The Delivery Room of the Future

The Fetal and Neonatal Resuscitation and Transition Suite

Neil N. Finer, MD[a,*], Wade Rich, RRT, CCRC[a],
Louis P. Halamek, MD, FAAP[b], Tina A. Leone, MD[c]

KEYWORDS

• Delivery room • Fetal-neonatal resuscitation and transition suite • Human factors
• Human performance • Neonatal resuscitation • Resuscitation room

KEY POINTS

- Adequate space for all members to operate during complex resuscitations must be provided to the neonatal resuscitation team.
- Current technology allows for the generation of multiple streams of real-time physiologic data during neonatal resuscitation.
- Raw physiologic data must be translated into coherent interpretable information to be useful during resuscitation.
- Human factors analysis will play an increasingly important role in the design and testing of the devices and techniques used to conduct safe, effective, and efficient resuscitation of the newborn.

INTRODUCTION

Compare a contemporary neonatal ICU (NICU) with one from the 1970s. Present-day NICUs are filled with modern technology, consisting of radiant warmers that become incubators with the flip of a switch, servo-controlled ventilators capable of measuring

---

Financial Disclosures: Dr. Halamek is a consultant to Laerdal Medical, Inc.
Conflicts: There are no conflicts of interest to report.
Dr Halamek's effort was sponsored in part by the Endowment for the Center for Advanced Pediatric and Perinatal Education at Packard Children's Hospital at Stanford.
[a] Division of Neonatology, Department of Pediatrics, UC San Diego Medical Center, UC San Diego School of Medicine, 402 Dickinson Street, MPF 1-140, San Diego, CA 92103, USA; [b] Fellowship Training Program in Neonatal-Perinatal Medicine, Division of Neonatal and Developmental Medicine, Department of Pediatrics, Center for Advanced Pediatric and Perinatal Education, Stanford University School of Medicine, 750 Welch Road, Suite 315, Palo Alto, CA, USA; [c] Neonatal-Perinatal Medicine Training Program, UC San Diego Medical Center, UC San Diego School of Medicine, 402 Dickinson Street, MPF 1-140, San Diego, CA 92103, USA
* Corresponding author.
E-mail address: nfiner@ucsd.edu

Clin Perinatol 39 (2012) 931–939
http://dx.doi.org/10.1016/j.clp.2012.09.014 **perinatology.theclinics.com**
0095-5108/12/$ – see front matter

tiny tidal volumes and displaying that information continuously at the bedside, intravenous pumps that accurately deliver miniscule doses of powerful medications, monitors with multiple color-coded real-time data streams that also store hours and days worth of information, communication systems that allow immediate discussion between bedside staff and neonatologists, and video cameras that allow parents to view their newborn via the Internet 24 hours per day.

Now think about a “modern” delivery room (DR). Most DRs are designed around the welfare of the pregnant patient and the comfort of the health care professionals (HCPs) making up the obstetric team. There may or may not be sufficient space dedicated to resuscitation of the newborn; in some DRs resuscitations are performed within a few feet of the mother. Not only is the amount of space typically restricted, so is the amount and quality of the technology that is consigned to the newborn. In many ways, the neonatal team continues to be limited to the same tools (their eyes, ears, and hands) that they have used for decades. The technology available in DRs has changed very little over the last 20 years. Individual centers have developed sophisticated monitoring systems[1,2] but, in general, with the exception of a pulse oximeter, the DRs in most hospitals today look very much like they did before the surfactant era, functioning as little more than a repository for aging equipment from the NICU. Published reviews have found significant variability in what types of equipment are used worldwide.[3–5] In addition, despite the current era of ever-increasing facilitated communication, the DR often remains an isolated venue.

The authors’ vision for the Fetal and Neonatal Resuscitation and Transition Suite of the future involves the development of user-friendly, highly interactive monitors and other devices characterized by artificial intelligence to guide decision-making; efficient modular warming environments; improved systemic communication abilities; audiovisual recording systems capable of generating high-definition video of every resuscitation; and well-trained, highly competent HCPs who actively participate in regular debriefings and maintain their cognitive, technical and behavioral skills through highly realistic simulations that involve all members of their multidisciplinary team.

Let us first examine the physical space where most newborns are resuscitated. Some institutions use “pass-through” windows that allow for resuscitation and stabilization of infants to occur in the NICU. Most delivery hospitals use a corner of the actual DR, and a few (about 15%) have a dedicated resuscitation room.[5] Basic requirements for a resuscitation room include the following: the ability to control the temperature of the room independent of the room where the mother is cared for so that it can be increased as needed to maintain normothermia in even the most immature infants, sufficient space to house the equipment and supplies needed for multiple births and accommodate up to three adult HCPs at each bedside, adjustable lighting, electrical and gas (air and oxygen) outlets, and the capability for both storage of continuous data streams on secure servers and wireless transmission of that same data including all monitor and video signals. The room should also have a hands-free phone or similar communication device as an aid to immediately and easily summon assistance, and all communications should be remotely monitored from a central communication station in the NICU to allow for complete two-way communication and enhanced situational awareness by NICU staff of the events taking place in the resuscitation room.

Proper therapy for the newborn in transition requires an understanding of the patient’s dynamic physiology. Parameters that should be readily available include the ECG, pulse oximetry (SPO2), end-tidal carbon dioxide, tidal volume, co-oximetry with hemoglobin measuring capability, patient temperature, room temperature, and time. The capability to measure cerebral oxygen delivery and consumption is also important and will become standard of care in the near future. In addition such a room in a tertiary or quaternary facility should be equipped with dedicated portable cardiac and general purpose ultrasound machines replete with a variety of transducers, a transilluminator, and a built-in portable radiograph machine with an extendable arm. A video-laryngoscope and bronchoscope should also be available with all video capable of being displayed on a large flat-panel display in full view of the resuscitation team. A central monitor programmed to record and store all of the parameters noted previously and display selected trends should be placed in a location easily visible by all members of the resuscitation team. There should be at least one overhead high-definition video camera to record team activity; this video feed should be integrated into the data stream that is displayed on the central monitor. The current resuscitation-transition room at the University of California San Diego Medical Center (UCSD) already has the capability of providing almost all of the above functionality. In addition, at UCSD, portable ultrasound is used in the resuscitation room for a variety of situations, including diagnosis of congenital cardiac disease, detection of air (pneumothoraces) and fluid (ascites) accumulations, and confirmation of proper tube and line placements.

Transition from the intrauterine environment to the DR radiant warmer during resuscitation and then to the transport unit for transfer to the NICU after stabilization involves a significant amount of connecting and disconnecting of sensors, cables, tubes, and lines. In addition to being a very inefficient use of time, this process creates multiple opportunities for potentially serious errors. This could be greatly simplified by the use of a “pod” that can be moved from the DR radiant warmer to the transport unit, then to the bed in the NICU, by simply sliding it out of one bed and into another. This type of device is currently used to transfer infants from an incubator to an MRI scanner without ever actually being removed from the incubator section of the transport unit and for air transport where space is severely limited and cannot accommodate a full-size incubator. To eliminate this inefficient and unsafe aspect of patient transport, a docking module that is intrinsic to the pod easily and quickly links to a receptacle in the radiant warmer or incubator, and incorporates all of the wires and tubes conveying the electrical signals from the leads and probes on the patient to all of the monitors and monitors, infusions from pumps to the intravenous lines placed within the patient, and any other devices as needed.

NICUs are replete with visual and auditory cues to alert HCPs to changes in patient status. Much of the monitoring equipment currently available does not function well during the transition from fetus to neonate in the first minutes of life and, as a result, those caring for newborns are often forced to silence those alarms in the DR. The Fetal and Neonatal Resuscitation and Transition Suite of the future will include devices that integrate physiologic data obtained from standard patient monitors with a resuscitation timeline to provide real-time cues to the members of the resuscitation team, thereby enhancing the timeliness and appropriateness of their interventions. Ideally, this system will be small, inexpensive, and easily installed in any area where newborn resuscitation takes place. Of course such a system should not be seen as a replacement for human intelligence and critical thinking during resuscitation. Any data that elicit a prompt for action would need to be confirmed as accurate before team members intervene based on the prompt.

Recommendations for the monitoring of infants at birth are moving from rudimentary methods based on direct clinical examination that have been found to be subjective and inaccurate[6,7] to more direct physiologic measurements using devices similar to those in the NICU. This requires an environment with dedicated wiring to secure data servers that securely store video, analog, and digital data from multiple systems in multiple rooms. Monitors should be specifically designed and purpose-built for such an environment. This will necessitate innovations in alarm algorithms that are appropriate for the

DR environment, such as automatic alarm silencing during the first minute and dynamic alarm limits for parameters that change over time, such as SPO2 values during the first 10 minutes of life. As an example of this type of innovative design, the Transitional Oxygen Targeting System (TOTS) has been developed at UCSD based on the work of Dawson and colleagues[8] (**Fig. 1**). TOTS generates a graphic display of prespecified high and low hemoglobin oxygen saturation limits, as well as a real-time display of hemoglobin oxygen saturation and administered supplemental oxygen values to assist resuscitation team members by providing them with a visual indicator of the effectiveness of their resuscitative efforts. Currently this system is capable of simply displaying the patient's SPO2 against the curves indicating high and low acceptable values. To more easily determine whether the SPO2 is within the target range, additional cues such as variable loudness, pitch, brightness, and color will need to be incorporated. Similarly, the heart rate alarm might be programmed to automatically silence for rates less than 60 beats per minute in the first 60 seconds, with the limits and the alarm volume gradually increasing over time based on normative data curves.[9]

As the number and type of monitoring devices in the DR increase, the need to incorporate all of this information into a single display that is visible to the entire team and is easily and quickly understood becomes critical. A flat-screen monitor mounted on the visual center of the radiant warmer provides enough surface area to effectively display SPO2 normative curves (as in TOTS), ECG, temperature, and time (**Fig. 2**). Multiparameter bedside monitors may be modified for this purpose or multichannel analog data acquisition systems can be interfaced to a standalone computer to generate the same tracings. During review sessions at UCSD, six channels of analog data are displayed as indicated in **Fig. 3**. The integration of these parameters onto a single display screen facilitates pattern recognition of not only current events but also trends over time.

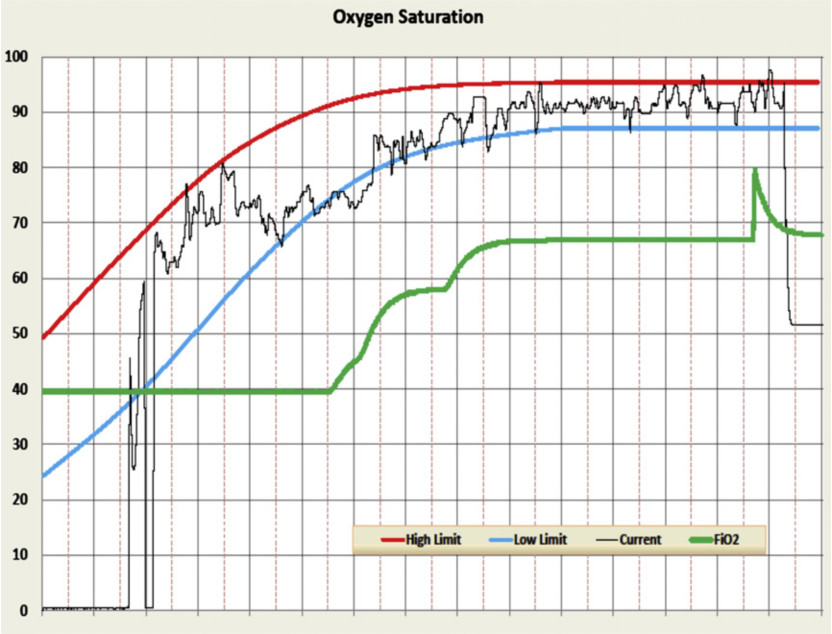

Fig. 1. The Transitional Oxygen Targeting System (TOTS) developed at UCSD.

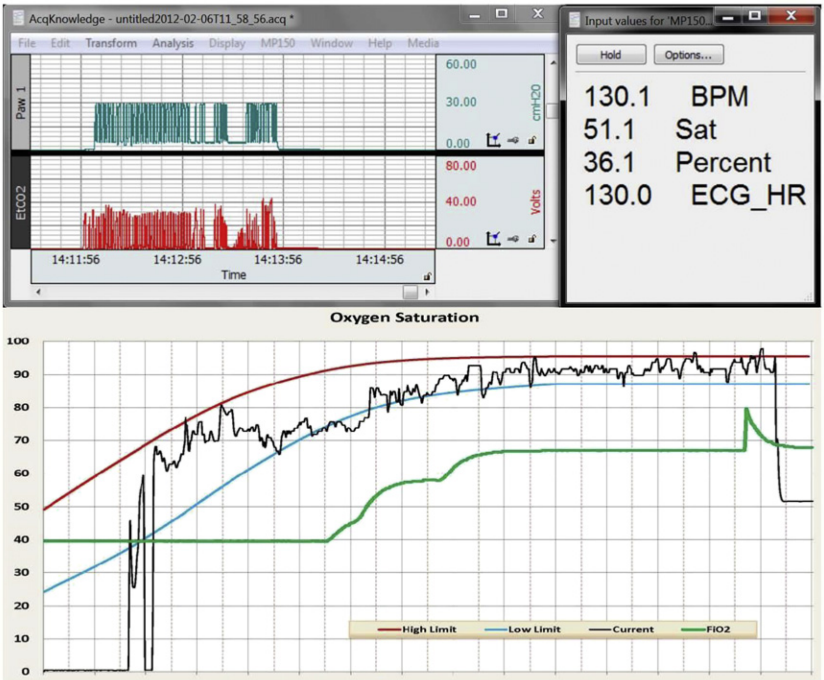

Fig. 2. Flat-screen monitor display of SaO2 normative curves (bottom, as in TOTS), airway pressure, end tidal CO2 graphic display (top left), ECG, pulse rate from oximeter, SpO2, percent inspired oxygen and ECG derived HR. Digital display (top right).

An area requiring intense investigation is the application of human factors engineering to patient monitoring.[10–12] Patient data must be presented in a manner in which it can be easily detected, assimilated, interpreted, and acted on. Therefore, one cannot simply study just the patient or just the technology, but also must critically examine how the human beings responsible for delivering care to the patients interface with that technology.[13] The design of patient monitors, specifically the display parameters and alarms, is a critical element in enabling HCPs to recognize and respond to abnormalities and changes in patient physiology. Simply providing more data will not necessarily translate into more useful information. What patient data are best recognized as a numerical display versus a waveform? What sizes, colors, and fonts of the numbers and what widths, textures, and hues of the waveforms produce optimal human performance? The same types of questions need to be asked of alarms and prompts. What is the ideal pitch and volume of an alarm that will allow it to grab the attention of those at the bedside most quickly? Should the pitch and volume vary over time or in response to changes in the physiologic variables themselves? Should prompts consist of visual or auditory cues? For those prompts that are best delivered via visual cues, what sizes and colors facilitate the most effective response by the members of the resuscitation team? For those prompts that are found to be optimally delivered by auditory cues, should mechanical tones or voice prompts be used? If tones are used, what is the best pitch and volume? If voice prompts are indicated, should the voice be male, female, or synthetic? Another key question involves the number of data points, data streams, and prompts that can be accurately processed by human beings working under the time pressure inherent in resuscitation.

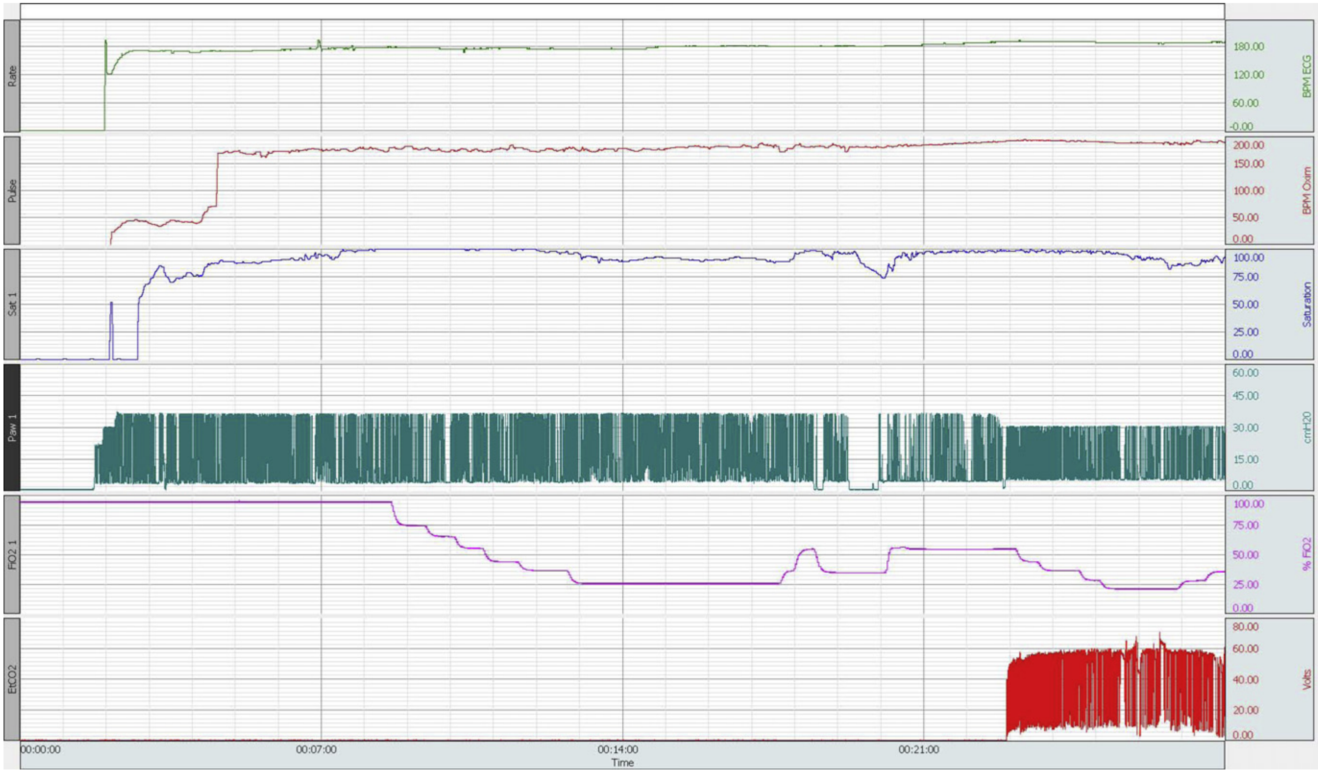

Fig. 3. Analog tracing of heart rate, pulse, hemoglobin oxygen saturation, airway pressure, fraction of inspired oxygen, and end-tidal carbon dioxide.

Thus, there are a tremendous number of questions to be answered to design the ideal monitoring technology for use during newborn resuscitation.

Communication among members of the resuscitation team is an element of performance that is critical to good patient outcomes. Communication at the bedside is primarily verbal, although nonverbal communication, in terms of hand signals, nods, and eye movements, also plays a role. Currently there is no standard methodology by which resuscitation team members communicate. The authors believe that a standardized, validated lexicon should be developed for resuscitation situations in health care; the system used in the commercial aviation industry for succinct transmission of information between aircraft crews and air traffic controllers is a suitable model for this purpose. In addition to the communication occurring among resuscitation team members in the DR, direct auditory and visual communication between those in the DR and the NICU will ensure that the NICU team is fully prepared for the eventual transport and arrival of the patient.

Selection and training of the human beings who make up the neonatal resuscitation team and who will be required to function at a high level in this intense environment will need also to be modeled after the type of training used in other industries in which there is substantial risk to human life. In most of these industries, frequent objective

Box 1
Steps in the initial selection and ongoing training of resuscitation team members at LPCH and CAPE

Step 1: Base appointment to the neonatal resuscitation team on performance

- Number of team members and team composition to be determined by NICU leadership
- Selection to team based on performance, experience, and motivation
- All team members must meet objective performance markers
- Experience and motivation will be critically evaluated

Step 2: Train resuscitation team members to the highest standards

- Undergo highly realistic simulation-based multidisciplinary team training in the management of challenging DR resuscitation situations, such as extreme prematurity, multiple gestation, multiple congenital anomalies, hydrops fetalis, congenital heart block, pneumothorax, ascites, death in the DR, initiation of comfort care, and so forth
- Participate in regular drills conducted in labor and delivery in collaboration with obstetric team members to enhance communication skill in intense, dynamic, and time-pressured situations
- Participate in constructive, objective debriefings of all simulation-based activities

Step 3: Record and debrief real resuscitations

- Record all challenging resuscitations
- Constructively and objectively debrief actual resuscitations in a manner that is protected under the appropriate state code of evidence

Step 4: Using data from real resuscitations, simulate areas of weakness

- Integrate these specific simulations into regular drills

Step 5: Evaluate effect of these interventions on safety, quality, and risk outcomes

- Facilitate active communication and collaboration among those delivering care, those responsible for training and simulation, and the professionals in the departments of patient safety, quality assurance, and risk management

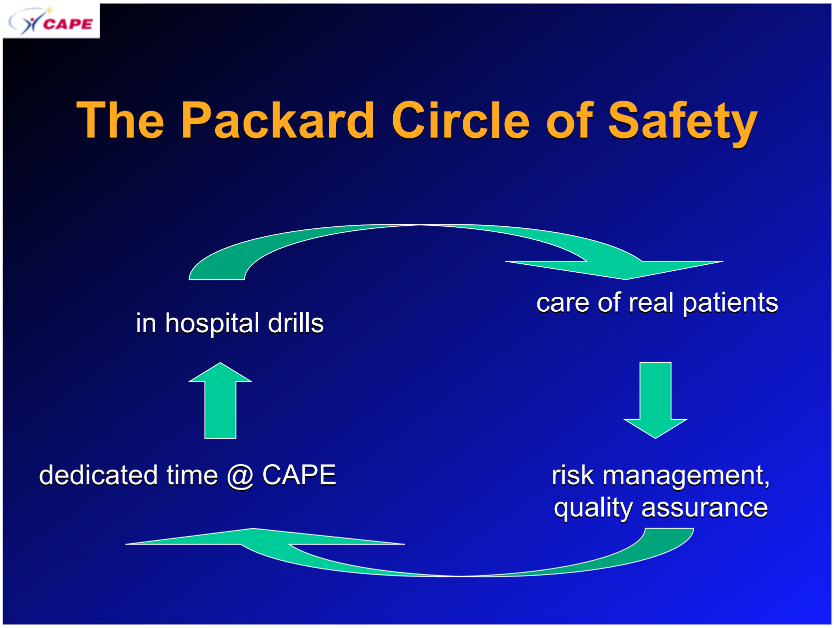

Fig. 4. The Packard Circle of Safety, a method for linking safety and simulation to address system and human weaknesses and improve the safety, effectiveness, and efficiency of patient care.

assessment and ongoing simulation-based learning is the standard for acquisition and maintenance of skill. Selection of the "best" and ensuring their ongoing optimal level of performance requires a comprehensive approach (**Box 1**). Resuscitation team members should be selected to and retained on the team based on objective performance criteria. Simulation-based learning should be an integral component of their initial preparation, as well as their ongoing learning. This should be complemented with regular review of their performance during real resuscitations so that any weaknesses can be readily identified and addressed. Such reviews should consist of objective, constructive, confidential debriefings of videos of their activities in the DR. The coupling of detailed reviews of real-life performance with simulations designed to address the weaknesses discovered from such reviews will provide the opportunity to enhance patient safety in a manner that is highly effective. This is the process that is being implemented at the Center for Advanced Pediatric and Perinatal Education (CAPE) and Lucile Packard Children's Hospital (LPCH) at Stanford (**Fig. 4**).

SUMMARY

The Fetal and Neonatal Resuscitation and Transition Suite of the future will be marked by several innovations in the design and standardization of the physical space and the monitoring and communication technologies that will facilitate optimal human performance in that domain. Although the patient will continue to be at the center of this process, increasing attention will be devoted to analysis of this environment from a human factors viewpoint, addressing ways in which to enhance the acquisition, maintenance, and application of the cognitive, technical, and behavioral skills of the members of the resuscitation team.

REFERENCES

1. Carbine DN, Finer NN, Knodel E, et al. Video recording as a means of evaluating neonatal resuscitation performance. Pediatrics 2000;106(4):654–8.
2. Schmolzer GM, Kamlin OC, Dawson JA, et al. Respiratory monitoring of neonatal resuscitation. Arch Dis Child Fetal Neonatal Ed 2010;95(4):F295–303.
3. Mitchell A, Niday P, Boulton J, et al. A prospective clinical audit of neonatal resuscitation practices in Canada. Adv Neonatal Care 2002;2(6):316–26.
4. Trevisanuto D, Doglioni N, Ferrarese P, et al. Neonatal resuscitation of extremely low birthweight infants: a survey of practice in Italy. Arch Dis Child Fetal Neonatal Ed 2006;91(2):F123–4.
5. Leone TA, Rich W, Finer NN. A survey of delivery room resuscitation practices in the United States. Pediatrics 2006;117(2):e164–75.
6. O'Donnell CP, Kamlin CO, Davis PG, et al. Clinical assessment of infant colour at delivery. Arch Dis Child Fetal Neonatal Ed 2007;92(6):F465–7.
7. Voogdt KG, Morrison AC, Wood FE, et al. A randomised, simulated study assessing auscultation of heart rate at birth. Resuscitation 2010;81(8):1000–3.
8. Dawson JA, Kamlin OF, Vento M, et al. Defining the reference range for oxygen saturation for infants after birth. Pediatrics 2010;125:e1340–7.
9. Dawson JA, Kamlin CO, Wong C, et al. 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(2):F87–91.
10. Walsh T, Beatty PC. Human factors errors and patient monitoring. Physiol Meas 2002;23:R111–32.
11. Gosbee J. Human factors engineering and patient safety. Qual Saf Health Care 2002;11:352–4.
12. Gawron VJ, Drury CG, Fairbanks RJ, et al. Medical error and human factors engineering: where are we now? Am J Med Qual 2006;21:57–67.
13. Hunt EA, Nelson KL, Shilkofski NA. Simulation in medicine: addressing patient safety and improving the interface between healthcare providers and medical technology. Biomed Instrum Technol 2006;40:399–404.