Cardiocirculatory Monitoring during Immediate Fetal-to-Neonatal Transition: A Systematic Qualitative Review of the Literature

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Key Words

Neonate · Transition · Heart · Circulation · Heart rate · Blood pressure · Cardiac function

Abstract

Background: The fetal-to-neonatal transition is a complex process that includes changes in cardiac and respiratory systems. **Objective:** The aim of this study is to review the different methods of cardiocirculatory monitoring during the immediate neonatal transition period. **Methods:** A systematic search of PubMed and Ovid Embase was performed using the following terms: infant, newborn, newborn infant, neonate, neonates, heart, cardiac, blood pressure, haemodynamic, hemodynamics, blood circulation, circulation, echocardiography, ultrasonography, sonography, electrocardiography, ECG, oximetry, pulse, pulse oximetry, monitoring, measurement, acclimatization, adaptation, transition, after birth and delivery room. Additional articles were identified by manual search of cited references. Only human studies describing cardiocirculatory monitoring during the first 15 min after birth were included. **Results:** Thirteen studies were

identified that described heart rate (HR). Additional five studies were identified that measured blood pressure. Four studies performed functional echocardiography during neonatal transition; two in addition to blood pressure monitoring and three in addition to HR monitoring. **Conclusion:** Routine HR monitoring using electrocardiography or pulse oximetry is used to evaluate adequate hemodynamic transition, and reference ranges have been established. Measuring blood pressure noninvasively though noncontinuously might be of some value in future, considering that the normative data have been established recently. Echocardiographic monitoring during the immediate transition period will improve the knowledge about cardiac function changes, but introduction in clinical routine remains questionable.

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Introduction

Immediate transition from intrauterine to extrauterine life (defined for this study as the first 15 min after birth) causes complex physiological processes affecting

Fig. 1. Flow diagram.

all vital organ systems [1]. During pregnancy the low-resistance placenta supplies the fetus with blood and oxygen. During fetal development, pulmonary vascular resistance remains high, the majority of the right ventricular output bypasses the lung and flows through the ductus arteriosus into the systemic circulation, whereas the left ventricular output (LVO) supplies the brain and the upper body. With the first breath immediately after birth, the pulmonary vascular resistance drops rapidly and the right ventricular output switches to the lungs [2]. In order to objectify the newborn's condition during this transition period, Virginia Apgar developed in 1953 a scoring system based on clinical assessments, which considers heart rate (HR), respiratory effort, reflex irritability, muscle tone and color [3]. However, a number of studies have already shown significant interobserver and intraobserver variability in clinical assessments of the newborn's condition [4, 5]. Therefore, more objective and reliable methods to evaluate the newborn infants' condition in the delivery room is needed. According to the latest resuscitation guidelines of the European Resuscitation Council [6], the American Heart Association [7] and the International Liaison Committee on Resuscitation [8], it is recommended, besides the clinical evaluation, to monitor arterial oxygen saturation (SpO₂) by using pulse oximetry in the delivery room. This enables noninvasive continuous monitoring of the SpO₂ as well as HR.

Clinical assessment and monitoring with pulse oximetry unfortunately does not always give information about potentially compromised cardiocirculatory status influencing oxygen transport to tissue. Further cardiocirculatory monitoring might therefore be useful to obtain information to guide hemodynamic management for optimizing not only SpO₂, but also cardiocirculation to improve oxygen transport to tissue.

The aim of the present systematic qualitative review was to identify studies describing noninvasive cardiocirculatory monitoring during the immediate transition time defined as the first 15 min after birth.

Search Strategy and Study Selection Criteria

Articles were identified using the stepwise approach specified in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Statement [9] (fig. 1).

Search Strategy

A systematic search was performed of PubMed and Embase to identify English-language articles published from July 1962 to July 2014. The studies had to address noninvasive cardiocirculatory monitoring in neonates during the first 15 min after birth. Search terms included: infant/newborn/newborn infant/neonate/neonates,

Table 1. Cardiocirculatory monitoring immediately after birth

	HR	BP	Cardiac function
Monitoring	PO/ECG continuous	Doppler/oscillometric noncontinuous	echocardiography noncontinuous
Study design	observational	observational	observational
Human studies	13	5	4
PO = Pulse oximetry.			

heart/cardiac/blood pressure/haemodynamic/hemodynamics/blood circulation/circulation, echocardiography/ultrasonography/sonography/electrocardiography/ECG/oximetry/pulse/pulse oximetry, monitoring/measurement, and acclimatization/adaptation/transition/after birth/delivery room (Appendix 1, 2). Additional published reports were identified through a manual search of references in retrieved articles and in review articles. Only human studies with cardiocirculatory monitoring within 15 min after birth were included. Studies starting cardiocirculatory monitoring 15 min after birth and animal studies were excluded.

Study Selection

Articles identified following literature review were evaluated independently by two authors (N.B., G.P.) for inclusion using the title and abstract. Where uncertainty remained regarding eligibility for inclusion, the full text was reviewed. Two reviewers independently identified relevant abstracts and critically appraised the full text of identified articles and assessed the methodological quality of included studies. All data were analyzed qualitatively. Data extraction included the characterization of study type, patient demographics, methods and results.

Results

The initial search detected 1,839 articles in PubMed and 950 in Ovid Embase; after removal of duplicates and rejection (e.g. no monitoring within the first 15 min after birth in human neonates; fig. 1), 17 studies were included in the qualitative review (table 1). All 17 studies performed cardiocirculatory monitoring during the first 15 min immediately after birth in human neonates. Thirteen studies placed importance on continuous measurement of HR (table 2). Three of them used only electrodes [10–

12], two used electrodes and pulse oximetry [13, 14], seven only pulse oximetry [15–21] and one did not mention the method of achieving HR [22]. Five studies described blood pressure (BP) during the defined transition period (table 3): one of them measured BP by the Doppler ultrasound method [23]; the other four used the oscillometric technique to achieve the results [11, 24–26]. Four studies performed functional echocardiography during neonatal transition (table 4) [11, 12, 20, 25]; two in addition to BP monitoring [11, 25] and three in addition to HR monitoring [11, 12, 20].

Discussion

The following parameters of cardiocirculatory monitoring have been described during the immediate transition period: HR, BP and cardiac function.

Heart Rate

A rapid increase in HR immediately after birth is currently the most important parameter for adequate fetal-to-neonatal transition [7]. If HR is <100/min, the international resuscitation guidelines suggest providing respiratory support [7]. However, HR <100/min has been reported to be common in term and preterm infants [17, 19]. Animal and human observational studies have reported two different patterns of HR changes during the immediate transition period [10, 27]. If cord clamping was performed before lung aeration occurred, a significant decrease in HR was observed [10]. However, if lung aeration was achieved before cord clamping, HR remained similar before and after cord clamping [10].

Changes in HR at birth are also affected by mode of delivery and maternal anesthesia. Several studies reported that vaginally delivered neonates had significantly higher HR compared to neonates born by caesarean section, which could also be an effect of maternal general anesthesia [18, 19]. In addition, vaginally born neonates with maternal epidural anesthesia had initially higher HR compared to neonates whose mothers did not receive any analgesia [15]. Between vigorous and slightly depressed term vaginally delivered newborns, no difference in HR was observed [22].

In healthy term and late-preterm (>32 weeks' gestation), several studies have reported that it can take several minutes until an increase in HR is observed [19]. In comparison, two different patterns of HR increase have been observed in infants requiring respiratory support [28, 29]. Resuscitation, either with 100% oxygen or with

Table 2. Heart rate monitoring in neonates immediately after birth

Author/year	Gestation	Mode of delivery	Method used	Infants	Tendency first 15 min	Respiratory support	First measurement	
							heart rate, bpm	time after birth, min
Brady [10], 1962	–	CS/VD	ECG	112	–	yes	152 ^a /125 ^b	2
Bustos [22], 1975	term	VD	–	23	increase	no	170	3–5
Meier-Stauss [13], 1990	preterm/term	CS	PO/ECG	53	–	yes	158	2
Gonzales [18], 1998	term	VD/CS	PO	380	increase	yes	133 VD/108 CS	1
Toth [15], 2002	preterm/term	VD	PO	50	decrease	no	157	2
Kopotic [16], 2002	preterm	–	PO	15	–	yes	110	2–3
Kamlin [14], 2008	preterm/term	–	PO/ECG	55	–	yes	–	2
Dawson [17], 2009	preterm	–	PO	126	increase	yes	<100	1
Dawson [19], 2010	preterm/term	VD/CS	PO	468	increase	no	96	1
van Vonderen [11], 2014	term	CS	ECG	24	stable	no	157	2
Noori [20], 2012	term	VD	PO	20	decrease	no	169	3–7
van Vonderen [12], 2014	term	CS	ECG	24	stable	no	158	2
Smit [21], 2014	term	VD	PO	109	increase	no	61	1

CS = Cesarean section; VD = vaginal delivery; PO = pulse oximetry. ^a Infants with onset of respiration before cord clamping.
^b Infants with onset of respiration after cord clamping.

Table 3. BP monitoring in neonates immediately after birth

Author/year	Gestation	Mode of delivery	Method used	Infants	First measurement, mm Hg		
					SBP	MBP	DBP
Marx [23], 1976	term	VD/CS	Doppler	134	67.7±0.6	48.0±0.6	–
Winberg [25], 1989	term	CS	oscillometric	16	67	45	32
Salihoglu [24], 2012	preterm/term	VD/CS	oscillometric	982	63.82±12.24	49.01±11.40	37.76±11.63
van Vonderen [11], 2014	term	CS	oscillometric	24	68.3±18.3	51.2±15.4	41.6±16.0
Pichler [26], 2014	preterm/term	VD/CS	oscillometric	108	62 (60–66)	49 (42–52)	42 (35–45)

SBP = Systolic BP; MBP = mean BP; DBP = diastolic BP; CS = cesarean section; VD = vaginal delivery.

Table 4. Cardiac function monitoring in neonates immediately after birth

Author/year	Gestation	Mode of delivery	Infants	Tendency first 15 min	First measurement	
					LVO, ml/kg/min	LVSF, ml/kg
Winberg [25], 1989	term	CS	16	–	238	1.55
Noori [20], 2012	term	VD	20	increase (LVO/LVSF)	168±42	1.01±0.23
van Vonderen [11], 2014	term	CS	24	increase (LVO/LVSF)	151±47	1.0±0.3
van Vonderen [12], 2014	term	CS	24	increase (LVO/LtoR shunting)	161±50	–

CS = Cesarean section; VD = vaginal delivery; LtoR = left-to-right shunting via the ductus arteriosus.

air in preterm neonates, had a similar effect on HR with a rising tendency [17]. Kopotic and Lindner [16] reported similar observations during resuscitation with 100% oxygen in a small number of extremely preterm neonates.

Several studies have compared HR monitoring using electrocardiography (ECG) with pulse oximetry and reported very good accuracy between ECG with pulse oximetry [14]. However, it has been reported that ECG placement can be applied more quickly compared to pulse oximetry [30].

An increase of HR during the first minutes after birth was observed in several studies in neonates without any need of medical support [19, 22] as well as in neonates with respiratory support [17, 18]. Three studies reported different findings concerning the course of HR: Toth et al. [15] and Noori et al. [20] described a decreasing tendency of HR in vaginally delivered newborn infants without any medical support, and van Vonderen et al. [11, 12] reported in two separate studies no significant change of HR (measured by applying electrodes) in the first 10 min in term newborn infants. This has led to the development of reference ranges describing HR in healthy term and late-preterm (>32 weeks' gestation) neonates without the need of any medical support in the first 10 min [19]. After midwifery-supervised uncomplicated vaginal birth, healthy neonates had significant lower values of HR and slower increase of HR in the first 3 min after birth compared to the international defined reference ranges [21].

Blood Pressure

BP is a composite of cardiac function and peripheral circulation as determined by cardiac output (CO) and systemic vascular resistance, respectively, and is therefore an important indicator of appropriate circulation. Recently, the reference ranges of BP in preterm and term neonates during the immediate transition have been established [26]. Further studies have reported comparable values of BP changes during the immediate transition period in term infants without any need of medical support [11, 23–25]. BP values have been described to be lower in preterm infants compared to term infants and increase with increased gestational age [24, 26]. Neonates after vaginal birth had significantly higher BP values compared to neonates born via caesarean section [23, 24, 26]. In addition, female neonates had higher mean systolic BP compared to male neonates [24]. Neonates recovering from asphyxia, exposed to maternal antihypertensive therapy and those born to

mothers receiving thiopental within 4 min prior to delivery showed decreased BP, suggesting neonatal cardiocirculatory impairment immediately after birth [23].

Invasive BP measurement is not feasible during the immediate transition period and resuscitation. Therefore, the Doppler ultrasound and oscillometric method represent possibilities to measure BP noninvasively, whereby the oscillometric method is easier to apply than the Doppler ultrasound.

Cardiac Function

Stroke volume determines HR and cardiac output at bedside. In term neonates, three studies reported an increase in LVO and left ventricular stroke volume (LVSV) within the first 10 min [11, 12, 20]. Winberg et al. [25] reported higher LVO and LVSV at 15 min after birth in 16 term neonates delivered by caesarean section compared to vaginally born neonates. Two other recent studies reported that LVO and LVSV have similar patterns of increase in neonates born either vaginally or via caesarean section [11, 20]. However, the reported difference in LVO and LVSV might be explained by the use of different techniques between the studies. In addition, shunting through a persistent ductus arteriosus has been described, becoming increasingly more left to right during the first 10 min after birth [12, 20].

Limitations

Evaluation of HR during immediate transition is recommended and already used to guide resuscitation. Pulse oximetry besides ECG is a noninvasive and continuous method to monitor the HR during immediate transition. It has been shown that ECG gets reliable signals more quickly than pulse oximetry [30]; however, applying ECG would be a further maneuver during neonatal resuscitation since the monitoring of SpO₂ by applying pulse oximetry is already recommended in the latest resuscitation guidelines [6–8], and it provides continuous monitoring of both SpO₂ and HR. Nevertheless, when using pulse oximetry, clinicians have to be aware of possible artefacts due to movements and manipulation.

Measuring BP noninvasively with the Doppler ultrasound as well as with the oscillometric method is absolutely feasible during neonatal transition, but the use of BP monitoring is limited due to the inability to measure BP continuously. Although these two methods measured comparable values of BP, the oscillometric method is eas-

ier to apply and therefore the practicability of the oscillometric method would be higher in the delivery room management setting.

Echocardiography has the ability to noninvasively measure cardiac functions during the immediate fetal-to-neonatal transition. However, the use of echocardiography is limited due to (1) inability to measure cardiac function continuously, (2) dependence on ability and experience of the examiner, (3) parameters need to be defined prior measurements to limit time on echocardiography and not to interfere with resuscitation procedures, and (4) currently no reference values during immediate transition period are available.

Conclusion

Cardiocirculatory monitoring provides additional information and might be helpful to guide further hemodynamic management in the future. Ideally, cardiocirculatory monitoring should be noninvasive and provide reliable data continuously. Currently, noninvasive monitoring is routinely used to measure HR continuously during the immediate neonatal transition. New technologies of continuously measuring BP and cardiac function noninvasively might offer further insights in cardiovascular transition in the future.

In order to optimize the oxygen supply and to guide oxygen therapy, pulse oximetry is recommended in neonatal resuscitation guidelines. Although pulse oximetry and ECG enables monitoring HR continuously, it does not always provide information about potentially compromised cardiocirculatory status influencing oxygen transport to tissue.

Measuring BP noninvasively though noncontinuously might be of some value in the future, considering that reference ranges have recently been established.

Echocardiographic monitoring during the immediate transition period will improve knowledge about cardiac function changes, but introduction in clinical routine remains questionable.

Disclosure Statement

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Appendix 1

Search strategy for PubMed: last performed July 8, 2014

No limits activated

#1	MeSH descriptor newborn explode all trees (result: 619,194)
#2	MeSH descriptor infant explode all trees (result: 977,013)
#3	MeSH descriptor neonate explode all trees (result: 511,862)
#4	((#1) OR #2) OR #3 (result: 1,098,441)
#5	MeSH descriptor after birth explode all trees (result: 83,120)
#6	MeSH descriptor transition explode all trees (result: 203,179)
#7	MeSH descriptor delivery room explode all trees (result: 6,857)
#8	((#5) OR #6) OR #7 (result: 291,327)
#9	MeSH descriptor heart explode all trees (result: 1,144,844)
#10	MeSH descriptor cardiac explode all trees (result: 1,339,030)
#11	MeSH descriptor circulation explode all trees (result: 363,881)
#12	MeSH descriptor hemodynamic explode all trees (result: 615,227)
#13	MeSH descriptor blood pressure explode all trees (result: 502,516)
#14	(((((#9) OR #10) OR #11) OR #12 OR) #13 (result: 1,962,768)
#15	MeSH descriptor monitoring explode all trees (result: 434,378)
#16	MeSH descriptor measurement explode all trees (result: 454,193)
#17	MeSH descriptor echocardiography explode all trees (result: 130,574)
#18	MeSH descriptor electrocardiography explode all trees (result: 180,047)
#19	MeSH descriptor ultrasonography explode all trees (result: 357,199)
#20	MeSH descriptor pulse oximetry explode all trees (result: 14,814)
#21	(((((#15) OR #16) OR #17) OR #18) OR #19) OR #20 (result: 1,352,440)
#22	((((#4) AND #8) AND #14) AND #21 (result: 1,839)

Appendix 2

Search strategy for Ovid Embase: last performed July 8, 2014

No limits activated	
#1	Newborn mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 359,885)
#2	Infants mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 172,020)
#3	Neonate mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 24,888)
#4	(#1 or #2 or #3) (result: 466,997)
#5	After birth mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 29,102)
#6	Transition mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 226,130)
#7	Delivery room mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 2,454)
#8	(#5 or #6 or #7) (result: 256,926)
#9	Heart mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 1,333,957)
#10	Cardiac mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 498,642)
#11	Circulation mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 156,431)
#12	Blood pressure mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 331,179)
#13	Hemodynamic mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 95,108)
#14	(#9 or #10 or #11 or #12 or #13) (result: 1,729,833)
#15	Monitoring mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 539,028)
#16	Measurement mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 511,899)
#17	Echocardiography mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 198,620)
#18	Electrocardiography mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 71,786)
#19	Pulse oximetry mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 10,415)
#20	Ultrasonography mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword] (result: 94,036)
#21	(#15 or #16 or #17 or #18 or #19 or #20) (result: 1,300,097)
#22	(#4 and #8 and #14 and #21) (result: 950)

References

- Rudolph AM: Fetal and neonatal pulmonary circulation. *Annu Rev Physiol* 1979;41:383–395.
- Noori S, Stavroudis TA, Seri I: Systemic and cerebral hemodynamics during the transitional period after premature birth. *Clin Perinatol* 2009;36:723–736, v.
- Apgar V: A proposal for a new method of evaluation of the newborn infant. *Curr Res Anesth Analg* 1953;32:260–267.
- O'Donnell CP, Kamlin CO, Davis PG, Carlin JB, Morley CJ: Clinical assessment of infant colour at delivery. *Arch Dis Child Fetal Neonatal Ed* 2007;92:F465–F467.
- O'Donnell CP, Kamlin CO, Davis PG, Carlin JB, Morley CJ: Interobserver variability of the 5-minute Apgar score. *J Pediatr* 2006;149:486–489.
- Richmond S, Wyllie J: European Resuscitation Council Guidelines for Resuscitation 2010 Section 7. Resuscitation of babies at birth. *Resuscitation* 2010;81:1389–1399.
- Kattwinkel J, Perlman JM, Aziz K, Colby C, Fairchild K, Gallagher J, Hazinski MF, Halamek LP, Kumar P, Little G, McGowan JE, Nightengale B, Ramirez MM, Ringer S, Simon WM, Weiner GM, Wyckoff M, Zaichkin J: Part 15: neonatal resuscitation: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation* 2010;122:S909–S919.
- Wyllie J, Perlman JM, Kattwinkel J, Atkins DL, Chameides L, Goldsmith JP, Guinsburg R, Hazinski MF, Morley C, Richmond S, Simon WM, Singhal N, Szlyd E, Tamura M, Velaphi S; Neonatal Resuscitation Chapter Collaborators: Part 11: neonatal resuscitation: 2010 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations. *Resuscitation* 2010;81(suppl 1):e260–e287.
- Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group: Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Int J Surg* 2010;8:336–341.
- Brady JP, James LS: Heart rate changes in the fetus and newborn infant during labor, delivery, and the immediate neonatal period. *Am J Obstet Gynecol* 1962;84:1–12.
- van Vonderen JJ, Roest AA, Siew ML, Blom NA, van Lith JM, Walther FJ, Hooper SB, Te Pas AB: Noninvasive measurements of hemodynamic transition directly after birth. *Pediatr Res* 2014;75:448–452.
- van Vonderen JJ, Te Pas AB, Kolster-Bijdevaate C, van Lith JM, Blom NA, Hooper SB, Roest AA: Non-invasive measurements of ductus arteriosus flow directly after birth. *Arch Dis Child Fetal Neonatal Ed* 2014;99:F408–F412.
- Meier-Stauss P, Bucher HU, Hurlimann R, Konig V, Huch R: Pulse oximetry used for documenting oxygen saturation and right-to-left shunting immediately after birth. *Eur J Pediatr* 1990;149:851–855.
- Kamlin CO, Dawson JA, O'Donnell CP, Morley CJ, Donath SM, Sekhon J, Davis PG: Accuracy of pulse oximetry measurement of heart rate of newborn infants in the delivery room. *J Pediatr* 2008;152:756–760.
- Toth B, Becker A, Seelbach-Gobel B: Oxygen saturation in healthy newborn infants immediately after birth measured by pulse oximetry. *Arch Gynecol Obstet* 2002;266:105–107.
- Kopotic RJ, Lindner W: Assessing high-risk infants in the delivery room with pulse oximetry. *Anesth Analg* 2002;94:S31–S36.
- Dawson JA, Kamlin CO, Wong C, Te Pas AB, O'Donnell CP, Donath SM, Davis PG, Morley CJ: Oxygen saturation and heart rate during delivery room resuscitation of infants <30 weeks' gestation with air or 100% oxygen. *Arch Dis Child Fetal Neonatal Ed* 2009;94:F87–F91.
- Gonzales GF, Salirrosas A: Pulse oxygen saturation and neurologic assessment in human neonates after vaginal and cesarean delivery. *Int J Gynaecol Obstet* 1998;63:63–66.
- Dawson JA, Kamlin COF, Wong C, Te Pas AB, Vento M, Cole TJ, Donath SM, Hooper SB, Davis PG, Morley CJ: Changes in heart rate in the first minutes after birth. *Arch Dis Child Fetal Neonatal Ed* 2010;95:F177–F181.
- Noori S, Wlodaver A, Gottipati V, McCoy M, Schultz D, Escobedo M: Transitional changes in cardiac and cerebral hemodynamics in term neonates at birth. *J Pediatr* 2012;160:943–948.
- Smit M, Dawson JA, Ganzeboom A, Hooper SB, van Roosmalen J, Te Pas AB: Pulse oximetry in newborns with delayed cord clamping and immediate skin-to-skin contact. *Arch Dis Child Fetal Neonatal Ed* 2014;99:F309–F314.
- Bustos R, Bejar R, Arroyave H, Jacomo AJ, Burghi M, Ramirez F, Cordano MC, Curbelo V, Guayasamin O, Minetti R, Guemberena L, Caldeyro-Barcia R: Heart rate in fetuses and neonates in normal conditions and with mild depression. *J Perinat Med* 1975;3:172–179.
- Marx GF, Cabe CM, Kim YI, Eidelman AI: Neonatal blood pressures. *Anaesthesist* 1976;25:318–322.
- Salihoglu O, Can E, Beskardes A, Koc BS, LhanTan I, Can G, Hatipoglu S: Delivery room blood pressure percentiles of healthy, singleton, liveborn neonates. *Pediatr Int* 2012;54:182–189.
- Winberg P, Jansson M, Marions L, Lundell BP: Left ventricular output during postnatal circulatory adaptation in healthy infants born at full term. *Arch Dis Child* 1989;64:1374–1378.
- Pichler G, Cheung PY, Binder C, O'Reilly M, Schwaberg B, Aziz K, Urlesberger B, Schmolzer GM: Blood pressure in term and preterm infants immediately after birth. *Abstract E-PAS* 2014:4655.4.
- Bhatt S, Alison BJ, Wallace EM, Crossley KJ, Gill AW, Kluckow M, Te Pas AB, Morley CJ, Polglase GR, Hooper SB: Delaying cord clamping until ventilation onset improves cardiovascular function at birth in preterm lambs. *J Physiol* 2013;591:2113–2126.
- Yam CH, Dawson JA, Schmolzer GM, Morley CJ, Davis PG: Heart rate changes during resuscitation of newly born infants <30 weeks gestation: An observational study. *Arch Dis Child Fetal Neonatal Ed* 2011;96:F102–F107.
- Palme-Kilander C, Tunell R: Pulmonary gas exchange during facemask ventilation immediately after birth. *Arch Dis Child* 1993;68:11–16.
- Katheria A, Rich W, Finer N: Electrocardiogram provides a continuous heart rate faster than oximetry during neonatal resuscitation. *Pediatrics* 2012;130:e1177–e1181.