Noninvasive Physiological Signal Analysis and Implementation of Monitoring and Control System for Premature Infants

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Manuscript submitted June 1, 2016; accepted August 17, 2016.
doi: 10.17706/ijbbb.2016.6.4.145-151

Abstract: Patent Ductus Arteriosus (PDA) is a common heart disorder found especially in low-weight premature infants. The purpose of this study is to apply the non-invasive monitoring equipment Philips M60 and a perfusion index (PI) value measuring equipment with customized software to obtain and record the ECG and PI signals of newborn babies. The self-developed software is applied to analyze heart rate variability (HRV) and PI value to observe the relationship between PDA status, PI and HRV. One-sample T-test is used for statistical analysis. Eight premature infants were recruited for this study in Level 3 Neonatal ICU of Taichung Veterans General Hospital, Taiwan. Results showed that the PDA in open status and close status in the RRI (RR Intervals) values of HRV signals (0.401±0.045 vs. 0.394±0.041, $p<0.05$) and PI values (1.021±0.323 vs. 1.48±0.457, $p<0.05$) of premature babies are significantly different. When the PDA is closed, the RRI values are lower than when PDA is open. On the other hand, when the PDA is open, the PI values are lower than when PDA is closed. The main reason is when ductus arteriosus (DA) is closed, blood in the main artery can not pass through the pulmonary artery and enter the lung through the opening duct, which lowers the pressure of the lung, and stops the left to right backflow.

Key words: Premature infant, heart rate variability, perfusion index, patent ductus arteriosus (PDA).

1. Introduction

Patent Ductus Arteriosus (PDA) is a disorder of concern for premature infant, some early research such as Chou-yen in 1993, has researched the relationship between PDA, heart rate variability (HRV) and status of PDA premature babies after surgery. Compared to the HRV value before the surgery, the HRV value is obviously increased a week after the surgery, and the HRV value is not different from healthy babies 1 to 3 months after the surgery. 3 of 8 samples of PDA premature babies have arrhythmia, but the result of echocardiography is normal after the surgery, but the autonomic nerve reaction changes a week after the surgery, and it becomes normal a month after the surgery. There are also a lot of researches about HRV in the laboratory, and the paper about the index of the wave shape of electrocardiogram (ECG) assists the test of Irregular pulse and the analysis of non-invasive physiology signal and monitoring system development of premature babies shows there are relationships between HRV and blood vessel. HRV can a non-invasive

solution of PDA status testing. Perfusion index can be used to evaluate the level of the predictable disease of new-born babies, and the stability of perfusion index of premature babies in the first week of their life. However, it affects the cardiac output of the heart [1], which changes the diastolic and systolic blood pressure indirectly, and this issue can be solved by measuring the change of pulse index.

The purpose of this research is mainly on measuring and recording ECG and perfusion index to observe the PDA status of premature babies by non-invasive techniques. When the ductus arteriosus (DA) of premature infant cannot close by itself, it makes the blood backflow from left to right through DA, and it affects the result of the ECG and perfusion index indirectly [2]. The relationship of DA and physiology status can be examined by analysing the time and frequency domains of ECG and the average statistics of the perfusion index. This system obtains ECG via the IntelliVue Philips MP60, and Masimo rainbow PI value measurement equipment obtains the perfusion index signal [3]. Based on these 2 signals, the closing level/status of PDA of premature babies will be observed to examine the hypothesis of above paper, and develop an easy caring and monitoring system, to notice the change of ill premature babies' status, and raise the survive rate of ill premature babies. This research records the physiology signal by a simple organized system, and analyses the information to provide the doctors the reference information for treatment and research [4].

Premature babies come to this world before their body matures, and it results in a lot of diseases. If the PDA becomes serious, it will cause many complications such as heart failure, pulmonary hypertension, intracranial bleeding, etc., and it decrease the survive rate of premature babies. Therefore, 24H monitoring of the status of premature babies' PDA is an urgent issue. According to previous research, the importance of this study project is starting by researching of relationship between PDA [5], perfusion index (PI) and HRV. Although traditional echocardiography can track the long term status of PDA intermittently, it consumes a lot of time and manpower, and is not convenient for long term judgment of heart disease experts, so full time monitoring of the patient by ECG and PI value is important, and through the development of convenient and useful program to record information such as ECG and PI value through this research, it will be possible to start the treatment as early as possible, and obtain more information in detail, if the premature babies has this type of heart disorder[6].

2. Materials and Methods

A computer monitoring system is developed which provides a long-term and stable analysis environment with monitoring and recording [7]. The system is mainly developed on personal computer. The ECG and PI values are observed for premature babies by this non-invasive monitoring system, and all information are recorded by Local Area Network (LAN) and RS-232, where the doctor can get information and record what he need through this system, and judge the PDA status by HRV and PI value etc., to improve the care of premature babies.

2.1. The Physiological Monitoring System (Philips MP60)

A computer monitoring system is developed which provides a long-term and stable analysis environment with monitoring and recording. The system is mainly developed on personal computer. The ECG and PI values are observed for premature babies by this non-invasive monitoring system [8], and all information are recorded by Local Area Network (LAN) and RS-232, where the doctor can get information and record what he need through this system, and judge the PDA status by HRV and PI value etc., to improve the care of premature babies [9]. This device is depicted in Fig. 1.

2.2. PI Value Measurement Device (Masimo Rainbow SET Pulse CO-Oximetry)

This measurement device is a monitoring device that uses non-invasive sensor technique through the

absorption of the light longer than 7 wavelengths to get continuous results of the substance of blood data, reaction of fluid, etc., and can also record important physiology signals such as Oxygen Saturation (SPO2), Pulse Rate (PR), Perfusion Index (PI), Pleth Variability Index (PVI, etc., as Figure 2 shows. The device can detect the change of the end of the blood vessel in detail, providing the precise physiology data. Using Rainbow Technology Algorithms, the device can separate, identify and measure a variety of haemoglobin. The measurement result of physiology parameter will then be shown in number on the plate [10]. This device is shown in Fig. 2.

Fig. 1. Philips MP60 device.

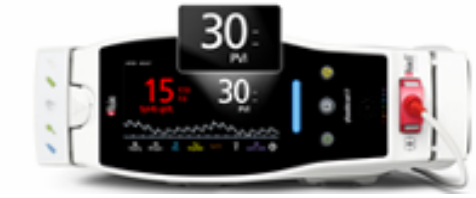

Fig. 2. Masimo rainbow SET pulse CO-oximetry measurement device.

2.3. The Structure of Premature Infant PDA Monitoring System

Fig. 3 shows there are 2 methods. Traditional Method: Doctors collect the data regularly by echocardiography, then judge the status of PDA, and make the decision.

Method From This Study: Though a custom physiology monitoring system (including hardware and software), the monitoring device can record the signal of premature babies [11], and the physiology monitoring device Philips M60 through monitoring software and LAN communicates data with the computer to analyze these information and record these data continuously and calculates the developing surrounding-written program by LabVIEW software, and display the results on the screen, the computer can monitor the patient and send the result of monitoring at the same time, to help doctors and nurses understand the status of patient with high efficiency.

Fig. 3. Physiology monitoring system.

2.4. Subjects

This experiment was designed to measure ECG and PI parameters, through the comparison of the status of the patent ductus arteriosus of whether it is closed or not by the measure of echocardiography. After the analysis of ECG, there must be some differences between the variation of heart rate and the average of perfusion index at this time [12].

Researchers chose the daytime, and collected the data beside the bed, including the information of every kind of the regular nursing care, the electrocardiogram, heart rate, frequency of pulse, perfusion index, and SPO2 etc. of premature infants were also measured and recorded constantly. After measuring electrocardiogram, the electrocardiogram, and perfusion index were taken every 20 minutes, in order to compare with the data later [13].

2.5. Range, Limitations, and Standards

Every case in our research included the period of the pregnancy and the birth weight and the age during the collection of research. In every experiment [14], the electrocardiogram and the perfusion index were measured, the medical diagnosis was also received recently and all medical measures which has been treated now. The physiological data included the heart rate and perfusion index which were recorded through the physiological signal monitor (Philips MP60) and Masimo rainbow SET pulse CO-Oximetry [15].

The variations of premature infants are extremely complex. In order to investigate deeply and simplify the problems, premature infants are limited to these conditions:

1) Less than 34 weeks of pregnancy.
2) Never used with anaesthetics or sleeping drugs.
3) Non-congenital malformation or non-congenital heart disease.
4) With parents' signature on the consent form.

Custom software interface which was adopted investigation for recording, analyzing, and saving data was used. Independent t-test was used to detect the relevance between the variation of heart rate, perfusion index of premature infants, and "close/open" status of patent ductus arteriosus.

This research was carried out by researching subjects in a third degree neonatal intensive care unit of the Taichung Veterans General Hospital. The number of the cases which was collected in this research was 8 premature infants (birth pregnancy less than 37 weeks and birth age less than 28 days). To consider the physical status of premature infants, the environment of research was chosen to be the infant Incubators.

2.6. Result of Monitor Physiology in Analysis and Experimental Verification

Research parameters included physiological information such as heart rate per minute, breath rate, SPO2, electrocardiogram, perfusion index etc. Professional medical personnel also recorded the behavior of premature infants [16], [17].

The posture of premature infants was set up to lie face down the day the data was collected. By echocardiography, the size of patent ductus arteriosus, and we implemented physiological monitor signal to obtain 20 minutes of information. The entire research period lasted about 2 hours per subject [18].

3. Experimental Results

From Aug 2014 to Jan 2015, in the neonatal intensive care unit of the Taichung Veterans General Hospital, there were 8 premature infants who were matched the conditions of our research (Male: 3, Female:5). This is shown in table 1. The average pregnancy length of the premature infants was 32.993 ± 3.482 week. This can be seen from table 2. The average birth body weight of premature infants was 1926.95 ± 503.43 gram, and the average size of patent ductus arteriosus of premature infants was 0.1405±0.0374cm. 5 minutes of clean data was selected for analysis. These can also be found on table 2. Table 3 consists of the parameters

that were calculated from the 5-minute data.

Table 1. Basic Data

	Male	Female	Total
Premature Infants	3	5	8

Table 2. Basic Parameters

Parameter	Mean ± Standard Deviation
Pregnancy Week at Birth (weeks)	32.993 ± 3.482
Birth Weight (grams)	1926.95 ± 503.43
Conduit Size (cm)	0.1405±0.0374

Table 3. Preterm and Full-Term Infant's Parameter Comparison

Parameter	Open state	Closed state	p-value
RRI (s)	0.401±0.045	0.394±0.041	0.03
NN50 (%)	0.049±0.174	0.273±0.614	0.153
PNN50 (%)	0.333±1.188	1.818±4.07	0.155
RMSSD (ms)	4.865±2.479	6.341±4.794	0.361
HR (bpm)	151.678±15.436	138.908±47.788	0.681
LF	95.664±103.4	144.091±223.317	0.432
LF(nu)	69.556±23.17	60.818±22.14	0.325
HF	104.104±198.153	125.923±203.232	0.778
HF(nu)	30.461±23.154	39.5±22.301	0.31
LF/HF	4.457±3.381	3.127±3.471	0.318
PI	1.021±0.323	1.48±0.457	0.004
PVI	13.744±7.13	17.391±4.511	0.141
BPM	147.833±14.509	151.273±14.894	0.545
SPO2	98.394±1.317	97.9±1.455	0.354

4. Discussion

Significant differences were found in RRI (RR Interval) and PI (Perfusion Index) ($p<0.05$). According to the references, no matter whether premature infants were awake or sleeping quietly, every parameter in the frequency domain (LF, HF) had no significant differences. However, the parameter of PI is shown to be affected by the state of patent ductus arteriosus (closed, open). Also, there are no significant differences in the parameters of PVI, BPM, SPO2. According to the past references, PI is obviously affected in patent ductus arteriosus of premature infants, and 24 to 72 hours after birth, the index of PI increase with time, which means that PI is related to PDA, and not found in PVI.

5. Conclusion

This research studied 8 premature infants from Taichung Veterans General Hospital by measuring their electrocardiograph and perfusion index when their patent ductus arteriosus status was open, and after their patent ductus arteriosus was closed. This study utilized a custom program written in LabVIEW® which obtained data from two medical devices and performed HRV calculations on the ECG signal. The results found in this study agree with previous studies that the status of patent ductus arteriosus affects the RRI and PI values of a premature infant. As there are only 8 subjects in this study, further research is required on a larger population in order to confirm these findings, as well as understand the mechanisms of

how the state of patent ductus arteriosus affects the RRI and PI values.

Acknowledgment

The authors would like to thank Dr. The-Ming Wang and nurses of NICU of Taichung Veterans General Hospital, as well as funding from the Taichung Veterans General Hospital under contract number TCVGH-FCU102820.

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