Review

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

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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, photo-plethysmography 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.

Traditionally, HR was determined by auscultation with stethoscope or palpation of umbilical cord pulsations.[1,4] Pulse oximetry has been used as an adjunct for HR assessment at birth, especially during resuscitation.[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.[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.[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.[6] The results follow the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement for meta-analysis in health care interventions.[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.[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.[5,12–14] Authors queried trial registries (US National Library of

Table 1 – PICOST Question.	
Population	Newborn infants in the delivery room
Intervention	Use of auscultation, palpation, pulse oximetry, Doppler ultrasound, digital stethoscope, photoplethysmography, video plethysmography, dry electrode technology or any other newer modalities
Comparison	1. Electrocardiogram 2. In between intervention comparison
Outcomes	1. Time for first HR assessment from the device placement, 2. Time for first HR assessment from birth and 3. Accuracy of HR assessment
Study Design	Randomized controlled trials and non-randomized studies (non-randomized controlled trials, interrupted time series, controlled before-and-after studies, cohort studies) are eligible for inclusion. Unpublished studies (e.g., conference abstracts, trial protocols) are excluded.
Timeframe	All years and all languages are included as long as there is an English abstract. Literature search updated to Aug 16, 2023.

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.[15] 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).[16,17] 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.[18] 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.[19] 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.[16] 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.[20] In one study mean and Standard Deviation (SD) were reported. These were con-
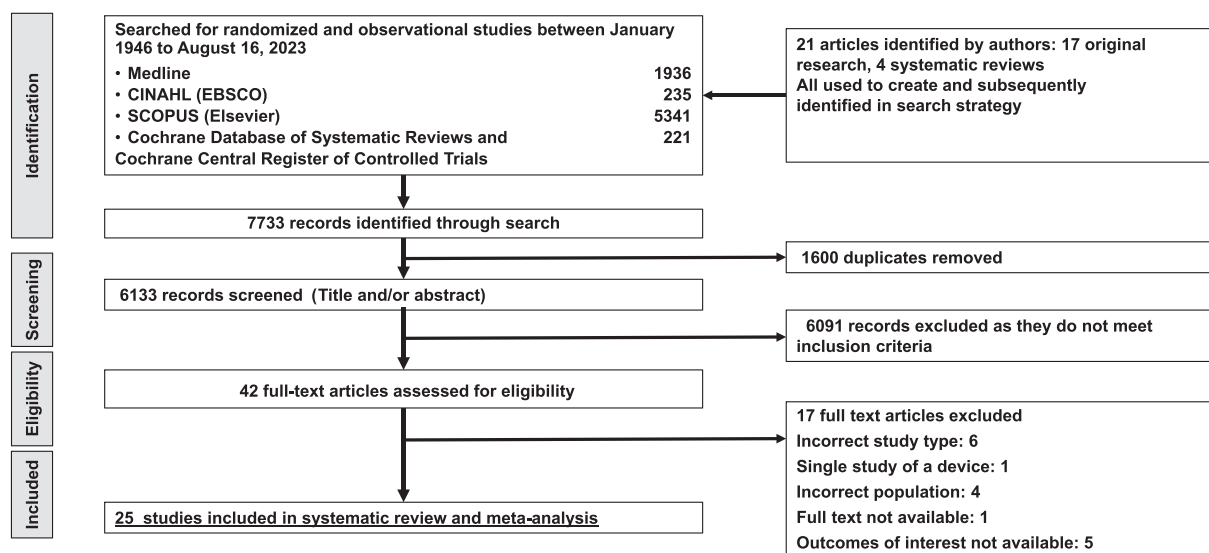

Fig. 1 – PRISMA study selection diagram.

Table 2 – Assessment methods of evaluation of the heart rate in newborns.

Comparison of HR assessment methods	Studies included
HR assessment modality vs ECG where ECG was considered gold standard	
Pulse oximeter vs ECG	Kamlin 2008, Katheria 2012, Mizumoto 2012, Dawson 2013, van Vonderen 2015, Iglesias 2016, Iglesias 2018, Murphy 2019, Henry 2021, Bjorland 2020, Murphy 2021, Bobillo-Perez 2021, Bush 2021, Abbey 2021
Auscultation vs ECG	Kamlin 2006, Murphy 2018, Treston 2019, Cavallin 2020, Bobillo-Perez 2021
Palpation vs ECG	Kamlin 2006, Cavallin 2020
Digital stethoscope vs ECG	Gaertner 2017, Treston 2019
Doppler ultrasound vs ECG	Shimabukuro 2017, Agrawal 2019
ECG device with dry electrodes incorporated in a belt vs conventional 3 lead ECG with gel adhesive electrodes	Bush 2021, Rettedal 2021, van Twist 2022
In between intervention comparison	
Auscultation vs Pulse oximeter	Murphy 2018, Bobillo-Perez 2021
Auscultation vs Palpation	Owen 2004, Cavallin 2020
Doppler ultrasound with Pulse oximeter	Zanardo 2019, Bobillo-Perez 2021

Table 3 – Study characteristics.									
Study	Country	Total N	GA	Eligibility criteria	Study Design	Index test	Reference Std	Primary outcome	Notes
Owen 2004	UK	60	Term	−All newly born term infants eligible − Any infant requiring significant resuscitation > 5 min was excluded (n = 1)	Randomized patients for method of palpation	Assess HR by palpation based on randomized method: femoral, brachial or umbilical cord	Assess HR simultaneously with stethoscope	Agreement of HR assessment by palpation method to auscultation	
Kamlin 2006	Australia	26	Term	Vigorous term infants who did not require resuscitation	2 care providers were randomly allocated to assess HR by either palpation or auscultation	1.Auscultation 2.Palpation of umbilical cord	ECG (Masked)	Accuracy of palpation or auscultation by comparing with ECG	
Kamlin 2008	Australia	55	Term and preterm (≥28 0/7 weeks)	Convenience sample	Cohort study	Pulse oximeter	ECG	Precision and accuracy of pulse oximeter for HR assessment	−37 excluded due to equipment malfunction −convenience sample
Katheria 2012	USA	46	Term and preterm (30 were 23–30 weeks')	Availability of video recording that included ECG and pulse oximeter data during the study period	Cohort	Pulse oximeter	ECG	Time to obtain continuous audible signal from pulse oximeter vs ECG	−Audible heartbeat was used as guide for reliable signal
Mizumoto 2012	Japan	20	Term and Preterm	High risk delivery attendance by team and video recording available	Cohort	Pulse oximeter	ECG	Accuracy of HR assessment ECG vs pulse oximeter	−Unclear if this is consecutive or convenience sample
Dawson 2013	Australia	44	Term or near term	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	Cohort	Pulse oximeter x 2 (Masimo and Nellcor)	ECG	−To compare SpO$_2$ measurements between Masimo and Nellcor oximeters −To compare HR measurements from both oximeters against HR measured by electrocardiograph (ECG).	−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

Table 3 (continued)

Study	Country	Total N	GA	Eligibility criteria	Study Design	Index test	Reference Std	Primary outcome	Notes
									contained < 100 'good signal quality' measurements from the ECG.
van Vonderen 2015	Nether-lands	48	Term and Preterm	Term and preterm infants born vaginally or by Cesarean were eligible for inclusion; infants were excluded if they had congenital abnormalities or cardiac defects	Cohort	Pulse oximeter	ECG	Reliability of Pulse oximeter for HR measurement during the first 10 min after birth	HR_{ECG} and HR_{PO} data were averaged for each infant at every 30-second intervals (2 s of data before and after each 30-second interval). Only good quality data were included for analysis, which was defined as clearly visible QRS complexes for ECG. For HR_{PO}, the signal identification and quality (SIQ) value provided by the device was > 0.30, and no alarm messages (low SIQ, low perfusion) were displayed. Four infants were excluded because of technical problems with the Pulse oximeter or Pulse oximeter data.
Iglesias 2016	Spain	39	<32 weeks and/or <1500 g	Preterm infants who were receiving resuscitation	Cohort	Pulse oximeter	ECG	Compare Pulse oximeter with ECG for HR assessment	Excluded infants with congenital anomalies or no complete resuscitation decided before birth. 45 recordings; 6 excluded due to recording failure.
Gaertner 2017	Australia	37	Not published but mean GA: $38^{4/7}$ ($36^{6/7}$–$39^{2/7}$)	Convenience sample	Cohort	Digital stethoscope (DS)	ECG	Performance of DS to evaluate HR in delivery room	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

Table 3 (continued)

Study	Country	Total N	GA	Eligibility criteria	Study Design	Index test	Reference Std	Primary outcome	Notes
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)
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 SpO$_2$	Auscultation Pulse oximeter	ECG	To compare the accuracy and speed of assessment of HR by auscultation with ECG and Pulse oximeter	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	Pulse oximeter	ECG	Time to first HR display	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.

Table 3 (continued)

Study	Country	Total N	GA	Eligibility criteria	Study Design	Index test	Reference Std	Primary outcome	Notes
Treston 2019	Ireland	60	Term	Term infants	Cohort study	−Handheld US (US) −Digital stethoscope (DS) −ECG	Auscultation	−To determine if US and DS could offer a quickly and effective method assessing HR in DR	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.
Agrawal 2019	India	131	≥34 weeks'	All newborns more than 34 weeks of gestation delivered by Cesarean section during routine working hours. Newborns needing PPV excluded	Cohort	Portable Doppler ultrasound (PDU)	ECG	Compare accuracy of HR determined by PDU	Excluded Congenital anomalies
Zanardo 2019	China	25	Term	Term, elective Cesarean section; consecutive sample	Cohort	PDU (SD1 Ultrasonic Pocket Doppler; combination of built-in speaker and fetal heart rate digital display)	Pulse oximeter	If PDU can assess HR quickly and effectively in elective Cesarean delivery compared to pulse oximeter	
Henry 2021	UK	18	≥37 weeks'	Convenience sample of ≥ 37 weeks' with no obvious requirement for resuscitation, based on antenatal history, and delivered by planned Cesarean section	Cohort	FhPPG (new cap mounted newborn HR device) Pulse oximeter	ECG	Accuracy and reliability of FhPPG compared to Pulse oximeter and ECG	Study had 2 phases. NICU phase data are not included in this systematic review. All infants had all 3 devices placed.

Table 3 (continued)

Study	Country	Total N	GA	Eligibility criteria	Study Design	Index test	Reference Std	Primary outcome	Notes
Cavallin 2020	Ethiopia	60	Infants at risk for resuscitation	Any infant having at least one condition: fetal distress by fetal auscultation, dystocia, suspected placenta abruption, cord prolapse fetal malpresentation, forceps assisted vaginal delivery, meconium-stained fluid	RCT	Auscultation by stethoscope Palpation of umbilical cord	ECG	Degree of agreement of HR obtained by auscultation or palpation compared to ECG	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
Bjorland 2020	Norway	104	≥34 weeks'	All infants ≥ 34 weeks' who received PPV at birth	Cohort	Pulse oximeter	ECG	To compare the efficacy of pulse oximeter versus ECG in providing a reliable HR signal during real-life newborn resuscitation	Review of video recordings
Bush 2021	USA	28	30–35 weeks' and Term infants	Infants with estimated fetal weight > 1500 g	Cohort	Dry electrode ECG pulse oximeter	ECG	To compare the time to accurate HR acquisition between pulse oximeter, ECG and dry electrode ECG	Excluded infants with skin or thoracic anomalies
Bobillo-Perez 2021	Spain	50	Term	Low risk term newborns	Cohort study	US pulse oximeter Auscultation	ECG	To compare the accuracy and speed of HR assessment through US when compared with ECG, pulse oximeter and auscultation	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
Murphy 2021*	Ireland	36	29–35 weeks'	Infants with known anomalies were excluded	RCT: randomly assigned to monitoring with IntelliVue (ECG + pulse oximeter) or Nellcor (pulse oximeter)	pulse oximeter	ECG + pulse oximeter	Time from start of monitor application to first HR display	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.

Table 3 (continued)

Study	Country	Total N	GA	Eligibility criteria	Study Design	Index test	Reference Std	Primary outcome	Notes
Abbey 2021	USA	51	<31 weeks GA	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	RCT	pulse oximeter	ECG	Time to stabilization, which was defined as the time it takes from birth for HR to be > 100 bpm and SpO2 to be in the goal range	ECG and pulse oximeter was placed on all newborns. They were randomized into either an ECG-displayed arm or an ECG-blinded arm.
Rettedal 2021	Norway	48	≥32 weeks'	Infants ≥ 32 weeks that received PPV within the first five minutes after birth	Cohort study	DEB pulse oximeter	ECG	(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	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.
van Twist 2022	Netherlands	18	≥32 weeks and/or birth weight ≥ 1.5 kg	≥32 weeks and birthweight ≥ 1.5 kg and in need of HR monitoring on the resuscitation table	Cohort study	DEB pulse oximeter	ECG	To test the accuracy of NeoBeat when compared to pulse oximeter and conventional ECG with disposable electrodes	Inclusion occurred through perinatal assessment when the investigators were on duty

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; SpO$_2$: oxygen saturation; US: ultrasound.

Table 4 – Evidence Summary per comparison.

Comparison	Studies	Patients	Certainty of Evidence*	Results	Pooled median difference (95% CI) or Bias (LoA with 95% CI)
Pulse oximeter (PO) vs ECG					
Time to first HR from device placement (RCT)	2	136	Very low	Found no difference for this outcome between PO and ECG.	Pooled difference HR_{PO} 12 s slower (95% CI 13 s faster to 38 s slower); $p > 0.05$
Time to first HR from device placement (Observational)	6	265	Low	PO is slower in acquiring HR signal than ECG.	Pooled difference HR_{PO} 57 s slower (95% CI 13 s slower to 101 s slower); $p < 0.05$
Time to first HR from birth (RCTs)	2	87	Very low	Found no difference for this outcome between PO and ECG.	Pooled difference HR_{PO} 6 s slower (95% CI 23 s slower to 10 s faster); $p > 0.05$
Time to first HR from birth (observational)	6	321	Low	PO is slower in acquiring HR signal than ECG.	Pooled difference HR_{PO} 52 s slower (95% CI 9 s slower to 94 s slower); $p < 0.05$
Accuracy of HR assessment (Pooled summary bias)	5	216 (28,211 Observations)	Very low	PO may be accurate but imprecise for HR estimation at birth	Summary mean Bias: −1.2 bpm 95% LoA −17.9 to 15.5 bpm (95% CI of 95% LoA-32.8, 30.4)
Identification of neonatal bradycardia ($HR_{ECG} < 100$ bpm)	3	145 (8342 Observations)	Very low	Sensitivity 0.83 (0.76, 0.88) Specificity 0.97 (0.93, 0.99)	N/A
Auscultation vs ECG					
Time for first HR from device placement	3	115	Moderate	No significant difference between auscultation and ECG	Pooled difference HR_{AUSC} 4 s faster (95% CI 10 s faster to 2 s slower); $p > 0.05$
Time for first HR from birth	2	70	Low	Auscultation detected HR faster than ECG at birth	Pooled difference HR_{AUSC} 24 s faster (95% CI 45 s faster to 2 s faster); $p < 0.05$
Accuracy of HR assessment	2	71	Low	Auscultation may be accurate but imprecise for HR estimation at birth	Summary mean bias ($HR_{AUSC} - HR_{ECG}$) was −9.9 bpm; 95% LoA −32 to 12 bpm (95% CI of 95% LoA-217, 198 bpm)
Palpation vs ECG					
Time for first HR from device placement				Data for the prespecified outcomes not available	
Time for first HR from birth				Data for the prespecified outcomes not available	
Accuracy of HR assessment	1	21	Very low	Palpation was inaccurate and imprecise	Mean bias of −21 bpm with SD of 21 bpm
Auscultation vs Palpation					
Time for first HR from device placement				Data for the prespecified outcome not available	
Time for first HR from birth				Data for the prespecified outcome not available	
Accuracy of HR assessment				Data for the prespecified outcome not available	
Digital stethoscope vs ECG					
Time for first HR from device placement				Data for the prespecified outcome not available	
Time for first HR from birth				Data for the prespecified outcome not available	
Accuracy of HR assessment	1	23	Very low	Digital stethoscope was accurate but imprecise	Mean difference ($HR_{DS} - HR_{ECG}$) 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)
Doppler US vs ECG					
Time for first HR from device placement				Not available	

Table 4 (continued)

Comparison	Studies	Patients	Certainty of Evidence*	Results	Pooled median difference (95% CI) or Bias (LoA with 95% CI)
Time for first HR from birth	1	131	Very low	DU was faster for presenting a HR signal than ECG	HR_{DU}: 76 s (IQR 51 s to 91 s); HR_{ECG} 96.5 s (IQR 74.2 s to 118 s); $p < 0.05$
Accuracy of HR assessment	2	164	Low	DU was accurate and precise compared to ECG	Summary mean bias ($HR_{DU} - HR_{ECG}$): −0.2 bpm, 95% LoA −5 to 6 bpm (95%CI of 95% LoA −222, 223)
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 HR_{DEB} 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	HR_{DEB} 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 ($HR_{DEB} - HR_{ECG}$) −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 HR_{AUSC} 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	HR_{AUSC}: 50 s (IQR 44.5 s to 75 s), HR_{PO}: 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 ($HR_{AUSC} - HR_{PO}$) 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 HR_{DU} 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	HR_{DU}:55 s (IQR 49 s to 81.5 s); HR_{PO}: 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.

verted to median and quartiles per the methodology of Wan et al.[21] For continuous outcomes, pooled difference and corresponding 95% confidence intervals (CI) were reported. If more than two studies provided required data, pre-specified subgroups included gestational age (<28 + 0 weeks', 28 + 0–33 + 6 weeks', ≥34 + 0 weeks'), administration of positive pressure ventilation and time epoch for HR assessment (≤60 s, 61–120 s, ≥121 s).

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.[43,45]

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

Comparison 1. Pulse oximetry vs. ECG

Fourteen studies addressed this comparison.[18,23–26,28–30,32,33,41–44] 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 2019[41] and Murphy 2021,[42] 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,[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.[41,42] There was no difference between pulse oximeter and ECG (Heart rate obtained by pulse oximetry (HR_{PO}) 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.[23,25,28,29,32,44] Pulse oximetry was slower than ECG from device placement (HR_{PO} 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.[18,42] There was no difference between pulse oximetry and ECG (HR_{PO} 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.[23,24,26,31,33,44] Pulse oximetry was slower than ECG (HR_{PO} 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[26,30,43,44] and one RCT[18] assessed whether HR_{PO} agreed with HR_{ECG} 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 ($HR_{ECG} < 100$ bpm) at birth: Using data from one RCT[18] and 2 observational studies[28,30] 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 ($HR_{ECG} < 60$ 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 $HR_{ECG} < 100$ bpm.[26]

Time epoch for HR assessment (≤ 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 HR_{PO} values were significantly lower than HR_{ECG}.[44] Another study noted HR_{PO} was lower than HR_{ECG} during the first 6 min after birth.[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.[42]

Comparison 2. Auscultation vs. ECG

Studies included: One RCT[40] involving 45 newborns and 4 observational studies[4,24,31,37] involving 156 newborns were included. Although Murphy et al. was a RCT, HR determined by auscultation using a stethoscope (HR_{AUSC}) and HR_{ECG} 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)
Time for first HR from device placement (Fig. 4a)
This was reported in 3 studies including 115 infants.[24,37,40] There was no significant difference between auscultation and ECG (pooled difference HR_{AUSC} 4 s faster, 95% CI (10 s faster to 2 s slower), $p > 0.05$). The evidence was of low certainty, downgraded for RoB.

Time for first HR from birth (Fig. 4b)
This was reported in 2 studies including 70 infants.[24,37] Auscultation detected HR faster than ECG (HR_{AUSC} 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 HR_{AUSC} agreed with HR_{ECG}, with observations, number of patients, mean bias and 95% LoA.[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.
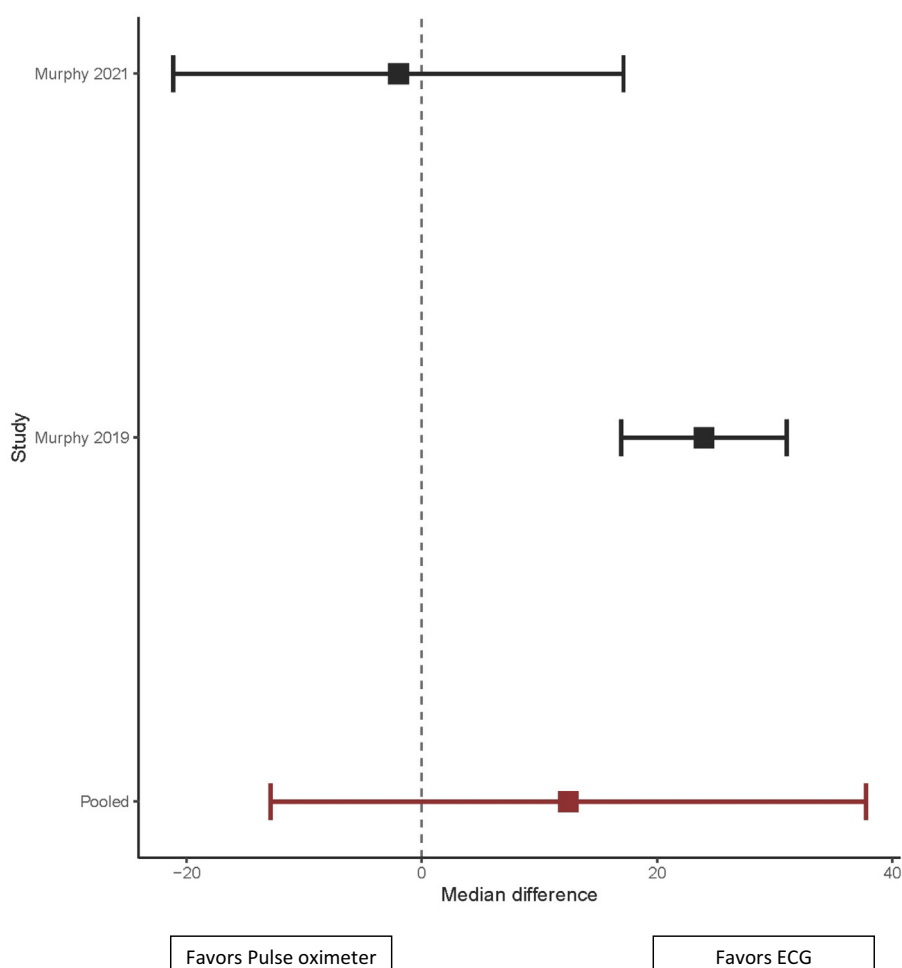
a. Randomized control trials

Fig. 2 – PO vs ECG time to HR from device placement. (a) Randomized control trials. (b) Observational studies.

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.
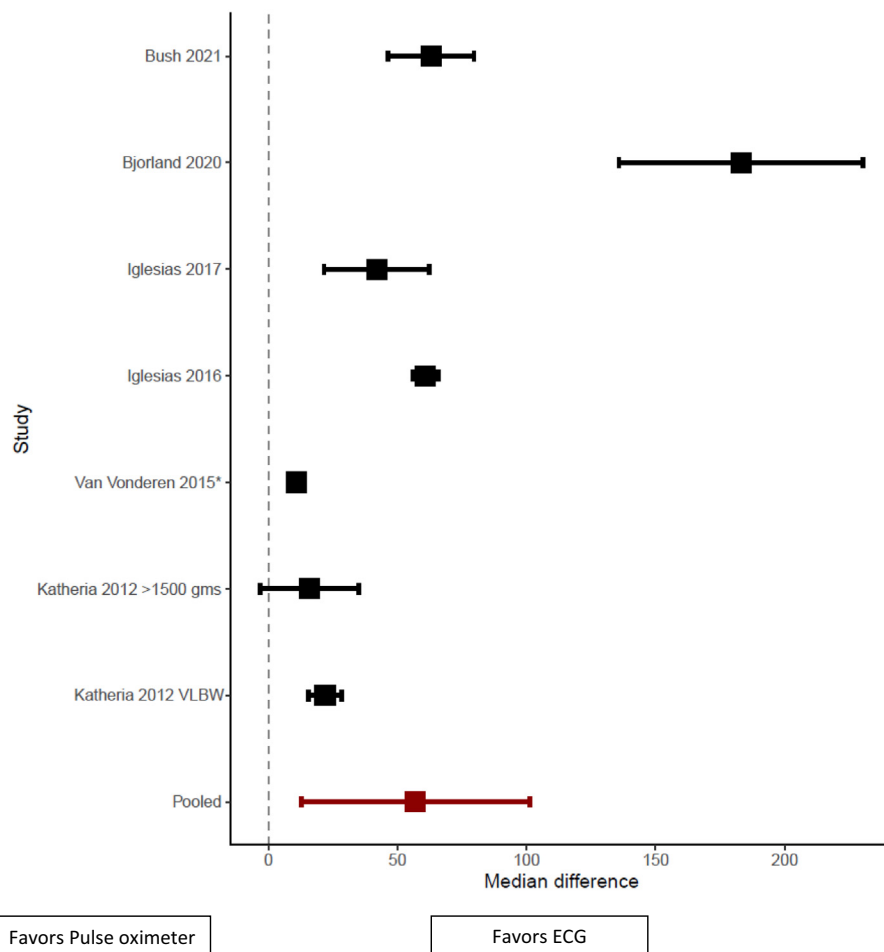
b. Observational studies

Fig 2. *(continued)*

Comparison 4: Auscultation vs Palpation

Studies included: There were 2 studies including 120 infants, [4,34] 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. [34]

Comparison 5: Digital stethoscope vs. ECG

There were 2 observational studies including 43 infants, [27,37] only one of which provided data for review. [27]
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 [27] 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. [22,36]

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. [22] Doppler Ultrasound was faster than ECG (HR_{DU} 76 s (interquartile range (IQR) 51 to 91 s) vs. HR_{ECG} 96.5 s, (IQR 74.2–118 s), $p < 0.05$). The evidence was of very low certainty, downgraded for RoB and applicability concerns.
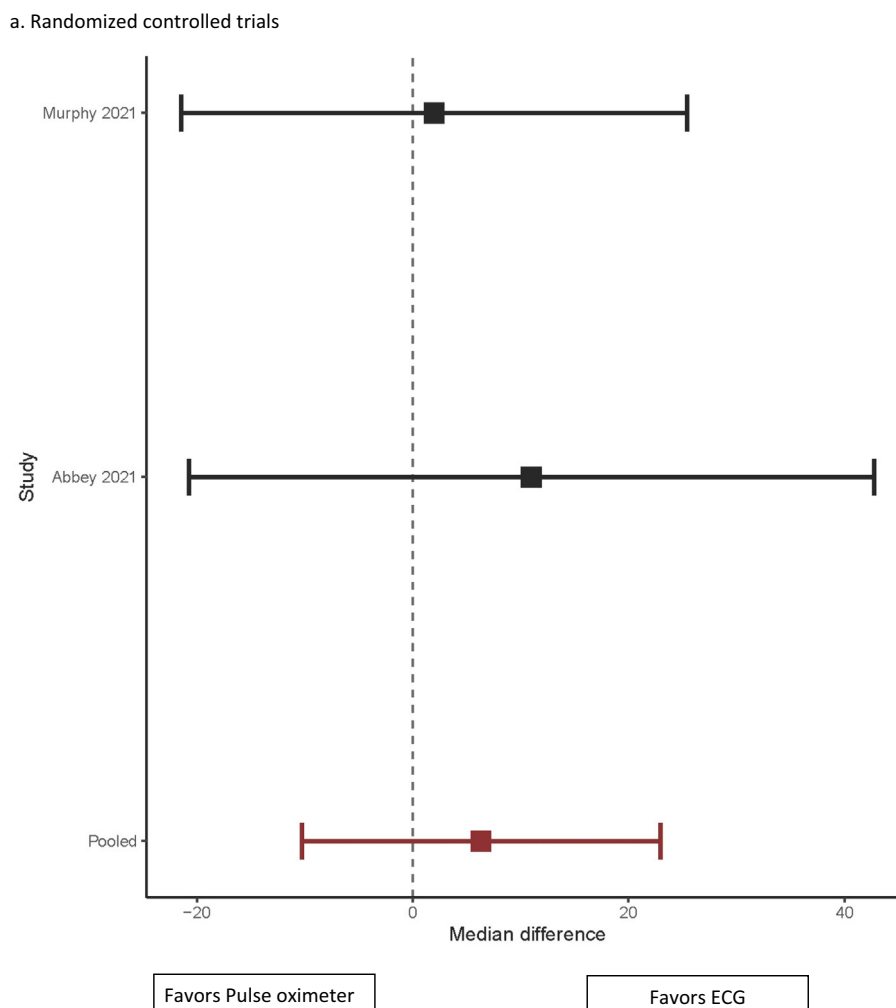
a. Randomized controlled trials

Fig. 3 – PO vs ECG Time for first HR from birth. (a) Randomized controlled trials. (b) Observational studies.

Accuracy of heart rate

The experimental test was Doppler ultrasound and the reference was ECG. Two studies provided data, reporting mean bias and LoA.[22,36] 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.[25,35,38]

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 76 infants.[25,35] ECG device with dry electrodes incorporated in a belt (DEB) was faster than con-

ventional 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.[35] 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.[35,38] 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.
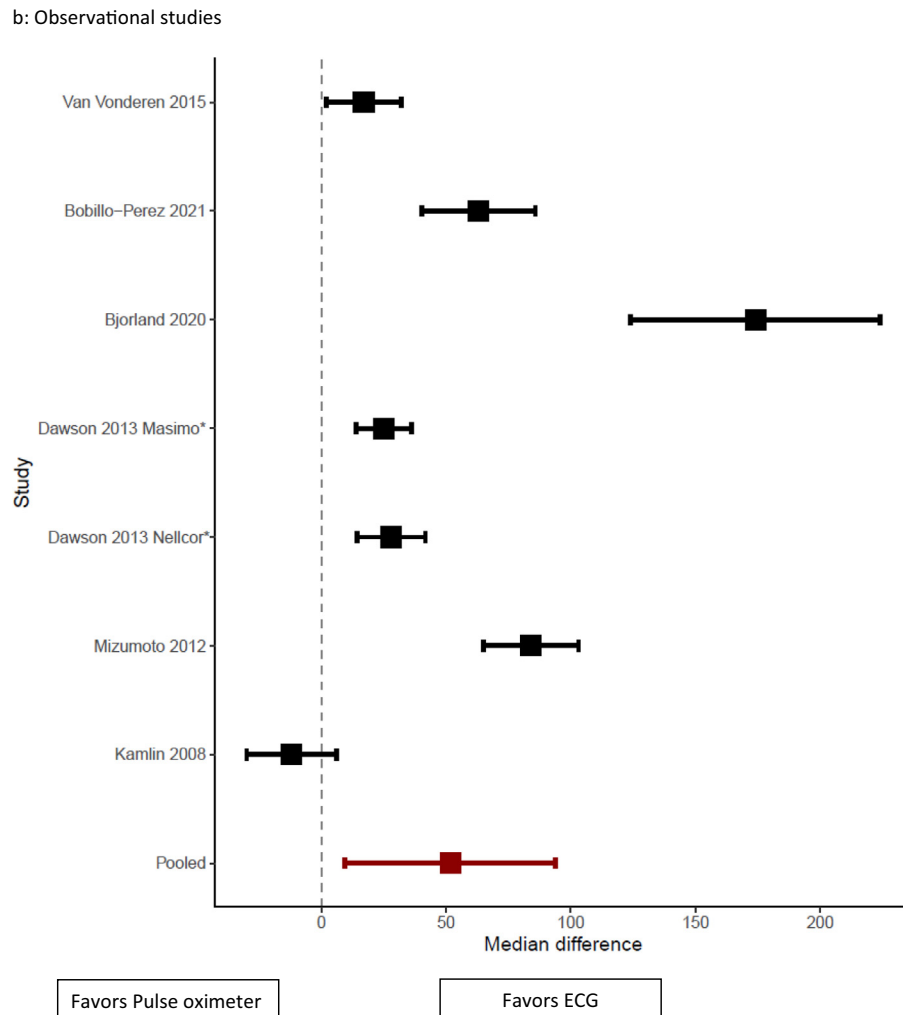
b: Observational studies

Fig 3. *(continued)*

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

a: Time to first HR from device placement (Observational studies)
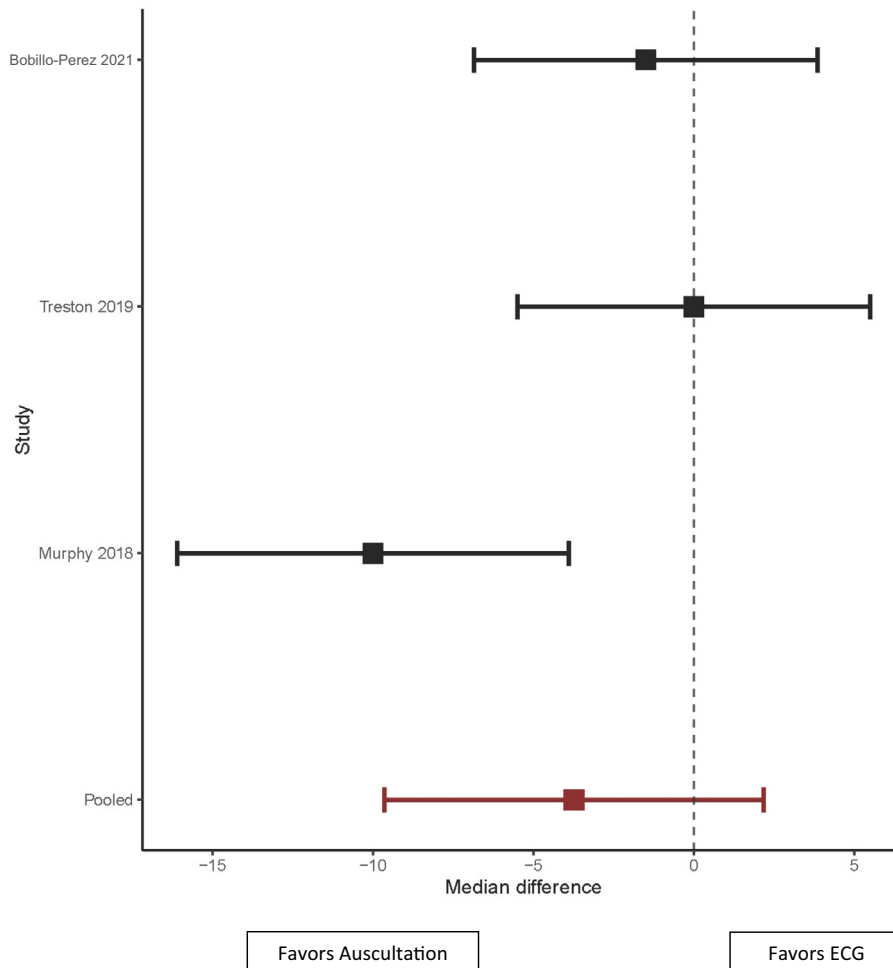

Fig. 4 – Auscultation vs ECG. (a) Time to first HR from device placement (Observational studies). (b) Time to first HR from birth (Observational studies).

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.[46] 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
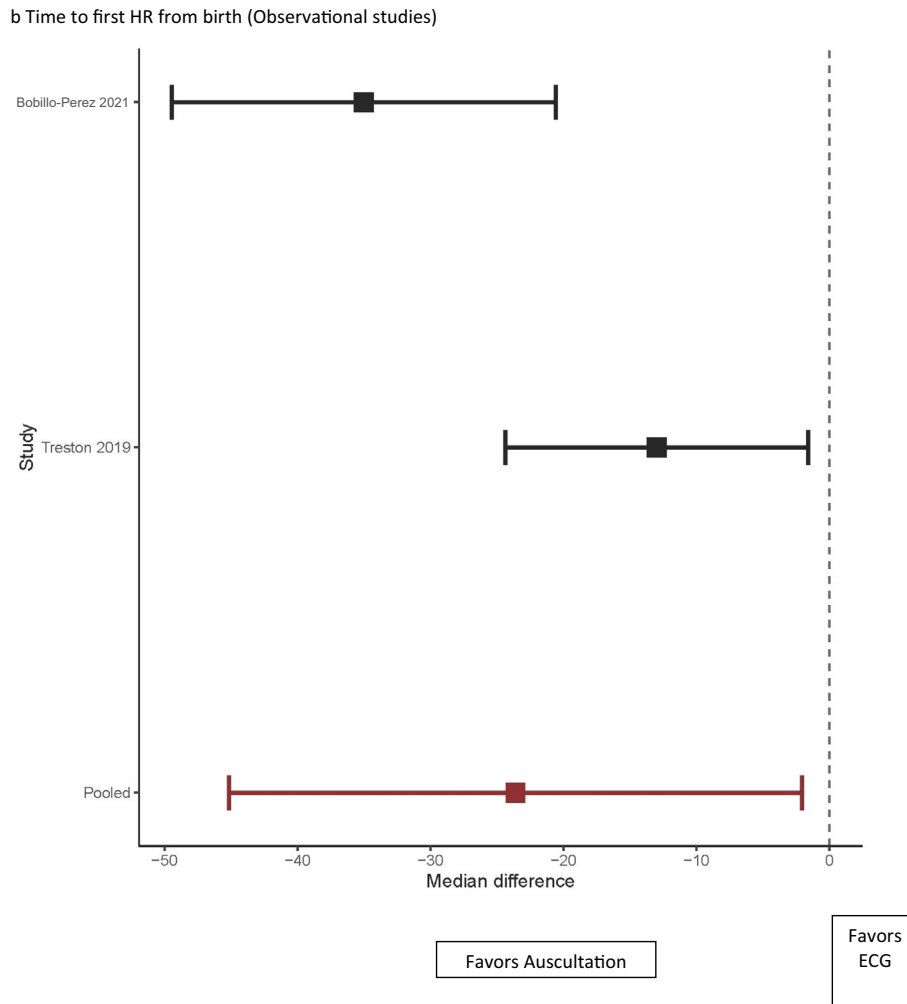
b Time to first HR from birth (Observational studies)

Fig 4. *(continued)*

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,[47–49] 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.[50] 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.[51] 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, Schmölzer 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. Schmölzer:** . **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

Supplementary material to this article can be found online at https://doi.org/10.1016/j.resplu.2024.100668.

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REFERENCES

1. Wyckoff MH, Greif R, Morley PT, et al. 2022 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations: Summary From the Basic Life Support; Advanced Life Support; Pediatric Life Support; Neonatal Life Support; Education, Implementation, and Teams; and First Aid Task Forces. Circulation 2022;146:e483–557.

2. Ersdal HL, Mduma E, Svensen E, Perlman JM. Early initiation of basic resuscitation interventions including face mask ventilation may reduce birth asphyxia related mortality in low-income countries: a prospective descriptive observational study. Resuscitation 2012;83:869–73.

3. Kapadia P, Hurst C, Harley D, et al. Trends in neonatal resuscitation patterns in Queensland, Australia - A 10-year retrospective cohort study. Resuscitation 2020;157:126–32.

4. Cavallin F, Cori MS, Negash S, et al. Heart rate determination in newborns at risk for resuscitation in a low-resource setting: a randomized controlled trial. J Pediatr 2020;221:88–92.e1.

5. Johnson PA, Cheung PY, Lee TF, O'Reilly M, Schmolzer GM. Novel technologies for heart rate assessment during neonatal resuscitation at birth – a systematic review. Resuscitation 2019.

6. Higgins JPT TJ, Chandler J, Cumpston M, Li T, Page MJ, Welch VA (editors). Cochrane handbook for systematic reviews of interventions. version 6.4 ed.

7. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 2009;6:e1000097.

8. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307–10.

9. Bland JM, Altman DG. Comparing methods of measurement: why plotting difference against standard method is misleading. Lancet 1995;346:1085–7.

10. Bland JM, Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res 1999;8:135–60.

11. Montenij LJ, Buhre WF, Jansen JR, Kruitwagen CL, de Waal EE. Methodology of method comparison studies evaluating the validity of cardiac output monitors: a stepwise approach and checklist. Br J Anaesth 2016;116:750–8.

12. Anton O, Fernandez R, Rendon-Morales E, Aviles-Espinosa R, Jordan H, Rabe H. Heart rate monitoring in newborn babies: a systematic review. Neonatology 2019;116:199–210.

13. Phillipos E, Solevag AL, Pichler G, et al. Heart rate assessment immediately after birth. Neonatology 2016;109:130–8.

14. Perlman JM, Wyllie J, Kattwinkel J, et al. Part 7: Neonatal resuscitation: 2015 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Circulation 2015;132:S204–41.

15. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. System Rev 2016;5:210.

16. Higgins JPT, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ 2011;343:d5928.

17. Whiting PF, Rutjes AW, Westwood ME, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. Ann Intern Med 2011;155:529–36.

18. Abbey NV, Mashruwala V, Weydig HM, et al. Electrocardiogram for heart rate evaluation during preterm resuscitation at birth: a randomized trial. Pediatric Res 2021:1–7.

19. Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ 2008;336:924–6.

20. McGrath S, Sohn H, Steele R, Benedetti A. Meta-analysis of the difference of medians. Biom J 2020;62:69–98.

21. Wan X, Wang W, Liu J, Tong T. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. BMC Med Res Methodol 2014;14:135.

22. Agrawal G, Kumar A, Wazir S, et al. A comparative evaluation of portable Doppler ultrasound versus electrocardiogram in heart-rate accuracy and acquisition time immediately after delivery: a multicenter observational study. J Maternal-Fetal Neonatal Med 2019:1–8.

23. Bjorland PA, Ersdal HL, Oymar K, Rettedal SI. Compliance with guidelines and efficacy of heart rate monitoring during newborn resuscitation: a prospective video study. Neonatology 2020;117:175–81.

24. Bobillo-Perez S, Balaguer M, Jordan I, et al. Delivery room ultrasound study to assess heart rate in newborns: DELIROUS study. Eur J Pediatr 2021;180:783–90.

25. Bush JB, Cooley V, Perlman J, Chang C. NeoBeat offers rapid newborn heart rate assessment. Arch Dis Child Fetal Neonatal Ed 2021;106:550–2.

26. Dawson JA, Saraswat A, Simionato L, et al. Comparison of heart rate and oxygen saturation measurements from Masimo and Nellcor pulse oximeters in newly born term infants. Acta Paediatr 2013;102:955–60.

27. Gaertner VD, Kevat AC, Davis PG, Kamlin COF. Evaluation of a digital stethoscope in transitioning term infants after birth. Arch Dis Child Fetal Neonatal Ed 2017;102:F370–1.

28. Iglesias B, Rodri Guez MAJ, Aleo E, Criado E, Marti Nez-Orgado J, Arruza L. 3-lead electrocardiogram is more reliable than pulse oximetry to detect bradycardia during stabilisation at birth of very preterm infants. Arch Dis Child Fetal Neonatal Ed 2018;103:F233–7.

29. Iglesias B, Rodriguez MJ, Aleo E, et al. Pulse oximetry versus electrocardiogram for heart rate assessment during resuscitation of the preterm infant. An Pediatr (Barc) 2016;84:271–7.

30. Kamlin CO, Dawson JA, O'Donnell CP, et al. Accuracy of pulse oximetry measurement of heart rate of newborn infants in the delivery room. J Pediatr 2008;152:756–60.

31. Kamlin CO, O'Donnell CP, Everest NJ, Davis PG, Morley CJ. Accuracy of clinical assessment of infant heart rate in the delivery room. Resuscitation 2006;71:319–21.

32. Katheria A, Rich W, Finer N. Electrocardiogram provides a continuous heart rate faster than oximetry during neonatal resuscitation. Pediatrics 2012;130:e1177–81.

33. Mizumoto H, Tomotaki S, Shibata H, et al. Electrocardiogram shows reliable heart rates much earlier than pulse oximetry during neonatal resuscitation. Pediatr Int 2012;54:205–7.

34. Owen CJ, Wyllie JP. Determination of heart rate in the baby at birth. Resuscitation 2004;60:213–7.

35. Rettedal S, Eilevstjonn J, Kibsgaard A, Kvaloy JT, Ersdal H. Comparison of heart rate feedback from dry-electrode ECG, 3-lead ECG, and pulse oximetry during newborn resuscitation. Children (Basel, Switzerland) 2021;8:1092.

36. Shimabukuro R, Takase K, Ohde S, Kusakawa I. Handheld fetal Doppler device for assessing heart rate in neonatal resuscitation. Pediatr Int 2017;59:1069–73.

37. Treston BP, Semberova J, Kernan R, et al. Assessment of neonatal heart rate immediately after birth using digital stethoscope, handheld ultrasound and electrocardiography: an observational cohort study. Arch Dis Child Fetal Neonatal Ed 2019;104:F227.

38. van Twist E, Salverda HH, Pas ABT. Comparing pulse rate measurement in newborns using conventional and dry-electrode ECG monitors. Acta Paediatr 2022;111:1137–43.

39. Zanardo V, Parotto M. Ultrasonic Pocket Doppler, novel technology for fetal and neonatal heart rate assessment. Resuscitation 2019;145:91–2.

40. Murphy MC, De Angelis L, McCarthy LK, O'Donnell CPF. Comparison of infant heart rate assessment by auscultation, ECG and oximetry in the delivery room. Arch Dis Child Fetal Neonatal Ed 2018;103:F490–2.

41. Murphy MC, De Angelis L, McCarthy LK, O'Donnell CPF. Randomised study comparing heart rate measurement in newly born infants using a monitor incorporating electrocardiogram and pulse oximeter versus pulse oximeter alone. Arch Dis Child Fetal Neonatal Ed 2019;104:F547–50.

42. Murphy MC, Jenkinson A, Coveney J, McCarthy LK, CPF OD. Randomised study of heart rate measurement in preterm newborns with ECG plus pulse oximetry versus oximetry alone. Arch Dis Child Fetal Neonatal Ed 2021;106:438–41.

43. Henry C, Shipley L, Ward C, et al. Accurate neonatal heart rate monitoring using a new wireless, cap mounted device. Acta Paediatr 2021;110:72–8.

44. van Vonderen JJ, Hooper SB, Kroese JK, et al. Pulse oximetry measures a lower heart rate at birth compared with electrocardiography. J Pediatr 2015;166:49–53.

45. van Leuteren RW, Kho E, de Waal CG, et al. Cardiorespiratory monitoring in the delivery room using transcutaneous electromyography. Arch Dis Child Fetal Neonatal Ed 2021;106:352–6.

46. Morina N, Johnson PA, O'Reilly M, et al. Doppler ultrasound for heart rate assessment in a porcine model of neonatal asphyxia. Front Pediatr 2020;8:18.

47. Downey C, Ng S, Jayne D, Wong D. Reliability of a wearable wireless patch for continuous remote monitoring of vital signs in patients recovering from major surgery: a clinical validation study from the TRaCINg trial. BMJ Open 2019;9:e031150.

48. Mestrom E, Deneer R, Bonomi AG, et al. Validation of heart rate extracted from wrist-based photoplethysmography in the perioperative setting: prospective observational study. JMIR Cardio 2021;5:e27765.

49. Nelson BW, Allen NB. Accuracy of consumer wearable heart rate measurement during an ecologically valid 24-hour period: intraindividual validation study. JMIR Mhealth Uhealth 2019;7:e10828.

50. Wyckoff MH, Wyllie J, Aziz K, et al. Neonatal life support 2020 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Resuscitation 2020;156:A156–87.

51. Kapadia VSKM, Strand M, Gately C, et al. Methods of heart rate monitoring in the delivery room and neonatal outcomes (NLS #5201). [Internet] Brussels, Belgium: International Liaison Committee on Resuscitation (ILCOR) Neonatal Life Support Task Force.