Heart Rate Assessment Immediately after Birth

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Key Words

Infants · Newborn · Neonatal resuscitation · Heart rate · Pulse oximetry · Electrocardiogram · Auscultation · Palpation · Doppler ultrasound · Photoplethysmography

Abstract

Background: Heart rate assessment immediately after birth in newborn infants is critical to the correct guidance of resuscitation efforts. There are disagreements as to the best method to measure heart rate. **Objective:** The aim of this study was to assess different methods of heart rate assessment in newborn infants at birth to determine the fastest and most accurate method. **Methods:** PubMed, EMBASE and Google Scholar were systematically searched using the following terms: 'infant', 'heart rate', 'monitoring', 'delivery room', 'resuscitation', 'stethoscope', 'auscultation', 'palpation', 'pulse oximetry', 'electrocardiogram', 'Doppler ultrasound', 'photoplethysmography' and 'wearable sensors'. **Results:** Eighteen studies were identified that described various methods of heart rate assessment in newborn infants immediately after birth. Studies examining auscultation, palpation, pulse oximetry, electrocardiography and Doppler ultrasound as ways to measure heart rate were included. Heart rate measurements by pulse oximetry are superior to auscultation and palpation, but there is contradictory evidence about its

accuracy depending on whether the sensor is connected to the infant or the oximeter first. Several studies indicate that electrocardiogram provides a reliable heart rate faster than pulse oximetry. Doppler ultrasound shows potential for clinical use, however future evidence is needed to support this conclusion. **Conclusion:** Heart rate assessment is important and there are many measurement methods. The accuracy of routinely applied methods varies, with palpation and auscultation being the least accurate and electrocardiogram being the most accurate. More research is needed on Doppler ultrasound before its clinical use.

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Introduction

The majority of newborn infants make the transition from the intrauterine to extrauterine environment successfully; however, approximately 10% of newborn infants require assistance during this transition. Heart rate (HR) is the most important clinical indicator to evaluate the status of a newborn, and is also used to guide any resuscitation efforts [1]. In addition, it has been shown that

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HR during the first minutes of life in infants needing resuscitation may be a predictor of early neonatal mortality and moderate to severe brain injury in those who survive [2]. Virginia Apgar recognised the importance of HR assessment immediately after birth in newborn infants [3]. She developed the Apgar score, which evaluates criteria of five items (HR, respiratory effort, reflex irritability, muscle tone and colour) to ascertain the condition of and response to resuscitative efforts in a newborn infant [3]. Immediately after birth, it is pertinent that the infant's HR is assessed as accurately and quickly as possible to determine if any interventions are needed. Overestimations of HR might result in delayed interventions while underestimations might result in the initiation of resuscitation when it is not required [4].

During neonatal resuscitation, international resuscitation guidelines recommend assessing a newborn's HR by 'listening to the precordium with a stethoscope, feeling for pulsations at the base of the umbilical cord, or feeling the brachial or femoral pulses' [1]. Several other methods have been described to evaluate HR in newborns, including: (i) pulse oximetry (PO), (ii) electrocardiography (ECG), (iii) Doppler ultrasound, and (iv) forehead reflectance photoplethysmography (PPG). The purpose of this review was to examine the literature about the efficacy of different methods for HR assessment in newborn infants.

Methods

We systematically searched for articles in PubMed, EMBASE and Google Scholar published between 1953 and 2015 (see Appendix) using the following terms: 'infant', 'heart rate', 'monitoring', 'delivery room', 'resuscitation', 'stethoscope', 'auscultation', 'palpation', 'pulse oximetry', 'electrocardiography', 'Doppler ultrasound', 'photoplethysmography' and 'wearable sensors'. Additional published articles were obtained via manual searches of the references in the obtained reports. Articles were assessed based on their title, abstract and methods, and included only if they focused on HR measurement by one or more of the methods mentioned above. Studies were excluded if other patient interventions were present. Only human and simulation studies were included, no language restrictions were applied. The use of PO to assess oxygen saturation was not the purpose of this review; therefore, we refer to a recent review by Tin and Lal [5].

Results

A total of 18 studies were identified and included. Reasons for exclusion were incorrect patient demographics, animal studies and/or use of the devices for reasons other

than HR measurement. Of the included studies, 4/18 described either palpation or auscultation [3, 4, 6, 7], 4/18 used PO alone to measure HR [8–11], and 5/18 studies compared PO and ECG [12–16]. Two studies compared auscultation, palpation and ECG/PO [17–18]. More recently, studies using Doppler ultrasound [19–21] (3/18) have been reported (table 1, 2).

Auscultation/Palpation

Auscultation is performed by placing a stethoscope on the left side of the newborn's chest, whereas palpation is done by placing the umbilical cord between the thumb and the index finger or feeling for the brachial or femoral artery (fig. 1). The HR is assessed by listening or feeling the pulse for 6 s then multiplying this value by 10 to obtain an HR in beats per minute (beats min^{-1}) [23]. We identified four studies that examined auscultation and/or palpation to assess a newborn's HR. Voogdt et al. [6] assessed the accuracy of and time to establish an HR by auscultation using predefined HR settings of 0, 40, 80 or 120 beats min^{-1} during simulated resuscitation scenarios. Overall, it took up to 17 s to assess HR, with up to 1/3 incorrectly assessed, potentially causing changes to neonatal resuscitation management in the delivery room. Chitkara et al. [7] evaluated the accuracy of HR assessment using palpation of the umbilical cord and auscultation on a manikin with set HRs of 50, 90 or 130 beats min^{-1} . Participants using auscultation incorrectly initiated or discontinued resuscitation in up to 75% of cases. In comparison, when using palpation, up to 33% of resuscitators incorrectly initiated or discontinued resuscitation. Evaluating HR before or after resuscitation intervention did not change its accuracy, but a significant number of HR assessments done by either method were incorrect and would have resulted in a change of intervention if performed in a clinical setting [7]. Kamlin et al. [17] compared the accuracy of HR assessment using auscultation and palpation of the umbilical cord with ECG immediately after birth in 26 infants. Overall, cord pulsations were impalpable at the time of assessment in 5 (19%) infants, and clinical assessment underestimated the ECG HR with a mean (SD) difference between auscultation and palpation and ECG HR of -14 (21) and -21 (21) beats min^{-1} . Owen and Wyllie [4] compared HR assessment via palpation of the femoral and brachial artery and umbilical cord to auscultation in 20 infants. Palpation correctly identified HR as being $>100 \text{ beats min}^{-1}$ in 20% via the femoral pulse, in 25% via the brachial pulse and in 55% via the umbilical cord. More concerning was that between 25 and 60% of the time the pulse was not detectable within 30 s, and between 15 and

Table 1. HR assessment in neonates with varying methods

First author, year	Gestation	Intervention	Comparison	Results
Apgar [3], 2015	Preterm/term	PA (n = 2,096)	N/A	Apgar score using 5-item criteria, including HR, was described
Chitkara [7], 2013	N/A (simulated)	AU (n = 33) PA (n = 31)	N/A	26–52% HR assessments including both methods were inaccurate
Voogdt [6], 2010	N/A (simulated)	AU (n = 61)	N/A	Time to assess HR was 11.5 s and it was inaccurate 28% of the time
Kamlin [17], 2006	Preterm/term	AU/PA (n = 26)	ECG	Mean difference between AU and PA with ECG HR was -14 and -22 beats min^{-1} , respectively
Owen [4], 2004	Preterm/term	PA (n = 60)	AU	Brachial, femoral and umbilical pulse assessment inaccuracies ranged from 20 to 45%
Deepak [11], 2014	Preterm/term	PO (n = 150)	N/A	PO sensor application was quicker when applied to the infant first (12 vs. 11 s), and gave a signal faster (16 vs. 10 s)
O'Donnell [9], 2005	Preterm/term	PO (n = 115)	N/A	Time from birth until PO data was displayed was 100 s if the sensor was connected to the PO first, and 68 s if the sensor was connected to the infant first
O'Donnell [14], 2005	Preterm/term	PO (n = 40)	ECG	Reliable HR displayed between 25 and 32 s
Kamlin [13], 2008	Preterm/term	PO (n = 55)	ECG	HR difference between ECG and PO was -2 beats min^{-1} overall, and -0.5 beats min^{-1} in infants receiving positive pressure ventilation
Smit [8], 2014	Term	PO (n = 109)	NICU Reference Ranges [25]	Delayed cord clamping and immediate skin to skin contact showed a slower HR increase in the first minutes after birth
Singh [12], 2008	Preterm	PO (n = 30)	ECG	HR difference between PO and ECG was -0.5 beats min^{-1}
Dawson [10], 2010	Preterm/term	PO (n = 468)	N/A	HR (IQR) rose from 96 (65–127) beats min^{-1} at 1 min to 163 (146–178) beats min^{-1} at 5 min. HR rose slower in preterm infants
Mizumoto [18], 2012	Preterm/term	PO/ ECG (n = 20)	AU/ PA	HR shown by ECG in 38 s vs. PO in 122 s after delivery
Katheria [15], 2012	Preterm/term	PO/ECG (n = 46)	N/A	Average time to place ECG was 23 s vs. 37 s for PO. ECG HR was displayed after a mean of 3 s vs. 33 s for PO
Hutchon [19], 2014	Preterm/term	Doppler	AU	Time taken for Doppler HR was a few seconds after birth and faster than AU
Goenka [21], 2014	Term	Doppler (n = 92)	PO/AU/PA	Doppler measured HR as 3.15 beats min^{-1} higher than ECG
Lemke [20], 2011	Term	Doppler (n = 16)	PA	HR detected by a prototype Doppler clamp applied to the umbilical cord was accurate compared to a palpated pulse
Grubb [22], 2014	Preterm/term	PPG (n = 77)	ECG	Difference between PPG and ECG was 8.39 beats min^{-1}
van Vonderen [16], 2015	Preterm/term	PO (n = 53)	ECG	Time from birth to assess HR was 99 s for PO and 82 s for ECG. HR was lower for PO than ECG. The mean difference between PO and ECG was -3 beats min^{-1}

AU = Auscultation; PA = palpation.

Table 2. Advantages and limitations of various methods of HR assessment in neonates

	Advantages	Limitations
Auscultation	<ul style="list-style-type: none">– Inexpensive– Easy to perform– Fast HR assessment– Not technology dependent	<ul style="list-style-type: none">– Inaccurate– External noise interference– Intermittent
Palpation	<ul style="list-style-type: none">– Inexpensive– Simple– Fast HR assessment– ‘Out of the way’ from the infant’s chest– Not technology dependent	<ul style="list-style-type: none">– Inaccurate– Infant’s movements may interrupt assessment– Intermittent
PO	<ul style="list-style-type: none">– Significantly more accurate– Continuous	<ul style="list-style-type: none">– Affected by poor tissue perfusion– Cost (compared to auscultation and palpation)
Doppler ultrasound	<ul style="list-style-type: none">– Accurate HR assessment by blood flow– Able to use through a polyethylene bag– Able to detect flow in situations of pulseless electric activity	<ul style="list-style-type: none">– Further research required before continual clinical use– Requires clinician experience to operate optimally– Cost (compared to auscultation and palpation)
ECG	<ul style="list-style-type: none">– Accurate, the ‘gold standard’– Relatively fast compared to PO– Continuous	<ul style="list-style-type: none">– May damage the skin of extremely premature infants– Requires clinician experience to operate optimally– Detects pulseless electrical activity– Cost (compared to auscultation and palpation)

Fig. 1. Potential sensor application.

45% of the infants had HRs incorrectly assessed as being <100 beats min^{-1} . This data suggests that palpation would have guided the team to potentially wrong interventions in up to 75% of real-life resuscitations. However, in the absence of devices when palpation is the only option to assess HR, palpation of the umbilical cord appears to be more reliable than palpation of the femoral or brachial artery. Interestingly, even though auscultation is more accurate, palpation may be more reliable in guiding resuscitation interventions than auscultation.

Pulse Oximetry

A pulse oximeter measures oxygen saturation and HR of a newborn simultaneously and continuously. Oxygen saturation is measured by comparing the amount of red and infrared light absorbed by oxygenated and deoxygenated blood, respectively [5]. During neonatal resuscitation the pulse oximeter should be placed on the right hand or wrist of the infant to obtain an oxygen saturation and HR measurement (fig. 1) [24]. Three studies evaluated the fastest way to obtain an HR in newborns using PO [9, 11, 14]. All studies compared sensor application to the infant first and then connection to the pulse oximeter, or vice versa. O'Donnell et al. [9, 14] performed two observational studies in the delivery room in preterm and

term infants ($n = 115$ and 60 , respectively) and determined that placing the sensor on the infant's hand/wrist before connecting it to the oximeter displayed an HR faster and more accurately. However, more recently, Louis et al. [11] performed a randomised controlled trial in 150 preterm and term infants in the delivery room and reported that connecting the sensor to the oximeter first and then placing the sensor onto the infant provided faster and more accurate results. Two studies, Singh et al. [12] and Kamlin et al. [13], assessed the accuracy of HR measurement by PO in the delivery room and Neonatal Intensive Care Unit (NICU) in 55 preterm and term, and 30 preterm infants, respectively. Both studies similarly reported a lower HR with PO than ECG. A small concern in the study by Kamlin et al. [13] was that PO only detected HR <100 beats min^{-1} 89% of the time.

Further studies evaluated HR assessment in the delivery room [8, 10]. Smit et al. [8] reported HR during 109 home births with midwife attendance and compared them to NICU reference ranges [10]. Skin to skin contact and/or delayed cord clamping resulted in lower HRs and a slower rate of HR rise [8]. Similar results examining preterm infants with delayed or immediate cord clamping have recently been published by Pichler et al. [25]. Reference ranges of oxygen saturation within the first 10 min after birth were reported by Dawson et al. [26] and showed that HR increases more slowly in: (i) preterm versus term infants, (ii) after Caesarean versus vaginal birth and (iii) in newborns after maternal analgesia administration.

Electrocardiography

Electrode leads are placed onto clean areas of the skin and connected to the electrocardiograph that measures the electrical activity of the heart and translates these measurements to tracings that mimic the atrial and ventricular depolarisations and repolarizations (fig. 1) [27]. Two studies measured the time from birth until a reliable HR was displayed, comparing PO versus ECG during neonatal resuscitation in preterm and term infants ($n = 46$ and 20 , respectively) [15, 18]. Both studies concluded that ECG was more reliable and the time to display HR was halved compared to PO. In addition, ECG leads were placed more quickly onto the infant compared to a PO sensor [15, 18]. van Vonderen et al. [16] described the accuracy and time needed to assess HR by ECG compared to PO in 53 preterm and term infants between 1 and 10 min after birth. The mean (SD) time from birth until HR detection using ECG and PO was 82 s (26) and 99 s (33), respectively, agreeing with the studies performed by Katheria et al. [15] and Mizumoto et al. [18]. Further-

more, PO measurements showed bradycardia twice as often within the first 2 min after birth compared to ECG, with a mean difference between PO and ECG HR of -3 beats min^{-1} within the first 10 min after birth.

Potential limitations of ECG include: (i) delay in signal acquisition due to skin cleaning and lead placement; (ii) all infants are born covered in blood, mucus, vernix or amniotic fluid and a proper signal cannot be obtained if these bodily fluids are not cleaned off prior to lead placement; (iii) in particular, extremely low birth weight infants have very fragile skin which ECG leads might damage, and (iv) there is the potential of pulseless electric activity, which could be interpreted as HR on an ECG, thus potentially delaying resuscitation efforts [15, 20, 28].

Doppler Ultrasound

A continuous wave Doppler ultrasound measures the difference in sound pitch between the emitted and reflected sound waves. The sound waves are reflected off circulating red blood cells and, based on the change in frequency, the speed of blood flow is calculated (fig. 1) [29]. Ultrasound is regularly used for fetal monitoring during pregnancy, including the assessment of fetoplacental circulation and in paediatric cardiology [29, 30]. Recently, this technique has been used to monitor a newborn's HR immediately after birth to guide resuscitation efforts. We identified three studies that used Doppler ultrasound to examine a newborn's HR in the delivery room [19–21]. Hutchon [19] reported that HR assessment using a Doppler ultrasound of the aortic artery (close to the heart) is faster and more reliable compared to auscultation. In a pilot study of 16 infants conducted by Lemke et al. [20], HR assessments done by a prototype Doppler ultrasound device were as reliable as manual palpation. The authors concluded that this device can be placed on the infant's umbilical cord immediately after birth to monitor HR by measuring arterial pulsations. A limitation of this prototype device is that it might affect cord blood flow by causing umbilical artery vasoconstriction, but further studies are required to confirm this assumption. Furthermore, in situations where vascular access through the umbilical vessels is needed, the clamp has to be removed [20]. Goenka et al. [21] reported a randomised control trial comparing HR obtained by Doppler to palpation, auscultation, PO and ECG in 92 term infants within the first minutes after birth. Overall, Doppler and ECG HRs were similar and PO was often as accurate as Doppler; however, sometimes it took >1 min to obtain a PO signal. Doppler had a significantly higher

accuracy compared to auscultation or palpation. In addition, the Doppler ultrasound probe could also be used through a polyethylene bag while newborns are kept warm [18].

Discussion

The 2010 International Consensus on Cardiopulmonary Resuscitation recommends repeated assessments of HR during neonatal resuscitation [1]. If HR is <100 beats min^{-1} and the newborn is not breathing regularly, positive pressure ventilation via a face mask should be initiated. If HR remains <100 beats min^{-1} despite mask ventilation, corrective steps (MR SOPA) should be performed to improve the mask ventilation. If HR continues to decrease to <60 beats min^{-1} , despite adequate mask ventilation and corrective steps, chest compressions should be initiated. Although these HR cut-offs (100 and 60 beats min^{-1}) are routinely used, they have not been rigorously evaluated to identify their clinical importance. Yam et al. [31] described the rate of HR rise during mask ventilation in 27 preterm infants <30 weeks gestation. They reported a median time of 73 and 243 s to reach an HR of >100 and >120 beats min^{-1} , respectively. Palme-Kilander and Tunell [32] reported similar results, with a rapid increase in HR after gas exchange occurred. These studies suggest that an HR cut-off of <100 beats min^{-1} immediately after birth alone neither indicates that resuscitation measures are required nor that an HR >100 beats min^{-1} indicates cardiorespiratory stability. Also, as universal application of delayed cord clamping may change the HR nomograms to lower HR values in the first minutes of life [8], one might argue that methods for HR assessment should be re-evaluated for reliability in the lower HR ranges.

In this review, studies assessing auscultation and palpation varied in methodology and patient demographics; however, they all reported similar concerns. Auscultation is superior to palpation, although neither technique provides an accurate assessment of current HR and both are intermittent. The current conflicting results suggest further studies are needed to determine the fastest and most accurate method to obtain an accurate HR using PO. Despite several advantages there are also some limitations for the use of PO during neonatal resuscitation. Advantages include being inexpensive, non-invasive, and providing a continuous display of HR values and trends. As opposed to the other common methods for HR assessment, i.e. auscultation and palpation, the benefit of having HR in addition to SpO_2 continuously visible to the

whole team may be significant. Limitations include the inaccuracy of HR measurements due to motion artefacts [11], delay in HR display, which could potentially delay resuscitation efforts [13] or poor tissue perfusion (e.g. hypothermia) [18]. Overall, PO is an accurate method by which to measure HR in the delivery room and should be used to monitor HR and oxygen saturation routinely during neonatal resuscitation. HR measurement using an ECG is the current 'gold standard' to continuously monitor an infant's HR in the NICU with an HR (median) of 93–154 (123) beats min^{-1} during the first day of life [18]. However, there are several important limitations that prevent ECG from being universally used for HR assessment in the delivery room. Any clinician using ECG to determine HR has to be trained in recognizing these limitations to avoid harm to a newborn infant. Further studies are needed to assess whether ECG or PO is faster at obtaining an HR immediately after birth in newborn infants. Doppler ultrasound to assess a newborn's HR remains in its infancy and further research is required until this can be used clinically. Doppler ultrasound provides an advantage over ECG in situations of pulseless electric activity, which often occurs in extremely sick, asphyxiated newborns. It may also be of potential use for HR assessment during delayed cord clamping, especially as it is portable and does not require the baby to be wiped off for it to be reliably applied.

Potential Future Developments

PPG can be used to monitor the HR and breathing rate in its 'reflectance mode'. A photodiode detects light that has been emitted from an LED light source which has had contact with tissue. The light is then amplified, converted into a voltage and measured (fig. 1) [22]. We searched specifically for studies using PPG in the DR, but as only one study from the NICU was identified [22], its potential for guiding DR resuscitation has yet to be explored. Future HR monitoring might also include digital technology (e.g. phonocardiography), smart phones or wearable sensors. Miao et al. [33] described a wearable, low-power, context-aware ECG monitoring system with Bluetooth capabilities for data transmission to smartphones. Huang et al. [34] proposed a wireless ECG sensor that can be worn around an individual's finger and can transmit HR data via WiFi. Albright et al. [35] developed a non-contact capacitive interface that allows HR measurement without touching the skin. This potentially provides an advantage for extremely low-birth-weight infants with

very fragile skin. More recently, wearable sensors have been integrated into smartwatches, bracelets or glasses, which use infrared and visible-light LED lenses and photodiode sensors to measure HR [36, 37]. An HR sensor could also be sewn into clothing or blankets [38]. Kevat et al. [39] described a digital stethoscope that is able to transmit HR measurements to a smartphone. The mean (SD) difference between HR measurements by this digital stethoscope and ECG was 7.4 (24) beats min⁻¹. The digital stethoscope is more inaccurate compared to ECG and PO; however, it obtains an HR faster, with a median (IQR) time to the first HR display of 2 (1–7) s. Balogh and Kovács [40] also described a digital stethoscope that can be connected to a laptop which they used to assess parameters of patent ductus arteriosus in preterm infants. There are several new technologies on the horizon; however, before they can be translated into clinical routine they have to be vigorously studied.

Conclusion

Immediately after birth a newborn's HR needs to be assessed quickly to determine any resuscitation measures. Auscultation and palpation are inaccurate and inconsistent, and might delay resuscitation efforts. PO slightly underestimates HR compared to ECG and Doppler ultrasound. Doppler ultrasound appears to have value but needs further research prior to clinical use.

Appendix

Search of PubMed – Last performed June 9, 2015

- #1 Infant (n = 1,005,745)
- #2 Infants (n = 1,043,078)
- #3 Heart Rate (n = 281,344)
- #4 Fetal (n = 386,672)
- #5 Monitoring (n = 465,514)
- #6 Delivery Room (n = 7,410)
- #7 Delivery Room Management (n = 2,411)
- #8 Resuscitation (n = 97,049)
- #9 Pulse Oximetry (n = 15,479)
- #10 Electrocardiograph (n = 184,587)
- #11 ECG (n = 202,133)
- #12 Doppler (n = 112,914)
- #13 Wearable Sensors (n = 816)
- #14 Stethoscope (n = 1,640)
- #15 Umbilical Cord (n = 36,936)
- #16 Radial Pulse (n = 3,532)
- #17 Brachial Pulse (n = 4,713)
- #18 Femoral Pulse (n = 6,002)
- #19 Heart Auscultation (n = 12,110)
- #20 Palpation (n = 15,296)

- #21 #1 AND #3 AND (#2 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20) [n = 2,358, 12, 541, 40, 21, 88, 173, 16]
- #22 #6 AND #8 AND (#9 OR #10 OR #11 OR #12 OR #23) [n = 48, 5, 6, 2, 1]
- #23 Photoplethysmography (n = 1,696)

Search of EMBASE – Last performed June 9, 2015

- #1 Infant (n = 538,919)
- #2 Infants (n = 538,919)
- #3 Heart Rate (n = 236,522)
- #4 Fetal (n = 251,666)
- #5 Monitoring (n = 657,680)
- #6 Delivery Room (n = 3,155)
- #7 Delivery Room Management (n = 99)
- #8 Resuscitation (n = 101,967)
- #9 Pulse Oximetry (n = 11,608)
- #10 Electrocardiograph (n = 1,959)
- #11 ECG (n = 81,229)
- #12 Doppler (n = 150,501)
- #13 Wearable Sensors (n = 289)
- #14 Stethoscope (n = 2,315)
- #15 Umbilical Cord (n = 43,431)
- #16 Radial Pulse (n = 746)
- #17 Brachial Pulse (n = 318)
- #18 Femoral Pulse (n = 1,978)
- #19 Heart Auscultation (n = 5,148)
- #20 Palpation (n = 19,488)
- #21 #1 AND #3 AND (#2 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20) [n = 673, 5, 58, 0, 1, 3, 13, 3]
- #22 #6 AND #8 AND (#3 OR #10 OR #11 OR #12 OR #23) [n = 68, 0, 6, 5, 0]
- #23 Photoplethysmography (n = 1,579)

Search of Google Scholar – Last performed June 9, 2015

- #1 Infant (n = ~2,330,000)
- #2 Infants (n = ~2,110,000)
- #3 Heart Rate (n = ~3,300,000)
- #4 Fetal (n = ~2,560,000)
- #5 Monitoring (n = ~4,450,000)
- #6 Delivery Room (n = ~2,870,000)
- #7 Delivery Room Management (n = ~2,010,000)
- #8 Resuscitation (n = ~712,000)
- #9 Pulse Oximetry (n = ~103,000)
- #10 Electrocardiograph (n = ~40,000)
- #11 ECG (n = ~1,190,000)
- #12 Doppler (n = ~1,950,000)
- #13 Wearable Sensors (n = ~94,300)
- #14 Stethoscope (n = ~71,800)
- #15 Umbilical Cord (n = ~571,000)
- #16 Radial Pulse (n = ~775,000)
- #17 Brachial Pulse (n = ~83,600)
- #18 Femoral Pulse (n = ~206,000)
- #19 Heart Auscultation (n = ~69,700)
- #20 Palpation (n = ~242,000)
- #21 #1 AND #3 AND (#2 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20) [n = ~266,000, ~17,100, ~44,000, ~18,800, ~19,800, ~21,700, ~22,300, ~23,000]
- #22 #6 AND #8 AND (#3 OR #10 OR #11 OR #12 OR #23) [n = ~15,100, ~18,700, ~17,800, ~15,000, 293]
- #23 Photoplethysmography (n = ~5,400)

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