Instrumentation for the Detection and Interruption of Apnea Episodes for Premature Newborn

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Abstract— **Apnea of prematurity is very frequent in premature newborns (PNB). If the apnea episode is not interrupted in time, it can cause several damages to the newborn's central nervous system. In this paper, we introduce a novel technology for detecting apnea of prematurity episodes, based on cardiac pulse frequency (PF) and arterial oxygen saturation (SpO2) simultaneously, and using vibrotactile stimulation to interrupt such episodes. The thresholds of the newborns' PF and SpO2 had been established to identify the apnea episode automatically through the proposed system: for babies ≤ 35 weeks gestation, PF is ≤ 100 bpm and SpO2 ≤ 80%; for babies >35 weeks gestation, PF is ≤ 80 bpm and SpO2 ≤ 80%. The system used vibrotactile stimuli at 250 Hz for 4 s. To manage the system that activates the vibratory device automatically and registers those parameters, a program had been developed. It registers apnea occurrence, period of manual stimulation and vibratory stimulation duration. This technique was tested on 4 PNB. It was observed 10 apnea episodes and the device was successful in the detection of all of them. The vibrotactile stimulation was capable of promoting the return of respiratory movements in 9 of the 10 detected events of apnea and seemed to be a promising means of handling them.**

I. Introduction

Apnea episodes in premature newborns cause great concern and apprehension for the team of Neonatal Intensive Care Unit (NICU), considering that those episodes are disclosed, sometimes suddenly, occurring several times a day, and the intervention for interrupting them must be fast and efficient.

Premature newborns are babies who were born before 36.6 weeks' gestation [1]. Apnea of prematurity is defined as an unexplained and alarming episode of cessation of breathing for 20 s or more or a shorter respiratory pause associated to bradycardia, cyanosis and pallor [2]. Moreover, Cloherty and Stark state that a newborn's apnea trigger factor is the cerebral trunk neural function immaturity [1]. Then, due to his birth prematurity, the babies' sleepiness presents physiological and anatomical problems that can harm their development, among other consequences, apnea of prematurity [2].

Nowadays, the existing treatments for apnea episodes prevention or interruption in PNB are manual stimulation, medicine, positive-pressure application in airways and mechanical ventilation [3]. Its application requires sufficient human resources at the hospital, so that immediately the occurrence of apnea interruption of the episode takes place [4]. Manual stimulation is performed by gently touching the PNBs´ dorsal, legs and abdominal regions.

As negative factors for interrupting sleep apnea by manual stimulation, it can be cited: (1) risk of cross-contamination [5] and (2) production of equal or even higher levels of stress and pain sensation; whereas the simple manual stimulation can produce pain with excessive manipulation of those newborns in NICUs [6-7]. Moreover, this intervention depends effectively on human action, subjected to failure, negligence, malpractice, and aggravated by insufficient numbers of professionals attending PNBs in NICUs. These factors may delay the effective action to revert the apneic event, causing damage on the baby.

By the other side, a vibrotactile device [8] attached to the baby´s body could revert automatically apnea events and solve the described limitations of manual manipulation.

So, in this paper, it is presented and discussed a simple and novel biomedical instrumentation for detection and automatic reversion of premature newborns apnea episodes based on pulse frequency (PF) and arterial oxygen saturation (SpO_2) parameters simultaneously, and by the application of vibrotactile stimulation to revert such episodes.

II. Materials and Methods

A. Instrumentation

It was necessary the establishment of physiological variables and their thresholds for apnea diagnostics in order to define the techniques susceptible to be applied in the development of an instrumentation system for detection and reversion of apnea episodes. So, it was established pulse frequency and arterial oxygen saturation as essential parameters to trigger the reverting device, according to Gerhardt and Bancalari, Poets and Southall, Samuels et al., Poets et al., Pacific Nurse Practitioners, Darnall et al., Eichenwald et al., Di Fiore et al. [9-16], and according to three neonatologists from hospitals at Curitiba, Brazil. It was defined that cardiac pulse frequency and arterial oxygen saturation together and simultaneously could discriminate

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apnea episodes in premature newborns when reaching the following thresholds: for babies with less than 35 gestational weeks, pulse frequency of 100 bpm and arterial oxygen saturation equal to 80%. For babies with more than 35 gestational weeks, the pulse frequency of 80 bpm and the arterial oxygen saturation equal to 80%. Those thresholds were used to configure the apnea detection system.

The apnea episode detection and reversion system was named "Anjo" and it is composed by: Acer Notebook, model Travelmate 210 TXR, Celeron 700 Processor; Nellcor 595 Oxymeter; VBW32 Skin Transducer Vibrator by Audiological Engineering; a program developed in LabView platform (National Instruments®) to manage the whole system; and an electronic circuitry with optical isolation.

Fig. 1 illustrates the functional diagram of the apnea detection and reversion set up. It operates as follows:

(1) the oxymeter sensor acquires signal from the newborn baby using PF and SpO2 optical transducer;

(2) the oxymeter processes those signals, presents them numerically on the display panel and sends the information provided from the newborn via serial RS-232 interface to the computer;

(3) the computer receives the pulse frequency and arterial oxygen saturation information in a digital format; it treats them through a program that manages the vibrator activation as well as the oxygen saturation and pulse frequency values during the application;

(4) if the baby´s oxygen saturation and pulse frequency apnea reaches the thresholds established for the apparatus, the computer sends an electrical pulse, passing through the electrical isolator circuit;

(5) the mechanical vibrator receives the trigger pulse from the optical isolator and vibrates at 250 Hz for 4 s. The vibration occurs only if the parameters get on the configured value limits.

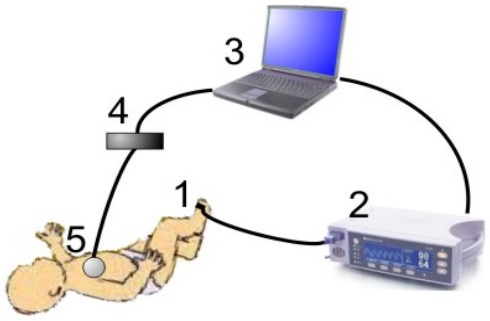

Figure 1. Functional diagram of apnea episode detection and reversion setup (1) oxymeter sensor; (2) oxymeter; (3) computer; (4) optical isolation; (5) vibrator.Example of a figure caption.

The developed software may perform three functional modes: (1) apnea detection mode, (2) vibration mode and (3) manual stimulation mode.

The detection module apnea aims to record the baby´s time of apnea before the manual stimulation. When activated, it inhibits the operation of the vibratory stimulation module.

The manual stimulation module is designed to generate a record of the time of manual stimulation in infants conducted by the health professional who works in the care of babies. When triggered, the system registers at each 2 s that the baby is receiving manual stimulation, and continues until the module is switched off manually.

In vibration module, the system detects the conditions supporting apnea, automatically triggers the vibrator and records the data as its configuration. The function that inhibits vibration can be adjusted at any time to prevent the vibratory stimulus occurs more than once, as the baby does not reach the physiological thresholds considered normal.

B. Experimental Protocol

There were adopted legal precautions for the application of this research in Intensive Care Units, attending resolution 196/96 of the National Council of Health, relating to research ethical aspects including human beings, approved by the Pontifical Catholic University of Paraná Ethical Committee under protocol n. 3049.

There have been developed two data collector tools. The first one collects relevant data to the identification, characteristics and particular details of the studied newborn baby. The second tool is created automatically by means of the program and registers baby's identification data, followed by PF and SpO_2 values registration every 2 s while the baby is being monitored. The generated archives were exported to Excel (Microsoft Corporation) for descriptive statistics calculation, graphics and tables.

The established criteria for the selection of babies were: both sex newborns, born with less than 36.6 weeks gestation, weight inferior to 2500g, no congenital anomalies, no cardiac disorders neither other associate pathology and non-drug-exposed babies during pregnancy.

After the baby selection, the researcher contacted their parents for explaining them the experimental research. There were observed four premature newborns.

The efficacy criteria for both of two used methods were the exact moment that accused spontaneous and regular breathing return and, as well as parameters of SpO2 $\geq$ 88% and cardiac frequency $\geq$ 100 bps. Those thresholds were based on Cloherty and Stark (pp. 372) [1].

The chose vibratory stimulation period was 4 s with frequency at 250 Hz and then 10 s of waiting time after the stimuli application for the returning of breathing movements. After that, if the apnea event had not ceased, the hospital clinical staff performed the standard procedure. It consisted of the stimulation of the premature newborn by rubbing the fingers gently on the diaphragmatic region, thorax (anterior or posterior), abdomen or feet of the newborn.

III. RESULTS

The developed system has three graphical interfaces:

Header, Configuration and Graphics. For each newborn, the first interface to be filled is that of the "Header", consisting of the file name for that PNB, the number of newborns in the study, the date of birth, gestational age and age group he belongs to. The system automatically populates the directory record and the date the experiment was performed. Fig. 2 illustrates the “Header” Interface.

Figure 2. "Header" interface for completing the data of the newborn.

In the "Setting" window are the fields to adjust the thresholds of SpO_2 and PF that the system uses to trigger: the vibrator, the alarm logs, the apnea register, the thresholds recording in non apneic state, the time of vibratory stimulation and the time of its inhibition. Fig. 3 shows the Configuration window.

Figure 3. "Setting" interface for filling the data that manage the system.

The "Graphics" interface, shown in Fig. 4, corresponds to the screen must be kept open during use. It is composed of visual indications for the occurrence of alarms for PF, SpO_2, or both, the occurrence of vibrotactile stimulus and whether it is being inhibited. It also presents two trend graphs which show the behavior of the parameters on a scale from 0 to 200 bpm for PF and 0 to 100% SpO_2.

The method of apnea episodes detection registered and detected successfully all the episodes in the four observed newborn babies.

In Fig. 5, as an example, we can observe the behavior of the pulse rate and oxygen saturation on PNB 1 before, during and after two vibratory stimuli applied and the parameters return to normal pulse rate and oxygen saturation, in the ascending phase.

The method of apnea episodes reversion using vibrotactile stimulation set in motion breathing movements in 9 of 10 episodes in the 4 observed newborns babies, as showed in Table I. In Table II, it is presented the mean period of time for the beginning of apnea and the triggering of vibrotactile stimuli, the duration of stimuli and the delay for returning of PNB1´s respiratory movements (RM).

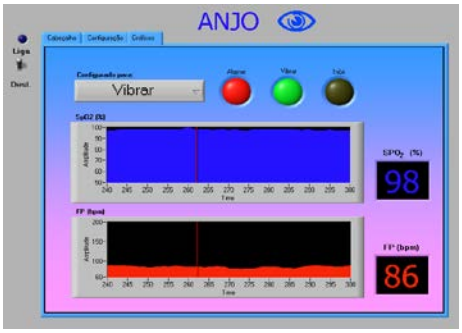

Figure 4. "Graphics" interface to monitor the newborn during the session.

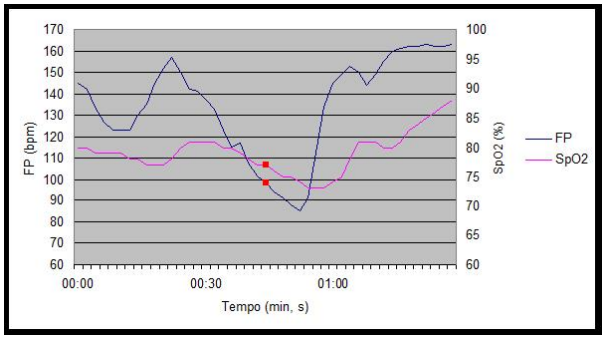

Figure 5. Behavior of the pulse frequency (FP) and oxygen saturation (SpO2) along the time (*Tempo*): before, during and after the second vibrotactile stimulus observed in PNB 1.

One possible explanation for the fact that only 50% of SpO_2 and PF values returned to normality in newborns who presented breathing movements after apnea termination as a result of the application of vibratory stimulus is airway obstruction, as reported by Dransfield et al. [17]. Another hypothesis, reported by Sharma, and Woldesenbet and Perlman is that the baby might be experiencing persistent pulmonary hypertension or cystic fibrosis, interstitial pneumonitis, among other congenital abnormalities [18,19].

IV. Conclusion

The method of apnea episode detection proved to be efficient in all newborn babies observed, detecting and registering all the presented apnea episodes. The application of the experimental protocol revealed that the proposed method is promising for apnea episode detections, since it was possible to detect and register all the presented apnea episodes. Meanwhile, it is a preliminary result and needs to be confirmed by a more representative group of individuals.

The method of apnea episodes reversion by vibrotactile stimulation using frequency at 250 Hz during 4 s was successful and seems to be a promising management form to cease the apnea of prematurity. It was possible stimulate the breathing movements in 9 of 10 apnea episodes presented in the 4 observed newborn babies.

TABLE I. EXPERIMENTAL PROTOCOL RESULTS USING VIBRATORY STIMULATION IN FOUR OBSERVED NEWBORN BABIES.

NEWBORN	Apnea treated with vibratory stimulation	Successful returning of breathing movements after vibratory stimulation	Successful returning of pulse frequency and oxygen saturation parameters after stimulation
1	2	2	2
2	1	1	1
3	2	2	1
4	5	4	1
Total	**10**	**9**	**5**

TABLE II. MEAN TIME FOR THE BEGINNING OF APNEA AND THE TRIGGERING OF VIBROTACTILE STIMULI, DURATION OF STIMULI AND THE RETURNING OF RESPIRATORY MOVEMENTS (RM) RN 1.

PNB 1	Type of stimulus	Stimuli duration mean time (s)	Mean time between the beginning of apnea and the starting of stimuli (s)	Mean time for MR´s returning after the end of stimuli application (s)
	Vibration	4	0	7
	Manual	4	0	4

The result was not conclusive. However, with a larger sample, it will be possible to prove statistically its efficacy. The developed method and system seem to be promising to control the apnea of prematurity, even with the small number of individuals involved in the research. We believe this technique may be extended to the management of several infantile apnea forms, such as those caused by infections, anemia, sudden infant death syndrome, etc.

The application of the apnea episode detection and interruption system by vibrotactile stimulation comes up like an alternative of early apnea episode detection for the newborn babies, as well as the stimulation activation as soon as the apnea is detected, without direct human interference, reducing risk of crossing infections and the apnea itself.

This kind of instrumentation can be a less stressing mode to obtain apnea reversion in newborn babies, getting more safety to protect them from serious after-effects from a non-reverted apnea. Moreover, it can provide a less stressing labor environment to the clinical staff due to the automatic system that takes care of premature newborn babies, at the same time, freeing their eyes and hands to other tasks.

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