Fast and accurate newborn heart rate monitoring at birth
A systematic review

International Liaison Committee on Resuscitation Neonatal Life Support Task Force

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Review

Fast and accurate newborn heart rate monitoring at birth: A systematic review

Vishal S. Kapadiaa,*, Mandira D. Kawakamib, Marya L. Strandc, Cameron Paul Hurstd, Angela Spencer,e, Georg M. Schmölzerf, Yacov Rabi,g, Jonathan Wyllieh, Gary Weineri, Helen G. Lileyj, Myra H. Wyckoffa, on behalf of the International Liaison Committee on Resuscitation Neonatal Life Support Task Force,1

Abstract

Aim: To examine speed and accuracy of newborn heart rate measurement by various assessment methods employed at birth.

Methods: A search of Medline, SCOPUS, CINAHL and Cochrane was conducted between January 1, 1946, to until August 16, 2023. (CRD 42021283364) Study selection was based on predetermined criteria. Reviewers independently extracted data, appraised risk of bias and assessed certainty of evidence.

Results: Pulse oximetry is slower and less precise than ECG for heart rate assessment. Both auscultation and palpation are imprecise for heart rate assessment. Other devices such as digital stethoscope, Doppler ultrasound, an ECG device using dry electrodes incorporated in a belt, photoplethysmography and electromyography are studied in small numbers of newborns and data are not available for extremely preterm or bradycardic newborns receiving resuscitation. Digital stethoscope is fast and accurate. Doppler ultrasound and dry electrode ECG in a belt are fast, accurate and precise when compared to conventional ECG with gel adhesive electrodes.

Limitations: Certainty of evidence was low or very low for most comparisons.

Conclusion: If resources permit, ECG should be used for fast and accurate heart rate assessment at birth. Pulse oximetry and auscultation may be reasonable alternatives but have limitations. Digital stethoscope, doppler ultrasound and dry electrode ECG show promise but need further study.

Keywords: Newborn, Resuscitation, Heart Rate, Electrocardiogram, Pulse oximeter, Auscultation, Palpation, Digital stethoscope, Doppler ultrasound, Dry electrode ECG, Bradycardia, ILCOR, NRP, Systematic review, Meta-analysis

Background

Most newborn infants undergo fetal to neonatal transition at birth with minimal intervention.1 However, 5–10% of newborn infants do not initiate adequate respiratory effort and require resuscitation.2,3 Heart rate (HR) is the most important vital sign during stabilization of newborn infants and a progressive increase in HR reflects effectiveness of resuscitation.1 Therefore, accurate and rapid assessment of HR is critical to decision-making in the delivery room.

Abbreviations: bpm, beats per minute, CI, confidence interval, CoE, certainty of evidence, ECG, electrocardiogram, GRADE, Grading of Recommendations, Assessment, Development and Evaluation, HR, heart rate, HRausc, HR determined by auscultation through stethoscope, HRDop, heart rate obtained by using ECG device with dry electrodes incorporated in a belt, HRECG, HR determined by ECG HRDU, heart rate obtained by Doppler ultrasound device, HRPALP, HR determined by palpation, HRPo, heart rate obtained by pulse oximetry, LCOR, International Liaison Committee on Resuscitation, IQR, interquartile range, LoA, limit of agreement, PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-analyses, QUADAS2, Quality Assessment of Diagnostic Accuracy Studies version 2, RCT, Randomized controlled trial, RoB, risk of bias, s, seconds, SD, standard deviation

☆ Article Summary: Speed and accuracy of different methods used for newborn heart rate assessment at birth are the focus of this systematic review.

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1 A complete list of Task Force members appears in the acknowledgments.

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Traditionally, HR was determined by auscultation with stethoscope or palpation of umbilical cord pulsations.\textsuperscript{1,4} Pulse oximetry has been used as an adjunct for HR assessment at birth, especially during resuscitation.\textsuperscript{1} Globally, none of the electronic devices that measure HR at birth, such as electrocardiogram (ECG), are universally available. Even in well-resourced countries there is a need to make pragmatic, but preferably evidence-based decisions about which devices to use for HR assessment at birth.\textsuperscript{5} Use of newer modalities like digital stethoscope, Doppler ultrasound, dry electrodes incorporated in a belt, electromyography and photoplethysmography for HR assessment has been reported.\textsuperscript{5} Different devices utilize different methods to measure a newborn’s heart rate at birth (Supplementary Table 1). Wanting to incorporate new evidence, the International Liaison Committee on Resuscitation (ILCOR) Neonatal Life Support Task Force designed this systematic review to examine speed and accuracy of newborn infant HR measurement by various methods in the delivery room.

Methods

Protocol
This systematic review was conducted in accordance with the Cochrane Handbook of Systematic Reviews of Interventions.\textsuperscript{6} The results follow the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement for meta-analysis in health care interventions.\textsuperscript{7} The protocol was submitted to the Prospective Register of Systematic Reviews (PROSPERO CRD 42021283364, registered on 8/11/2021).

PICOST
The Population, Intervention, Comparator, Outcome, Study designs and Timeframe (PICOST) were created by the ILCOR Neonatal Life Support Task Force and approved by the ILCOR Scientific Advisory Committee (Table 1).

Eligibility criteria
Randomized or non-randomized studies that compared HR monitoring modalities and reported any of the prespecified outcomes were included. Animal studies, simulation studies, case series, conference abstracts, trial protocols and studies of HR assessment performed outside the delivery room were excluded. Publications in all languages were eligible if they had an English abstract.

Outcomes
Time for first HR from device placement, first HR from birth and accuracy of HR were included as outcomes by consensus of the ILCOR Neonatal Life Support Task Force. For this review, HR determined by ECG (HR_{ECG}) was considered the gold standard. Accuracy was examined using:

1. Pooled Bland-Altman analysis: The Bland-Altman plot is used to measure agreement between two quantitative measurements.\textsuperscript{8–11} The Bland-Altman plot determines agreement between the ECG (reference technique) and other methods (experimental techniques). The Bland-Altman analysis calculates the bias (mean difference between experimental and reference techniques) to assess accuracy. For this systematic review a mean difference of 10 beats per minute (bpm) was considered clinically acceptable. The Bland-Altman plot includes 95% limits of agreement (LoA) to measure precision. The experimental technique for measurement of HR was considered imprecise if the 95% LoA was wide. The 95% LoA represent the range in which 95% of the differences between the two methods are expected to fall. When multiple studies report Bland-Altman plot analysis, the data are pooled to summarize the estimate of accuracy and precision. This establishes agreement intervals and does not determine clinical acceptability.

2. Aggregated sensitivity and specificity analyses for the index HR monitoring modality was conducted to identify HR_{ECG} < 100 bpm and HR_{ECG} < 60 bpm.

Search strategy
MEDLINE (Ovid), SCOPUS (Elsevier), CINAHL (EBSCO), Cochrane Register of Controlled Trials, and Cochrane Database of Systematic Reviews were searched between January 1, 1946, and October 29, 2021 (Supplemental Information) without language restrictions. The search was updated on August 16, 2023. Authors hand-searched the ILCOR 2015 Consensus on Science and Treatment Recommendations and reference lists of other systematic reviews on this topic.\textsuperscript{5,12–14} Authors queried trial registries (US National Library of Medicine, ClinicalTrials.gov).

<table>
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<th>Table 1 – PICOST Question.</th>
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<td><strong>Population</strong></td>
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<td><strong>Intervention</strong></td>
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<td><strong>Comparison</strong></td>
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<td><strong>Outcomes</strong></td>
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<td><strong>Study Design</strong></td>
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<td><strong>Timeframe</strong></td>
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</table>

Abbreviation: HR—heart rate.
Medicine, International Standard Randomized Controlled Trial Number registry, and European Union Clinical Trials Register) from inception to August 16, 2023.

**Study selection and data extraction**

Two authors (V.S.K. and M.D.K.) utilized Rayyan (https://rayyan.qcri.org) to independently review titles and abstracts. For discrepancies during abstract screening the authors evaluated the full text. Subsequently, the two reviewers independently conducted full text reviews to determine eligibility, documenting reasons for exclusion based on a predetermined list.

**Data collection, Risk of Bias (RoB) and Certainty of Evidence (CoE)**

The predetermined characteristics and outcomes of the studies were extracted independently by the reviewers, compared, and consensus was reached. Pairs of independent authors evaluated the risk of bias using the Quality Assessment of Diagnostic Accuracy Studies version 2 (QUADAS2). V.S.K. is an author of one included study in the systematic review but did not participate in any aspect of that evaluation of the study. The CoE, or confidence in the estimate of effect, for each outcome was assessed using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) framework. The evaluations of both RoB and GRADE were reviewed by other authors and a consensus reached.

**Data analysis**

GRADEpro (McMaster University, Hamilton, Canada) with Review Manager software (v5.4; The Nordic Cochrane Center, Copenhagen, Denmark) was utilized for data summarization and analysis, respectively. Data analysis followed methods of the Cochrane Collaboration. Trials were combined using the random-effect model. Values for time to HR detection from birth or device placement were typically reported as medians. Meta-analysis of the difference of medians was done as described by McGrath et al. In one study mean and Standard Deviation (SD) were reported. These were con-
<table>
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<tr>
<th>Study</th>
<th>Country</th>
<th>Total N</th>
<th>GA</th>
<th>Eligibility criteria</th>
<th>Study Design</th>
<th>Index test</th>
<th>Reference Std</th>
<th>Primary outcome</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>Owen 2004</td>
<td>UK</td>
<td>60</td>
<td>Term</td>
<td>All newly born term infants eligible</td>
<td>Randomized</td>
<td>Assess HR by palpation based on randomized method: femoral, brachial or umbilical cord</td>
<td>Assess HR simultaneously with stethoscope</td>
<td>Agreement of HR assessment by palpation method to auscultation</td>
<td></td>
</tr>
<tr>
<td>Kamlin 2006</td>
<td>Australia</td>
<td>26</td>
<td>Term</td>
<td>Vigorous term infants who did not require resuscitation</td>
<td>2 care providers were randomly allocated to assess HR by either palpation or auscultation</td>
<td>1. Auscultation 2. Palpation of umbilical cord</td>
<td>ECG (Masked)</td>
<td>Accuracy of palpation or auscultation by comparing with ECG</td>
<td></td>
</tr>
<tr>
<td>Kamlin 2008</td>
<td>Australia</td>
<td>55</td>
<td>Term and preterm (≥ 28 0/7 weeks)</td>
<td>Convenience sample</td>
<td>Cohort study</td>
<td>Pulse oximeter</td>
<td>ECG</td>
<td>Precision and accuracy of pulse oximeter for HR assessment</td>
<td>– 37 excluded due to equipment malfunction – convenience sample</td>
</tr>
<tr>
<td>Katheria 2012</td>
<td>USA</td>
<td>46</td>
<td>Term and preterm (30 were 23–30 weeks)</td>
<td>Availability of video recording that included ECG and pulse oximeter data during the study period</td>
<td>Cohort</td>
<td>Pulse oximeter</td>
<td>ECG</td>
<td>Time to obtain continuous audible signal from pulse oximeter vs ECG</td>
<td>– Audible heartbeat was used as guide for reliable signal</td>
</tr>
<tr>
<td>Mizumoto 2012</td>
<td>Japan</td>
<td>20</td>
<td>Term and Preterm</td>
<td>High risk delivery attendance by team and video recording available</td>
<td>Cohort</td>
<td>Pulse oximeter</td>
<td>ECG</td>
<td>Accuracy of HR assessment ECG vs pulse oximeter</td>
<td>– Unclear if this is consecutive or convenience sample</td>
</tr>
<tr>
<td>Dawson 2013</td>
<td>Australia</td>
<td>44</td>
<td>Term or near term</td>
<td>Eligible infants were those born by elective Cesarean section at or near term when at least two members of the research team were available to attend the birth; infants with congenital abnormalities and infants of non-English speaking parents were excluded</td>
<td>Cohort</td>
<td>Pulse oximeter x 2 (Masimo and Nellcor)</td>
<td>ECG</td>
<td>– To compare SpO₂ measurements between Masimo and Nellcor oximeters – To compare HR measurements from both oximeters against HR measured by electrocardiograph (ECG).</td>
<td>– During this period, there were 71 elective Cesarean sections, resulting in 64 infants eligible for the study. Consent was obtained to study 56 infants, and they were unable to attend the remaining eight deliveries. Twelve infants were excluded from statistical analysis – 1 due to technical problems with the monitoring equipment and 11 because their DR recording</td>
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<tr>
<td>Study</td>
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<tr>
<td>van Vonderen 2015</td>
<td>Netherlands</td>
<td>48</td>
<td>Term and preterm infants born vaginally or by Cesarean were eligible for inclusion; infants were excluded if they had congenital abnormalities or cardiac defects</td>
<td>Cohort</td>
<td>Pulse oximeter</td>
<td>ECG</td>
<td>Reliability of Pulse oximeter for HR measurement during the first 10 min after birth</td>
<td>contained &lt; 100 'good signal quality' measurements from the ECG.</td>
<td></td>
</tr>
<tr>
<td>Iglesias 2016</td>
<td>Spain</td>
<td>39</td>
<td>Preterm infants who were receiving resuscitation</td>
<td>Cohort</td>
<td>Pulse oximeter</td>
<td>ECG</td>
<td>Compare Pulse oximeter with ECG for HR assessment</td>
<td>Excluded infants with congenital anomalies or no complete resuscitation decided before birth. 45 recordings; 6 excluded due to recording failure. 7 excluded due to ECG failure (n = 3) or unavailability of researcher (n = 4). – 14 newborns for whom the DS did not display the HR were continuously crying – data recorded every second for 60 sec – None of the infants were bradycardic or received respiratory support</td>
<td></td>
</tr>
<tr>
<td>Gaertner 2017</td>
<td>Australia</td>
<td>37</td>
<td>Not published but mean GA: 38(^{\text{w7}}) (36(^{\text{w7}})–39(^{\text{w7}}))</td>
<td>Convenience sample</td>
<td>Digital stethoscope (DS)</td>
<td>ECG</td>
<td>Performance of DS to evaluate HR in delivery room</td>
<td>(continued on next page)</td>
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<tr>
<td>Study</td>
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</table>
| Shimabukuro 2017| Japan   | 33      | ≥37 weeks low risk (no PPV or CPAP) | Convenience sample | Cohort        | Handheld fetal Doppler (FDD) | ECG           | Compare FDD and ECG and to determine equivalency                                                        | --Congenital anomalies excluded 
--Measurement of total five times at minutes 1–5 after delivery 
--If HR measurement by FDD required ≥ 10 s: considered invalid |
| Iglesias 2018    | Spain   | 39      | <32 weeks           | Video recordings of preterm infants with bradycardia were analyzed, 29 such episodes included. | Cohort       | Pulse oximeter       | ECG           | Reliability of ECG compared with pulse oximeter during bradycardia episodes                              | --ECG blinded to the clinical team 
--Excluded congenital anomalies 
--10 min recording; 6 exclusions due to technical problems (camera failure, ECG or pulse oximeter malfunction or lack of adequate recording) |
<p>| Murphy 2018*     | Ireland | 100     | Term low risk Cesarean section | Infants were randomly assigned to monitoring with Philips IntelliVue X2 which incorporates ECG and Masimo pulse oximeter, or with the Nellcor Portable SpO2 | Infants were monitored with the IntelliVue and Nellcor monitors on 47 and 53 occasions, respectively. HR determination by auscultation was recorded on 92 occasions. As soon as an HR appeared on the monitor, a clinician was asked to auscultate the HR. Clinicians were masked to the monitor on all occasions. |
| Murphy 2019*     | Ireland | 100     | Term                | Term infants born via Cesarean section | Infants were randomly assigned to monitoring with IntelliVue (ECG + Pulse oximeter) or Nellcor (pulse oximeter) only | Time to first HR display | ECG           | The ECG electrodes were reapplied in 21/47 (45%) infants (once in 14, twice in 6 and three times in 1 infant, respectively). This was most often due to the electrodes not sticking on the skin; but vigorous infants removed the electrodes on occasion. |                                                                                  |</p>
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<tbody>
<tr>
<td>Treston 2019</td>
<td>Ireland</td>
<td>60</td>
<td>Term</td>
<td>Term infants</td>
<td>Cohort study</td>
<td>--Handheld US (US)</td>
<td>Auscultation</td>
<td>--To determine if US and DS could offer a quickly and effective method assessing HR in DR</td>
<td>Two physicians attended each delivery, one assessed the HR by auscultation and the second assessed the HR using either handheld US, Digital stethoscope or ECG. The time to achieve first HR and the HR recorded were noted, then when both modalities were recording a simultaneous HR was recorded. Each physician was blinded to the others recording modality during assessment. All infants were vigorous and crying.</td>
</tr>
<tr>
<td>Agrawal 2019</td>
<td>India</td>
<td>131</td>
<td>≥34 weeks</td>
<td>All newborns more than 34 weeks of gestation delivered by Cesarean section during routine working hours. Newborns needing PPV excluded</td>
<td>Cohort</td>
<td>Portable Doppler ultrasound (PDU)</td>
<td>ECG</td>
<td>Compare accuracy of HR determined by PDU</td>
<td>Excluded Congenital anomalies</td>
</tr>
<tr>
<td>Zanardo 2019</td>
<td>China</td>
<td>25</td>
<td>Term</td>
<td>Term, elective Cesarean section; consecutive sample</td>
<td>Cohort</td>
<td>PDU (SD1 Ultrasonic Pocket Doppler; combination of built-in speaker and fetal heart rate digital display)</td>
<td>Pulse oximeter</td>
<td>If PDU can assess HR quickly and effectively in elective Cesarean delivery compared to pulse oximeter</td>
<td></td>
</tr>
<tr>
<td>Henry 2021</td>
<td>UK</td>
<td>18</td>
<td>≥37 weeks</td>
<td>Convenience sample of ≥37 weeks’ with no obvious requirement for resuscitation, based on antenatal history, and delivered by planned Cesarean section</td>
<td>Cohort</td>
<td>FhPPG (new cap mounted newborn HR device) Pulse oximeter</td>
<td>ECG</td>
<td>Accuracy and reliability of FhPPG compared to Pulse oximeter and ECG</td>
<td>Study had 2 phases. NICU phase data are not included in this systematic review. All infants had all 3 devices placed.</td>
</tr>
<tr>
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<tr>
<td>Cavallin 2020</td>
<td>Ethiopia</td>
<td>60</td>
<td>Infants at risk for resuscitation</td>
<td>RCT</td>
<td>Auscultation by stethoscope</td>
<td>ECG</td>
<td>Degree of agreement of HR obtained by auscultation or palpation compared to ECG</td>
<td>Exclusion of congenital anomalies and birth between 12:01 PM and 7:59 AM. Provider masked for ECG and Pulse oximeter HR compared at 60, 90, 120, and 300 s. Research team not blinded when assessing outcome measures</td>
<td></td>
</tr>
<tr>
<td>Bjorland 2020</td>
<td>Norway</td>
<td>104</td>
<td>All infants ≥ 34 weeks who received PPV at birth</td>
<td>Cohort</td>
<td>Pulse oximeter</td>
<td>ECG</td>
<td>To compare the efficacy of pulse oximeter versus ECG in providing a reliable HR signal during real-life newborn resuscitation</td>
<td>Review of video recordings</td>
<td></td>
</tr>
<tr>
<td>Bush 2021</td>
<td>USA</td>
<td>28</td>
<td>30–35 weeks’ and Term infants</td>
<td>Cohort</td>
<td>Dry electrode ECG pulse oximeter</td>
<td>ECG</td>
<td>To compare the time to accurate HR acquisition between pulse oximeter, ECG and dry electrode ECG</td>
<td>Excluded infants with skin or thoracic anomalies</td>
<td></td>
</tr>
<tr>
<td>Bobillo-Perez</td>
<td>Spain</td>
<td>50</td>
<td>Low risk term newborns</td>
<td>Cohort study</td>
<td>US pulse oximeter Auscultation</td>
<td>ECG</td>
<td>To compare the accuracy and speed of HR assessment through US when compared with ECG, pulse oximeter and auscultation</td>
<td>Five physicians attended each delivery, one assessed the HR by auscultation, the second using ECG, the third through pulse oximeter, the fourth using US, and the fifth physician stabilized the infant</td>
<td></td>
</tr>
<tr>
<td>Murphy 2021*</td>
<td>Ireland</td>
<td>36</td>
<td>Infants with known anomalies were excluded</td>
<td>RCT: randomly assigned to monitoring with IntelliVue (ECG + pulse oximeter) or Nellcor (pulse oximeter)</td>
<td>Pulse oximeter</td>
<td>ECG + pulse oximeter</td>
<td>Time from start of monitor application to first HR display</td>
<td>Study stopped early due to COVID-19 pandemic. Glare reflected from the screen of the IntelliVue monitor precluded determination of the exact time to display of first ECG HR 3 times.</td>
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<td>Study</td>
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<tr>
<td>Abbey 2021</td>
<td>USA</td>
<td>51</td>
<td>&lt;31 weeks GA</td>
<td>All inborn neonates of obstetrical GA 23 0/7–30 6/7 weeks for whom the high-risk resuscitation team was present at birth and who required active resuscitation</td>
<td>RCT</td>
<td>pulse oximeter</td>
<td>ECG</td>
<td>Time to stabilization, which was defined as the time it takes from birth for HR to be &gt; 100 bpm and SpO2 to be in the goal range</td>
<td>ECG and pulse oximeter was placed on all newborns. They were randomized into either an ECG-displayed arm or an ECG-blinded arm.</td>
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<tr>
<td>Røttedal 2021</td>
<td>Norway</td>
<td>48</td>
<td>≥32 weeks</td>
<td>Infants ≥32 weeks that received PPV within the first five minutes after birth</td>
<td>Cohort study</td>
<td>DEB pulse oximeter</td>
<td>ECG</td>
<td>(i) time from birth to placement of the devices, (ii) device placement time, (iii) time to HR presentation, (iv) proportion of time during resuscitation with HR feedback, and (v) HR correlation between devices</td>
<td>248 were resuscitated with PPV, of which 206 had consent for participation. 48 infants had complete datasets and were included in the study. NeoBeat, ECG, and pulse oximeter were applied to newborns resuscitated at birth. Resuscitations were video recorded, and HR was registered every second.</td>
</tr>
<tr>
<td>van Twist 2022</td>
<td>Netherlands</td>
<td>18</td>
<td>≥32 weeks and/or birth weight ≥ 1.5 kg</td>
<td>≥32 weeks and birthweight ≥ 1.5 kg and in need of HR monitoring on the resuscitation table</td>
<td>Cohort study</td>
<td>DEB pulse oximeter</td>
<td>ECG</td>
<td>To test the accuracy of NeoBeat when compared to pulse oximeter and conventional ECG with disposable electrodes</td>
<td>Inclusion occurred through perinatal assessment when the investigators were on duty</td>
</tr>
</tbody>
</table>

BPM: beats per minute; DEB: dry electrodes incorporated in a belt; DR: delivery room; DS: digital stethoscope; ECG: electrocardiogram; FDD: fetal Doppler device; FhPPG: Forehead Phtoplethysmography; HR: heart rate; PDU: portable Doppler ultrasound; PPV: positive pressure ventilation; RCT: randomized controlled trial; SIQ: signal identification and quality; SpO2: oxygen saturation; US: ultrasound.
Table 4 – Evidence Summary per comparison.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Studies</th>
<th>Patients</th>
<th>Certainty of Evidence*</th>
<th>Results</th>
<th>Pooled median difference (95% CI) or Bias (LoA with 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse oximeter (PO) vs ECG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time to first HR from device placement (RCT)</td>
<td>2</td>
<td>136</td>
<td>Very low</td>
<td>Found no difference for this outcome between PO and ECG.</td>
<td>Pooled difference HR&lt;sub&gt;PO&lt;/sub&gt; 12 s slower (95% CI 13 s faster to 38 s slower); p &gt; 0.05</td>
</tr>
<tr>
<td>Time to first HR from device placement (Observational)</td>
<td>6</td>
<td>265</td>
<td>Low</td>
<td>PO is slower in acquiring HR signal than ECG.</td>
<td>Pooled difference HR&lt;sub&gt;PO&lt;/sub&gt; 57 s slower (95% CI 13 s slower to 101 s slower); p &lt; 0.05</td>
</tr>
<tr>
<td>Time to first HR from birth (RCTs)</td>
<td>2</td>
<td>87</td>
<td>Very low</td>
<td>Found no difference for this outcome between PO and ECG.</td>
<td>Pooled difference HR&lt;sub&gt;PO&lt;/sub&gt; 6 s slower (95% CI 23 s slower to 10 s faster); p &gt; 0.05</td>
</tr>
<tr>
<td>Time to first HR from birth (observational)</td>
<td>6</td>
<td>321</td>
<td>Low</td>
<td>PO is slower in acquiring HR signal than ECG.</td>
<td>Pooled difference HR&lt;sub&gt;PO&lt;/sub&gt; 52 s slower (95% CI 9 s slower to 94 s slower); p &lt; 0.05</td>
</tr>
<tr>
<td>Accuracy of HR assessment (Pooled summary bias)</td>
<td>5</td>
<td>216</td>
<td>Very low</td>
<td>PO may be accurate but imprecise for HR estimation at birth</td>
<td>Summary mean bias: −1.2 bpm 95% LoA −17.9 to 15.5 bpm (95% CI of 95% LoA-32.8, 30.4)</td>
</tr>
<tr>
<td>Identification of neonatal bradycardia (HR&lt;sub&gt;ECG&lt;/sub&gt; &lt; 100 bpm)</td>
<td>3</td>
<td>145</td>
<td>Very low</td>
<td>Sensitivity 0.83 (0.76, 0.88) Specificity 0.97 (0.93, 0.99)</td>
<td>N/A</td>
</tr>
<tr>
<td>Auscultation vs ECG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for first HR from device placement</td>
<td>3</td>
<td>115</td>
<td>Moderate</td>
<td>No significant difference between auscultation and ECG</td>
<td>Pooled difference HR&lt;sub&gt;AUSC&lt;/sub&gt; 4 s faster (95% CI 10 s faster to 2 s slower); p &gt; 0.05</td>
</tr>
<tr>
<td>Time for first HR from birth</td>
<td>2</td>
<td>70</td>
<td>Low</td>
<td>Auscultation detected HR faster than ECG at birth</td>
<td>Pooled difference HR&lt;sub&gt;AUSC&lt;/sub&gt; 24 s faster (95% CI 45 s faster to 2 s faster); p &lt; 0.05</td>
</tr>
<tr>
<td>Accuracy of HR assessment</td>
<td>2</td>
<td>71</td>
<td>Low</td>
<td>Auscultation may be accurate but imprecise for HR estimation at birth</td>
<td>Summary mean bias (HR&lt;sub&gt;AUSC&lt;/sub&gt; – HR&lt;sub&gt;ECG&lt;/sub&gt;) was −9.9 bpm; 95% LoA −32 to 12 bpm (95% CI of 95% LoA-217, 198 bpm)</td>
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<tr>
<td>Palpation vs ECG</td>
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<tr>
<td>Time for first HR from device placement</td>
<td></td>
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<td></td>
<td>Data for the prespecified outcomes not available</td>
<td></td>
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<tr>
<td>Time for first HR from birth</td>
<td></td>
<td></td>
<td></td>
<td>Data for the prespecified outcomes not available</td>
<td></td>
</tr>
<tr>
<td>Accuracy of HR assessment</td>
<td>1</td>
<td>21</td>
<td>Very low</td>
<td>Palpation was inaccurate and imprecise</td>
<td>Mean bias of −21 bpm with SD of 21 bpm</td>
</tr>
<tr>
<td>Auscultation vs Palpation</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Time for first HR from device placement</td>
<td></td>
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<td></td>
<td>Data for the prespecified outcome not available</td>
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<td>Time for first HR from birth</td>
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<td>Data for the prespecified outcome not available</td>
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<tr>
<td>Accuracy of HR assessment</td>
<td></td>
<td></td>
<td></td>
<td>Data for the prespecified outcome not available</td>
<td></td>
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<tr>
<td>Digital stethoscope vs ECG</td>
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<tr>
<td>Time for first HR from device placement</td>
<td></td>
<td></td>
<td></td>
<td>Data for the prespecified outcome not available</td>
<td></td>
</tr>
<tr>
<td>Time for first HR from birth</td>
<td></td>
<td></td>
<td></td>
<td>Data for the prespecified outcome not available</td>
<td></td>
</tr>
<tr>
<td>Accuracy of HR assessment</td>
<td>1</td>
<td>23</td>
<td>Very low</td>
<td>Digital stethoscope was accurate but imprecise</td>
<td>Mean difference (HR&lt;sub&gt;DS&lt;/sub&gt; – HR&lt;sub&gt;ECG&lt;/sub&gt;) of 0.2 bpm (95% CI −17.6 to 18 including crying periods and 1 bpm, 95% CI −10.5 to 12.6 if excluding crying periods)</td>
</tr>
<tr>
<td>Doppler US vs ECG</td>
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<td></td>
</tr>
<tr>
<td>Time for first HR from device placement</td>
<td></td>
<td></td>
<td></td>
<td>Not available</td>
<td></td>
</tr>
</tbody>
</table>
Table 4 (continued)

<table>
<thead>
<tr>
<th>Comparison</th>
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<th>Certainty of Evidence*</th>
<th>Results</th>
<th>Pooled median difference (95% CI) or Bias (LoA with 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time for first HR from birth</td>
<td>1</td>
<td>131</td>
<td>Very low</td>
<td>DU was faster for presenting a HR signal than ECG</td>
<td>HRDU: 76 s (IQR 51 s to 91 s); HR ECG 96.5 s (IQR 74.2 s to 118 s); p &lt; 0.05</td>
</tr>
<tr>
<td>Accuracy of HR assessment</td>
<td>2</td>
<td>164</td>
<td>Low</td>
<td>DU was accurate and precise compared to ECG</td>
<td>Summary mean bias (HRDU – HR ECG): –0.2 bpm, 95% LoA –5 to 6 bpm (95% CI of 95% LoA –222, 223)</td>
</tr>
</tbody>
</table>

Dry electrodes in a belt (DEB) vs conventional ECG

| Time for first HR from device placement | 2       | 76       | Low                    | DEB was faster for presenting a HR signal than ECG | Pooled median difference HRDEB 19 s faster, 95% CI 29 s faster to 10 s faster, p < 0.05 |
| Time for first HR from birth           | 1       | 28       | Very low               | DEB was faster for presenting a HR signal than ECG | HRDEB: 22 s (IQR 13–45 s) vs. HR ECG 171 s (IQR 129–239 s) |
| Accuracy of HR assessment              | 2       | 66       | Low                    | DEB was accurate and precise for HR estimation when compared to ECG | Summary mean bias (HRDEB – HR ECG): –1.4 bpm, 95% LoA –2.5 to 5.2 bpm (95% CI of 95% LoA –30, 33) |

Auscultation vs PO

| Time for first HR from device placement | 2       | 95       | Very low               | Auscultation is faster than PO for HR estimation at birth | Pooled difference HRAUSC 49 s faster (95% CI 64 s faster to 34 s faster); p < 0.05 |
| Time for first HR from birth           | 1       | 50       | Very low               | Auscultation is faster than PO for HR estimation at birth | HRAUSC: 50 s (IQR 44.5 s to 75 s), HRPO: 148.5 s (IQR 120 s to 195 s) |
| Accuracy of HR assessment              | 1       | 45       | Very low               | Auscultation underestimates HR compared to PO | Mean difference (HRAUSC –HRPO) of –5 bpm (95% CI –12 to 2 bpm) |

Doppler US vs PO

| Time for first HR from device placement | 2       | 75       | Very low               | Doppler US is faster than PO for HR estimation | Pooled difference HRDU 43 s faster (95% CI 62 s faster to 23 s faster); p < 0.05 |
| Time for first HR from birth           | 1       | 50       | Very low               | Doppler US is faster than PO for HR estimation at birth | HRDU: 55 s (IQR 49 s to 81.5 s); HRPO: 148.5 s (IQR 120 s to 195 s) |
| Accuracy of HR assessment              |         |          |                        | Data for the prespecified outcome not available | |

CI: confidence interval; DS: digital stethoscope; DU: Doppler ultrasound; ECG: electrocardiogram; HR: heart rate; IQR: interquartile range; LoA: limit of agreement; PO: pulse oximetry; RCT: randomized controlled trial; SD: standard deviation.

Results

Literature search and study selection

The search identified 7733 records. After removing 1600 duplicates, 6133 records were screened by title and abstract. Forty-two full-text articles were assessed and 25 were included.4,18,22–44 Cohen’s kappa was 0.9 for abstracts and 1.0 for full-text. See Fig. 1 for the PRISMA diagram, including reasons for study exclusion. Assessment methods of pulse oximetry, auscultation, palpation, digital stethoscope, Doppler ultrasound and ECG device with dry electrodes incorporated in a belt were compared with the reference ECG (Table 2). In addition, between-intervention comparisons were performed for auscultation vs. pulse oximetry, auscultation vs. palpation and Doppler ultrasound vs. pulse oximetry.

Study characteristics

The characteristics of included studies are summarized in Table 3. Meta-analyses for photoplethysmography vs. ECG and electromyography vs. ECG were not performed as there was only one study for each comparison.

RoB (Supplementary Table), outcome analysis and CoE are presented in Table 4.

Comparison 1. Pulse oximetry vs. ECG

There were three RCTs including 187 newborns and eleven observational studies including 452 newborns (Table 2). In all observational studies, both ECG and pulse oximetry were used for all newborns, hence each infant served as its own control. In Murphy 201910 and Murphy 202111 ECG data came from newborns randomized to IntelliVue™ (Phillips Electronics UK Ltd.) monitors and pulse oximetry data comes from newborns randomized to Nellcor™ (Medtronic, USA).
monitors. Similarly, in Abbey 2021,\textsuperscript{17} when calculating time to HR detection from birth, ECG data comes from babies randomized to the ECG-visible group and pulse oximetry data comes from the ECG-blinded group. Analysis by the brand of monitor was not done.

**Risk of bias (Supplementary Table)**
All RCTs were of unclear RoB. The observational studies were of high or unclear RoB due primarily to patient selection. RoB in RCTs and observational studies were assessed using QUADAS2.

**Outcome analysis (Table 4)**
Pooled estimates and results are presented separately for RCTs and observational studies.

1. Time for first HR from the device placement (Fig. 2a and b)
   a. RCTs: This was reported in 2 RCTs including 136 infants\textsuperscript{41,42} There was no difference between pulse oximeter and ECG (Heart rate obtained by pulse oximetry (HRPO) 12 s (s) slower, 95% CI (13 s faster to 38 s slower), $p > 0.05$). The evidence was of very low certainty, downgraded for RoB, inconsistency and imprecision.
   b. Observational studies: This was reported in 6 studies including 265 infants\textsuperscript{23,25,26,29,32,44} Pulse oximetry was slower than ECG from device placement (HRPO was 57 s slower, 95% CI (13 s slower to 101 s slower), $p < 0.05$). The evidence was of low certainty, downgraded for RoB and imprecision.

2. Time for first HR from birth (Fig. 3a and b)
   a. RCTs: This was reported in 2 RCTs including 87 infants\textsuperscript{18,42} There was no difference between pulse oximeter and ECG (HRPO 6 s slower, 95% CI (23 s slower to 10 s faster), $p > 0.05$). The evidence was of very low certainty, downgraded for serious RoB and imprecision.
   b. Observational studies: This was reported in 6 studies including 321 infants\textsuperscript{23,24,26,31,33,44} Pulse oximetry was slower than ECG (HRPO 52 s slower, 95% CI (9 s slower to 94 s slower), $p < 0.05$). The evidence was of low certainty, downgraded for RoB and imprecision.

3. Accuracy of heart rate: The experimental test was pulse oximetry and reference standard was ECG.
   a. Bland-Altman plot meta-analysis: Four observational studies\textsuperscript{28,30,43,44} and one RCT\textsuperscript{18} assessed whether HRPO agreed with HRPO by reporting total observations, number of patients, average difference (mean bias) and 95% LoA. Meta-analysis from 28,211 observations in 216 infants showed that pulse oximetry may be accurate but imprecise for HR estimation at birth (summary mean bias was $-1.2$ bpm; 95% LoA ($-17.9$ to 15.5 bpm), 95% CI of LoA ($-32.8$, 30.4 bpm)). The evidence was of very low certainty, downgraded for RoB, inconsistency and imprecision. The 95% CI of LoA was very wide, indicating that pulse oximetry may underestimate or overestimate the HR substantially. The meta-analysis cannot assess accuracy at various levels of HR or in different time epochs after birth.
   b. Identification of bradycardia (HRPO < 100 bpm) at birth: Using data from one RCT\textsuperscript{18} and 2 observational studies\textsuperscript{39,30} enrolling 145 newborns with 8342 observations, pooled sensitivity of pulse oximetry was 0.83 (0.76, 0.88) and pooled specificity was 0.97 (0.93, 0.99). Marked heterogeneity ($I^2 > 80\%$) was noted. The evidence was of very low certainty, downgraded for RoB, imprecision and inconsistency.
   c. Identification of severe bradycardia (HRPO < 60 bpm): No studies reported this outcome.

**Subgroup analysis**
Administration of positive pressure ventilation: No studies reported sufficient data to perform this subgroup analysis. Dawson et al. noted that there were slightly larger differences between HR measurements obtained from pulse oximetry and those from ECG when HRPO < 100 bpm.\textsuperscript{26}

Time epoch for HR assessment ($\leq 60$ s, $61–120$ s, $>120$ s): No studies reported sufficient data to perform this subgroup analysis. van Vonderen et al. noted that for the first 2 min after birth HRPO values were significantly lower than HRPO.\textsuperscript{44} Another study noted HRPO was lower than HRPO during the first 6 min after birth.\textsuperscript{29}

Gestational age subgroups: No studies reported sufficient data to perform this subgroup analysis. One study compared subgroups of infants of 29–32 and 32–35 weeks’ gestation and found no difference between them in the time to HR for either ECG or pulse oximetry.\textsuperscript{42}

**Comparison 2. Auscultation vs. ECG**

Studies included: One RCT\textsuperscript{40} involving 45 newborns and 4 observational studies\textsuperscript{24,31,37} involving 156 newborns were included. Although Murphy et al. was a RCT, HR determined by auscultation using a stethoscope (HRPO) and HRPO were reported for neonates in both intervention and control groups, so the contributed data were treated as a nested cohort study.

**Risk of bias (Supplementary Table)**
All studies were of unclear RoB due to patient selection.

**Outcome analysis (Table 4)**

1. Time for first HR from device placement (Fig. 4a)
   This was reported in 3 studies including 115 infants.\textsuperscript{24,37,40} There was no significant difference between auscultation and ECG (pooled difference HRPO 4 s faster, 95% CI (10 s faster to 2 s slower), $p > 0.05$). The evidence was of low certainty, downgraded for RoB.

2. Time for first HR from birth (Fig. 4b)
   This was reported in 2 studies including 70 infants.\textsuperscript{24,37} Auscultation detected HR faster than ECG (HRPO 24 s faster, 95% CI (45 s faster to 2 s faster), $p < 0.05$). The evidence was of low certainty, downgraded for RoB and imprecision.

**Accuracy of heart rate**
The experimental test was auscultation and the reference was ECG. Two studies provided data regarding whether HRPO agreed with HRPO with observations, number of patients, mean bias and 95% LoA.\textsuperscript{31,40} Meta-analysis from 71 infants demonstrated that auscultation may be accurate but imprecise (summary mean bias was $-9.9$ bpm; 95% LoA ($-32$ to 12 bpm), 95% CI of LoA ($-217$, 198 bpm)). The evidence was of low certainty, downgraded for RoB and imprecision.
Subgroup analysis

No data were available to perform subgroup analyses based on administration of positive pressure ventilation or gestational age.

Time epoch for HR assessment (≤60 s, 61–120 s, >120 s): No data were reported for these epochs. Some data were available to compare accuracy at 90 s vs. 120 s after birth. At 90 s auscultation was accurate but imprecise (summary mean bias was −9.6 bpm; 95% LoA (−52 to 33 bpm), 95% CI of LoA (−307, 203 bpm)), derived from very low certainty evidence, downgraded for RoB and imprecision from 2 observational studies including 110 infants.4,24 At 120 s, auscultation was accurate but imprecise (summary mean bias −0.4 bpm; 95% LoA (−34 to 35 bpm), 95% CI of LoA (−594, 189 bpm)), derived from very low certainty evidence downgraded for RoB and imprecision from the same 2 observational studies.4,24

Comparison 3. Palpation vs. ECG

Two observational studies involving 86 newborns were included.4,31

Risk of bias (Supplementary Table)

All studies were of unclear RoB due to patient selection.

Outcome analysis (Table 4)

Neither study reported the outcome of time for first HR from the device placement nor from birth.

Accuracy of heart rate

The experimental test was palpation and the reference was ECG. One study involving 21 newborns assessed whether HR_{Palp} agreed with HR_{ECG}.31 Palpation was inaccurate and imprecise (mean bias of −21 bpm with SD of 21 bpm). The evidence was of very low certainty, downgraded for RoB and applicability concerns.

Subgroup analysis

No data were available to perform subgroup analyses based on administration of positive pressure ventilation or gestational age.

Time epoch for HR assessment (≤60 s, 61–120 s, >120 s): No data were reported for pre-specified time epochs. Cavallin et al. reported that palpation was inaccurate and imprecise when assessed at 60 s, 90 s, 120 s and 300 s.4 This was very low certainty evidence, downgraded for RoB and applicability concerns from one observational study including 60 infants.
Comparison 4: Auscultation vs Palpation

Studies included: There were 2 studies including 120 infants, neither of which provided data assessing outcomes of the review.

Outcome analysis
Neither study reported the outcome of time for first HR from the device placement or birth, or accuracy of heart rate assessment. The study authors noted that all palpation methods (femoral, brachial and umbilical cord) showed very poor agreement with auscultated HR.

Comparison 5: Digital stethoscope vs. ECG

There were 2 observational studies including 43 infants, only one of which provided data for review.

Neither study reported the outcome of time for first HR from the device placement nor from birth.

Accuracy of heart rate
The experimental test was digital stethoscope and the reference was ECG. One study involving 23 newborns showed digital stethoscope was accurate but imprecise (mean difference of 0.2 bpm, 95% CI (−17.6 to 18 bpm), including crying periods). The mean difference was 1 bpm, 95% CI (−10.5 to 12.6 bpm), if excluding crying periods. The evidence was of very low certainty, downgraded for RoB and applicability concerns. The study authors found digital stethoscope unreliable in detecting a signal during crying.

Comparison 6. Doppler Ultrasound vs. ECG

Studies included: There were two observational studies involving 164 newborns.

Risk of bias
Shimabukuro et al. was judged to have high RoB and Agrawal et al. was judged to be of unclear RoB (Supplementary Table).

Outcome analysis (Table 4)
Neither study reported time for first HR from the device placement. Time for first HR from birth was reported in one observational study including 131 infants. Doppler Ultrasound was faster than ECG (HRDU 76 s (interquartile range (IQR) 51 to 91 s) vs. HRECG 96.5 s, (IQR 74.2–118 s), p < 0.05). The evidence was of very low certainty, downgraded for RoB and applicability concerns.
Accuracy of heart rate
The experimental test was Doppler ultrasound and the reference was ECG. Two studies provided data, reporting mean bias and LoA. Meta-analysis of these data from 164 infants showed Doppler ultrasound was accurate and precise compared to ECG (summary mean bias $-0.2$ bpm; 95% LoA ($-5$ to 6 bpm), 95% CI of LoA ($-222$, 223 bpm)). The evidence was of low certainty, downgraded for RoB, imprecision and applicability concerns.

Comparison 7. ECG device with dry electrodes incorporated in a belt compared to conventional ECG with gel adhesive electrodes
There were three observational studies involving 94 newborns.

Risk of bias (Supplementary Table)
All studies were judged to be of unclear RoB due to patient selection.

Outcome analysis (Table 4)
Time for first HR from device placement
This was reported in 2 studies including 76 infants. ECG device with dry electrodes incorporated in a belt (DEB) was faster than conventional ECG ($HR_{DEB}$ 19 s faster, 95% CI (29 s faster to 10 s faster), $p < 0.05$). The evidence was of low certainty, downgraded for RoB and applicability concerns.

Time for first HR from birth
This outcome was reported in 1 study including 28 infants. ECG device with dry electrodes incorporated in a belt was faster than conventional ECG ($HR_{DEB}$ 22 s (IQR 13–45 s) vs. $HR_{ECG}$ 171 s (IQR 129–239 s)). The evidence was of very low certainty, downgraded for RoB and applicability concerns.

Accuracy of heart rate
The experimental test was ECG device with dry electrodes incorporated in a belt and the reference was conventional ECG with gel adhesive electrodes. Two studies provided data, reporting mean bias and LoA. Meta-analysis from 66 infants showed that ECG device with dry electrodes incorporated in a belt was accurate and precise for HR estimation compared to conventional ECG (summary mean bias $-1.4$ bpm; 95% LoA ($-2.5$ to 5.2 bpm), 95% CI of LoA ($-30$, 33 bpm)). The evidence was of low certainty, downgraded for RoB and applicability concerns.
Comparison 8: Auscultation vs pulse oximetry

Studies included: Two studies involving 95 newborns were included.24,40

Risk of bias (Supplementary Table)
All studies were judged to be of unclear RoB due to patient selection.

Outcome analysis (Table 4)
Time for first HR from the device placement
This was reported in 2 studies including 95 infants.24,40 Auscultation detected HR faster than pulse oximetry (HR_{AUSC} 49 s faster, 95% CI (64 s faster to 34 s faster), p < 0.05). The evidence was of very low certainty, downgraded for RoB and imprecision.

Time for first HR from birth
This outcome was reported in 1 study.24 Auscultation was faster to detect HR (88.5 s faster (IQR 60–134)). The evidence was of very low certainty, downgraded for RoB and imprecision.

Accuracy of heart rate
The experimental test was auscultation and the reference was pulse oximetry. One study reported that auscultation underestimated the HR_{PO} 40 (mean difference −5 bpm, 95% CI (−12 to 2 bpm)). The evidence was of very low certainty, downgraded for RoB and imprecision.

Comparison 9. Doppler US vs pulse oximetry

Studies included: Two studies involving 75 newborns were included.24,39

Risk of bias (Supplementary Table)
All studies were of unclear RoB due to patient selection.

Outcome analysis (Table 4)
Time for first HR from the device placement
This outcome was reported in 2 studies including 75 infants.24,39 Doppler ultrasound detected HR faster than pulse oximetry (HR_{DU} 43 s faster, 95% CI (62 s faster to 23 s faster), p < 0.05). The evidence was of very low certainty, downgraded for RoB and imprecision.

Time for first HR from birth
This outcome was reported in 1 study.24 Doppler ultrasound was faster to detect HR (HR_{DU} 55 s (IQR 49–81.5 s) vs. HR_{PO} 148.5 s (IQR 103–209)) and the evidence was of very low certainty, downgraded for RoB and imprecision.
120–195 s)). The evidence was of very low certainty, downgraded for RoB and imprecision.

Accuracy of heart rate: Neither study reported this outcome.

Discussion

This review evaluates speed and accuracy of different methods of HR assessment in the delivery room, including 25 studies. ECG using standard adhesive gel electrodes was used as the index test. Only low or very low certainty evidence was available for all comparisons. Experimental tests included pulse oximetry, auscultation, palpation, digital stethoscope, Doppler ultrasound and ECG device with dry electrodes incorporated in a belt.

Pulse oximetry, auscultation and palpation are commonly available methods of HR assessment immediately after birth. Pulse oximetry is slower to achieve signal and less precise than ECG for HR assessment, though it provides oxygen saturation values that ECG does not. Auscultation and palpation add no additional cost to the delivery room care but are imprecise for HR assessment. Both help recognize pulseless electrical activity. Auscultation may provide caregivers additional information about lung inflation.

Few infants were included in studies evaluating digital stethoscope, Doppler ultrasound and ECG device with dry electrodes incorporated in a belt. Digital stethoscope is fast and accurate. Doppler ultrasound and ECG device with dry electrodes incorporated in a belt are fast, accurate and precise compared to ECG. Positive pressure ventilation may interfere with Doppler ultrasound signal and could be misinterpreted. These technologies are not widely available currently, but they may become so in coming years.

This review has methodological rigor: adherence to a prespecified published protocol, a search strategy developed by an information specialist, the use of GRADE methodology to assess certainty of evidence and reporting according to PRISMA. The PICOST was

Fig. 4 – Auscultation vs ECG. (a) Time to first HR from device placement (Observational studies). (b) Time to first HR from birth (Observational studies).
developed by consensus of the review team and multidisciplinary experts on the ILCOR Neonatal Life Support Task Force. It includes both widely available and emerging technologies.

Limitations to conclusions that can be drawn from this review are due to low or very low certainty of evidence. Furthermore, there was little evidence relevant to infants who were bradycardic, received positive pressure ventilation, or were extremely premature. Infants included in studies of newer methods were few, limiting applicability. Although ECG remains the standard of HR assessment in the neonatal intensive care unit, it remains unclear if measurement of heart electrical activity is sufficient when assessing HR in a newborn requiring resuscitation, because used alone, it will not identify pulseless electrical activity. For the purposes of this review, an agreement within 10 bpm between index and reference tests was considered clinically acceptable. Although similar ranges have been used in industry, the clinical significance of such a small difference in a non-bradycardic newborn remains unclear, while in an infant with bradycardia, an even smaller difference could cross a threshold for a treatment decision.

Very few studies reported data that enabled calculation of accuracy and precision at threshold levels for clinical interventions, such as 100 bpm and 60 bpm as recommended in resuscitation flow diagrams. These should be reported in future studies. It is possible that index tests may be less accurate or precise for HR measurement in the first few minutes after delivery compared to later during resuscitation. Data regarding accuracy in different time epochs were limited so nuances could not be assessed.

To decide which HR assessment method to use, clinicians should consider various factors such as cost, local resources, impact on training and human factors, resuscitation performance and clinical outcomes, in addition to speed and accuracy. It is important to consider whether the device gives fast, continuous and accurate HR in situations where it is needed most, such as extremely low birth weight infants and infants who are receiving resuscitation. Different methods of HR assessment utilize different physiological measurements. In rare cases where pulseless electrical activity is suspected, clinicians using ECG in the delivery room should confirm cardiac output using other methods.
Conclusion

Heart rate is the most important vital sign in determining resuscitative interventions for newborns in the delivery room. Speed, precision and accuracy are important factors to consider in HR assessment. Based on the current low-certainty evidence, if resources permit, ECG should be used for fast and accurate HR assessment at birth. Pulse oximetry and auscultation may be reasonable alternatives and provide additional information but have limitations. Digital stethoscope, Doppler ultrasound and ECG device with dry electrodes incorporated in a belt show promise but need larger studies before routine use can be recommended.

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Systematic review registration

This systematic review has been registered with the Prospective Register of Systematic Reviews (https://www.crd.york.ac.uk/prospero/identifier: CRD 42021283364).

Contributors’ statement

Drs. Kapadia and Kawakami prepared the protocol, screened studies, abstracted data, completed risk-of-bias and Grading of Recommendations Assessment, Development and Evaluation evaluations, completed the analysis, and prepared the first draft of the manuscript.

Dr. Strand reviewed the protocol, screened studies, abstracted data, completed risk-of-bias and Grading of Recommendations Assessment, Development and Evaluation evaluations, reviewed the analysis, and prepared the first draft of the manuscript.

Dr. Hurst reviewed the protocol, conducted statistical analysis and helped with editing the manuscript.

Ms. Spencer reviewed the protocol, helped develop search strategy, searched for articles using the strategy on various databases, reviewed the analysis and helped with editing the manuscript.

Drs. Liley, Wyckoff, Wyllie, Weiner, Schmöller and Rabi were involved in reviewing the protocol, reviewing the analysis, and writing and editing the manuscript.

All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

CRediT authorship contribution statement

Vishal S. Kapadia: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. Mandira D. Kawakami: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. Marya L. Strand: Writing – review & editing, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. Cameron Paul Hurst: Writing – review & editing, Software, Resources, Investigation, Formal analysis. Angela Spencer: Software, Resources, Methodology, Investigation, Data curation. Georg M. Schmöller: . Yacov Rabi: Writing – review & editing, Project administration, Methodology, Investigation, Data curation, Conceptualization. Jonathan Wyllie: Writing – review & editing, Supervision, Methodology, Investigation, Data curation, Conceptualization. Gary Weiner: Writing – review & editing, Supervision, Conceptualization. Helen G. Liley: Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. Myra H. Wyckoff: Writing – review & editing, Supervision, Methodology, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: ‘Dr. Kapadia is a co-author of one of the studies included in this review. Drs. Liley and Rabi are editorial board members for the Resuscitation Plus journal. The other authors have no conflicts to disclose.’.

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The data used in this systematic review and meta-analysis are from published literature. Data may be shared on reasonable request.

Appendix A. Supplementary material

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