

This device was used to investigate the correlation between the amplitude of the first heart sound and left ventricular function. The ViScope DS was shown to be advantageous as an accessible and portable bedside diagnostic tool, useful for evaluating left ventricular systolic function (35).

**EkoCore and EkoDuo Digital Stethoscopes**

The EkoCore Stethoscope (Eko Devices, Berkeley, California, USA) is unique in that it is a hybrid device which has the capability to operate as a traditional acoustic stethoscope or as an electronic stethoscope. Eko Devices also offers an attachment, compatible with most acoustic stethoscopes, which connects to and digitalises the acoustic stethoscope. This DS is currently being further advanced with the introduction of the EkoDuo, a device that focuses on cardiac auscultation at the bedside. It combines digital stethoscope with a one-lead ECG, which may be displayed in real-time (36).

Only one study has utilised this device to auscultate various murmur types and compare the accuracy of physician diagnosis using traditional auscultation methods compared to the DS (37).

**Meditron/Meditron M30 Stethoscope**
The Meditron Stethoscope (Meditron ASA, Oslo, Norway) was developed in 2001 and was at one stage partnered with Welch Allyn (The Stethoscope) (38).

The Meditron DS has been used in conjunction with automated systems to discriminate between pathological and innocent heart murmurs in children (39) as well as clinician diagnosis over telemedicine (12).

In summary, a variety of DS are currently available and offer unique additions to the prospect of easing medical diagnosis for the clinician. The Thinklabs, Littman, Clinicloud, ViScope, Eko and Meditron DS have all been utilised in clinical research. There may be other brands of DS commercially available in addition to this list.

**Digital Stethoscope use in Paediatrics (Table 2)**

*Cardiac applications*

In recent years, there has been growing interest in the use of DS in paediatrics. A number of studies have investigated the accuracy of utilising electronic and DS technology to detect murmurs as well as differentiate innocent ones from those that are pathological. These studies produced phonocardiograms from the acquired heart sound recordings and evaluated the ability of medical professionals to interpret these accurately, often against a gold-standard measure of diagnosis such as echocardiogram (12, 22, 40-43). In addition, DS has also been used to develop computerised algorithms for recognition of heart sounds and murmurs (44). Heart sound recordings have also been coupled with artificial neural networks for the same purpose of differentiating pathological from innocent murmurs (45). These systems may allow efficient and effective diagnosis without inter-listener discrepancies.

DS technology has also been used to assess pulmonary artery hypertension (PAH). Frequency analysis on heart sound recordings displayed distinct characteristics found in children with PAH when compared to controls (20, 21). This analysis allowed for the non-invasive demonstration of a unique visual signature for this specific condition (46), demonstrating that digital auscultation may be effective in differentiating children with PAH from those with a normal pulmonary artery pressure. This could prove to be useful as a diagnostic tool.

*Respiratory applications*

Use of DS and accompanied sound analysis has been useful in characterising the unique sound variations in different patient populations and disease states. The Thinklabs DS was utilised to investigate baseline spectral parameters of non-pathological respiratory sounds in the young
paediatric population. Respiratory sound parameters were found to be related to age, height and weight, confirming findings of earlier investigations (26, 47, 48).

DS technology has also been applied to the detection of abnormal breath sounds, such as wheeze and crackles, in children. The ability to detect abnormal sounds using an electronic stethoscope was shown to be improved in comparison to an experienced doctor’s auscultation with an acoustic stethoscope in one small study (33). In another investigation, a DS was used to assess preschool age children with a confirmed radiographic diagnosis of pneumonia. Although sensitivity for detection of pneumonia through crepitation detection was only 56% in comparison to plain chest x-ray, the research displays a novel use for the technology as a bedside assessment tool (27). This was followed by a large multi-country case-control study across Africa and Asia where the same technology was used again to identify abnormal pulmonary sounds in paediatric cases of pneumonia (49). The study concluded that use of this technology in low-resource settings is feasible and interpretations from the sound recordings can reliably be achieved.

**Digital Stethoscope use in Neonatology**

As heart rate (HR) plays a major role in the determination of intervention and/or resuscitation requirements, especially at birth, the focus of clinical studies of DS applied to the neonatal population so far has focussed on accurate detection of this vital sign. Electronic stethoscopes offer an alternative to the widespread auscultatory or palpatory methods of acquiring HR from a newborn. The Clinicloud DS with smartphone heart rate detection algorithm has been shown to have greater accuracy than chest auscultation and cord palpation in determining newborn HR by two and three-fold respectively (32, 50). The feasibility of utilising this device in the transitioning infant within the delivery room has also been examined. Accurate and non-invasive determination of HR with strong correlation with ECG was possible (31). Compared to the Littman 3200, the Clinicloud DS dictates a more accurate HR reading (51). Difficulty producing an accurate HR reading during crying episodes was cited as a limitation of the device in this particular patient population.

The only other study involving this mode of technology and analysis in the transitioning newborn dates back to the late 1990s where Shirota et al. utilised a customised microphone, amplifier and recording system, comparable to an early form of a custom-built DS. This study investigated differences in the sound wave characteristics of breath sounds of infants born via caesarean section and the vaginal route. It was hypothesised that frequency bands of breath sounds in the transitioning infant would increase with larger volumes of lung fluid. Lung sounds at multiple intervals over a 72-hour period were recorded, and it was observed that in caesarean deliveries, the
frequency of the sounds began to decline close to 72 hours post-birth, as opposed to vaginally
delivered newborns, who showed a decline by 48 hours(52).

DS has been used to monitor abdominal sounds in neonates (53) and was able to describe the
frequencies of bowel sounds in relation to feeding, which allow the assessment of bowel motility
patterns in newborns (24). This technology was evaluated as a means of commenting on feeding
maturation in newborns. By recording the sounds associated with swallowing, features such as
frequency and rhythm of swallows were able to be correlated with gestation of the newborn (28).

**Artificial Neural Networks**

Artificial neural networks (ANN) are computer systems designed to detect patterns within a dataset
and draw conclusions based on trained algorithms. These systems are being applied to digital
recordings of heart and lung sounds via a DS to produce automated clinical diagnoses. Many
algorithms have been developed to date with varying levels of accuracy. One such ANN was able to
obtain 100% sensitivity and specificity for correctly distinguishing between innocent and
pathological murmurs (45), while an ANN designed to detect adventitious respiratory sounds
obtained an accuracy of 95.12% (23). ANNs to detect specific diagnoses such as pneumonia are
currently being trialled (10, 15). The definitive development of robust algorithms would strengthen
the benefits of ANN and DS as an interpretation tool in routine clinical practice.

**Limitations of Digital Stethoscopes**

It should be noted that each brand of DS is unique therefore holds individual product limitations. As
a technology, there are some overall limitations to the use in clinical medicine. For the purpose of
diagnosis, the DS device alone has no ability to identify pathology or abnormal sounds. It simply acts
as a recording instrument and in some cases may visually display the sound in the form of a
phonocardiogram. Automated diagnosis is only possible with the development and accompaniment
of computer algorithms. With automated systems there is an expected rate of false positives and
false negatives that could occur. In the majority of studies available, the methodology describes a
single chest recording. However, this is often insufficient for the purpose of complex diagnosis. The
requirement of multiple auscultation points may introduce further error.

Whilst these devices are easy to use and require very minimal to no training to operate, the quality
of sound recordings may vary with usage. Some of the brands such as the Clinicloud DS do not offer
real-time listening, so the sound can only be evaluated post recording. DS technology is without
question opening new gates to the clinician’s ability to monitor or assess pulmonary, cardiac and
bowel sounds in particular. There may be concern however, as to the possibility or extent of loss of auscultation skill that may occur due to the automated nature of these devices.

Future of Digital Stethoscope use

Recently, interest in digitalising the traditional stethoscope has grown and is leading to further development in patient monitoring and diagnostic capabilities. The scope of potential benefits this technology may impart upon paediatric medicine is still unknown, and there are many areas yet to be explored. Currently, it would appear the main area of use for these devices are in the classification of cardiac auscultation, including the recognition of murmur aetiology. Pathology in the newborn is yet to be investigated. Considering the well-documented shift from paper-based to electronic medical records underway in many healthcare settings (54), this technology may have a role in standard practice for data recording and data-sharing in patient care. The need for frequent reassessment and repeated auscultation by multiple clinicians may be reduced by a single recording being made accessible to any member of the treating team, uploaded to the patients’ electronic medical record (55). Large databases of heart sound recordings and phonocardiograms have been established in adult medicine, with the potential for the development of clinical decision support systems from this data (56). There is the opportunity to extend this into a paediatric and neonatal database of sound. Application to the burgeoning field of telemedicine has already begun; DS have been shown to be both practical and effective in telehealth in multiple studies (12-14). The potential implications of being able to easily record and transmit patient sound recordings from one location to another are significant. Access to specialist care in rural and remote regions continues to require further attention and innovation. In the future, more efficient and accurate diagnosis is a key advantage the DS and associated software may offer.

Accuracy and consistency of current more traditional auscultation techniques are sub-optimal (57), and as low as 20% correct identification of cardiac abnormality among clinicians has been reported (58). Not only do DS carry the potential to advance the teaching abilities of medical faculties (19), they also possess the capability to remove the user-dependant error with the development of artificial neural networks and the amalgamation of these technologies to create an automated diagnostic program (45, 59).

Further validation and testing of these devices is required. Comparison studies between available models of DS would be useful in identifying strengths and flaws of each as well as identifying clinical situations for which each DS may be most appropriately suited. It is likely that the next decade will see significant advances in the use of DS, and we predict they will have a role in routine clinical practice.
List of abbreviations

DS – Digital Stethoscope/s
HR – Heart Rate
PAH – Pulmonary Artery Hypertension

Conflict of interest and funding

We declare that none of the authors have any conflicts of interest or disclosures to declare. No author holds any interest in any of the commercially available stethoscope companies. Dr Atul Malhotra is supported by a Royal Australasian College of Physicians Fellowship.

References


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### Tables

**Table 1: Commercially available Digital Stethoscopes used in published paediatric literature**

<table>
<thead>
<tr>
<th>Stethoscope name (Developer)</th>
<th>Image</th>
<th>Technical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Littman Electronic Stethoscope Model 3200/4000 (3M, Maplewood, Minnesota, USA) (18)</td>
<td><img src="image1.png" alt="Image" /></td>
<td>Sound amplification: 24x acoustic Filters: Ambient noise reduction and frictional noise dampening (85% of ambient noise removal) Offers a remote TeleSteth system</td>
</tr>
<tr>
<td>ThinkLabs One Digital Stethoscope (ThinkLabs, Centennial, Colorado, USA) (25)</td>
<td><img src="image2.png" alt="Image" /></td>
<td>Sound amplification: 100x acoustic Filters: Multiple frequency filters Offers connection to a smartphone app</td>
</tr>
<tr>
<td>Clinicloud Digital Stethoscope (Clinicloud, Melbourne, Australia) (30)</td>
<td><img src="image3.png" alt="Image" /></td>
<td>Sound amplification: None Filters: None Records at 44.1kHz, 16 bit</td>
</tr>
<tr>
<td>ViScope Visual Stethoscope (HD Medical, Silicon Valley, California, USA) (34)</td>
<td><img src="image4.png" alt="Image" /></td>
<td>Sound amplification: 30x acoustic Filters: Tunable filters for heart sounds and murmurs Offers real-time phonocardiograph display</td>
</tr>
<tr>
<td>Stethoscope Model</td>
<td>Manufacturer/Location</td>
<td>Sound Amplification</td>
</tr>
<tr>
<td>-----------------------------------</td>
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</tr>
<tr>
<td>EkoCore and EkoDuo Digital</td>
<td>Eko Devices, Berkeley, California, USA</td>
<td>40x acoustic</td>
</tr>
<tr>
<td>Welch Allyn Meditron/Meditron M30</td>
<td>Meditron ASA, Oslo, Norway</td>
<td>30x acoustic</td>
</tr>
</tbody>
</table>
Table 2: Summary of published studies utilising Digital Stethoscopes in children

<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Study Parameter</th>
<th>Population</th>
<th>Stethoscope Used</th>
<th>Potential use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dahl (2002)</td>
<td>Heart murmurs</td>
<td>Mean 5 years (1 month to 13 years)</td>
<td>The Stethoscope, Welch Allyn</td>
<td>Telemedicine feasibility for differentiating pathological from innocent or no murmur</td>
</tr>
<tr>
<td>Finley (2006)</td>
<td>Heart murmurs</td>
<td>Range 1 month to 19 years</td>
<td>3M Littman Model 4000</td>
<td>Differentiation between innocent and pathological murmurs</td>
</tr>
<tr>
<td>Germanakis (2007)</td>
<td>Abnormal heart sounds</td>
<td>Mean 4.6 years (1 month to 13 years)</td>
<td>The Stethoscope, Welch Allyn</td>
<td>Possibility for use as a screening tool for recommendation of patients to Echocardiogram</td>
</tr>
<tr>
<td>De Vos (2007)</td>
<td>Heart murmurs</td>
<td>Range 1 month to 16 years</td>
<td>Welch Allyn Meditron</td>
<td>Discriminate between pathological and innocent murmurs</td>
</tr>
<tr>
<td>Mahnke (2008)</td>
<td>Heart murmurs</td>
<td>Mean 10.2 years (2 to 19.5 years)</td>
<td>Handheld STG, Stethographics</td>
<td>Accurate differentiation between pathological and innocent murmurs</td>
</tr>
<tr>
<td>Hill (2008)</td>
<td>Abdominal sounds</td>
<td>Premature infants</td>
<td>ThinkLabs</td>
<td>Method for identifying or</td>
</tr>
<tr>
<td>Author and Year</td>
<td>Condition</td>
<td>Age Range</td>
<td>Device</td>
<td>Main Findings</td>
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<tr>
<td>Strehle (2009)</td>
<td>Heart sounds</td>
<td>Range 8 to 10 years</td>
<td>AMD SmartStethoscope</td>
<td>Teaching medical students cardiac examination via telemedicine</td>
</tr>
<tr>
<td>Repelaer van Driel (2011)</td>
<td>Wheeze</td>
<td>Mean 14 months</td>
<td>ThinkLabs</td>
<td>Accurate identification of wheeze</td>
</tr>
<tr>
<td>Baker (2013)</td>
<td>Pulmonary sounds in abnormal lungs</td>
<td>Pediatric</td>
<td>3M Littman Model 3200</td>
<td>Telemedicine for monitoring ventilated patients</td>
</tr>
<tr>
<td>Emmanouilidou (2013)</td>
<td>Pulmonary sounds in normal lungs</td>
<td>Pediatric</td>
<td>ThinkLabs</td>
<td>Method for characterisation of normal breath sounds</td>
</tr>
<tr>
<td>Ellington (2014)</td>
<td>Pulmonary sounds in normal lungs</td>
<td>Mean 2.2 years</td>
<td>ThinkLabs</td>
<td>Method for characterisation of normal breath sounds</td>
</tr>
<tr>
<td>Knox (2014)</td>
<td>Bowel sounds</td>
<td>1 to 3 days of life</td>
<td>3M Littman Model 3200</td>
<td>Assessment of bowel motility patterns in newborns</td>
</tr>
<tr>
<td>Ince (2014)</td>
<td>Swallowing</td>
<td>Term mean 38.4 weeks and preterm mean 33.7 weeks</td>
<td>ThinkLabs</td>
<td>Characterisation of swallowing patterns in respect to gestation</td>
</tr>
<tr>
<td>Elgendi (2015)</td>
<td>Heart sounds related to Pulmonary</td>
<td>Median 7 years (3 month to 19 years)</td>
<td>3M Littman Model 3200</td>
<td>Method of diagnosis of PAH</td>
</tr>
<tr>
<td>Author</td>
<td>Measurements</td>
<td>Age Range</td>
<td>Device</td>
<td>Description</td>
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<tr>
<td>Kevat (2015)</td>
<td>Heart rate</td>
<td>Infant 26.7 to 54.7 weeks corrected gestation</td>
<td>Clinicloud</td>
<td>Accurate and clinically easily useable method of obtaining HR</td>
</tr>
<tr>
<td>Lai (2016)</td>
<td>Heart murmurs</td>
<td>Mean 8 years (1 day to 18 years)</td>
<td>3M Littman Model 3200</td>
<td>Accurate diagnosis of pathological murmurs</td>
</tr>
<tr>
<td>Scrafford (2016)</td>
<td>Pulmonary sounds associated with pneumonia</td>
<td>Range 2 to 35 months</td>
<td>ThinkLabs</td>
<td>Accurate diagnosis of cases with pneumonia</td>
</tr>
<tr>
<td>Sepehri (2016)</td>
<td>Heart murmurs</td>
<td>Range 1 to 18 years</td>
<td>Welch Allyn Meditron</td>
<td>Identification of murmurs</td>
</tr>
<tr>
<td>Kevat (2017)</td>
<td>Pulmonary sounds</td>
<td>Mean 6.7 years (4.6 to 17.1)</td>
<td>Clinicloud</td>
<td>Detection of abnormal pulmonary sounds (wheeze and crackles)</td>
</tr>
<tr>
<td>McCollum (2017)</td>
<td>Pulmonary sounds associated with pneumonia</td>
<td>Range 1 to 59 months</td>
<td>ThinkLabs</td>
<td>Accurate diagnosis of cases with pneumonia</td>
</tr>
<tr>
<td>Gaertner (2017)</td>
<td>Heart rate</td>
<td>Newborn (mean 93 sec post-birth)</td>
<td>Clinicloud</td>
<td>Accurate and clinically easily useable method of obtaining HR</td>
</tr>
<tr>
<td>Pyles (2017)</td>
<td>Heart murmur</td>
<td>Mean 9.9 years</td>
<td>ThinkLabs</td>
<td>Accurate identification of murmurs over telemedicine</td>
</tr>
<tr>
<td>Khan (2017)</td>
<td>Adventitious lung</td>
<td>Mean 2 years</td>
<td>3M Littman</td>
<td>Detection of adventitious lung sounds</td>
</tr>
<tr>
<td>Sounds</td>
<td>Model 3200</td>
<td>Adventitious sounds</td>
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<tr>
<td>Behere (2018) Heart murmur</td>
<td>Mean 7.8 years</td>
<td>EkoCore</td>
<td></td>
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<tr>
<td>Treston (2018) Heart rate</td>
<td>Newborn (mean 120 sec post-birth)</td>
<td>3M Littman Model 3200</td>
<td>Method for obtaining HR</td>
<td></td>
</tr>
</tbody>
</table>
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