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Photoplethysmographic and SpO_2 Readings from the Neonatal Anterior Fontanelle: a case Study

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Abstract— There is a need for a more reliable, non-invasive and alternative measurement site for the monitoring of arterial blood oxygen saturation in critically ill neonates when peripheral perfusion is poor. The anterior fontanelle, a unique anatomical feature of the neonate, has been presented as an alternative site for the estimation of arterial blood oxygen saturation (SpO_2). A new fontanelle photoplethysmographic sensor and processing system has been developed to investigate fontanelle photoplethysmographic (PPG) signals and estimate SpO_2 values at this anatomical location. Preliminary clinical trials have shown that good quality PPG signals with large amplitudes and high signal to noise ratio can be obtained from the neonatal fontanelle. The estimation of SpO_2 values from the fontanelle were in broad agreement with a commercial foot pulse oximeter.

I. INTRODUCTION

Pulse oximeters are widely used in neonatal anesthesia and intensive care but they have some severe limitations. The technique relies on the presence of adequate peripheral arterial pulsations, which are detected as photoplethysmographic signals (PPG). When peripheral perfusion is poor, as in states of hypovolaemia, hypothermia, vasoconstriction, and low cardiac output, seen typically in meningococcal septicaemia, oxygenation readings become extremely unreliable or cease [1-4]. The problem arises because conventional sensors must be attached to the most peripheral parts of the body, such as the finger or toe, where pulsatile flow is most easily compromised. Hence, pulse oximetry becomes unreliable in a significant group of neonates just at the time when accurate readings are most needed. To overcome this limitation, the anterior fontanelle (AF) is proposed as a potential measurement site on the hypothesis that perfusion may well be better preserved at this central site.

The fontanelles, commonly referred to as the "soft-spots" on the new-born baby's head, are features that allow the skull to flex during labor so that the baby can pass through the birth canal. There is no bone present at these sites, only a thin membrane and the skin on the scalp protects the brain from direct contact. The largest of the fontanelles is the anterior fontanelle situated on the midline between the coronal and sagittal sutures [5]. Running directly beneath the AF is the sagittal sinus. The fontanelle does not fully close, usually, until about eighteen months after birth. It is surmised that these unique properties will allow the AF to be utilized as an optical window (ultrasonic monitoring already makes use of the AF as an acoustical window to make scans) to the brain for measuring PPGs and therefore enable the estimation of arterial blood oxygen saturation (SpO_2) continuously and non-invasively.

An earlier study looked at obtaining PPGs from the scalp of the neonate [6], and included the AF as a study site; however the results were inconclusive as they could not determine whether the PPG signals received were from the scalp or from deeper underlying tissues. It was concluded that pulsations from the sagittal sinus may have been a source of error that influenced the signals received from the scalp at the AF. Considering this, we have surmised that if pulsations are coming from the sagittal sinus, then new information may be extracted from the PPG that goes beyond the standard SpO_2 measurements.

A new reflectance photoplethysmographic/SpO_2 sensor has been designed and developed [7] in an effort to investigate PPGs signals and SpO_2 values from the fontanelle in critically ill neonates. This paper describes the preliminary acquisition of PPGs and estimation of SpO_2 values from the neonatal fontanelle.

II. METHOD

A. Instrumentation

A reflectance fontanelle PPG sensor has been designed and developed utilizing miniature optical components (Fig. 1). The technical details of this sensor have been described in a previous publication [7]. Also, an identical (optical and electrical) foot PPG

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sensor was also developed in order to provide PPG comparison studies between the two sites. A dual channel PPG processing system was also developed to detect and pre-process all acquired PPG signals (fontanelle and foot) simultaneously [7]. All PPG signals were digitized using a 16-bit data acquisition card (USB-6212, National Instruments, USA). A Virtual Instrument (VI) implemented in LabVIEW (National Instruments, USA) was developed to acquire, display (on a laptop computer), analyze and archive all PPG signals. Algorithms were also developed for the real time estimation of SpO_2 from both sensors. Figure 2 shows a photo of the fontanelle/foot PPG system.

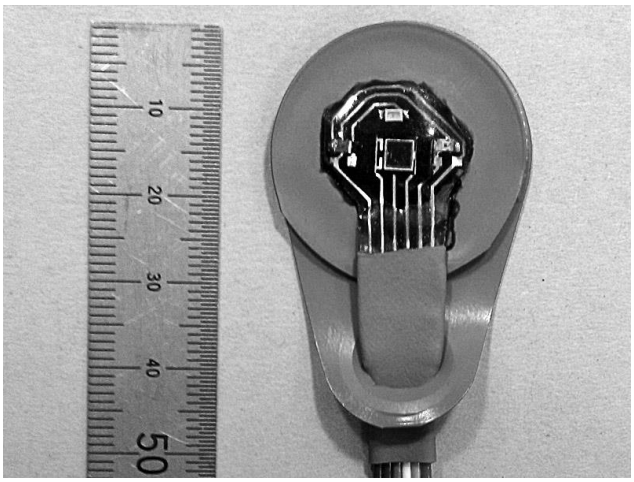

Fig. 1: Custom PPG fontanelle sensor.

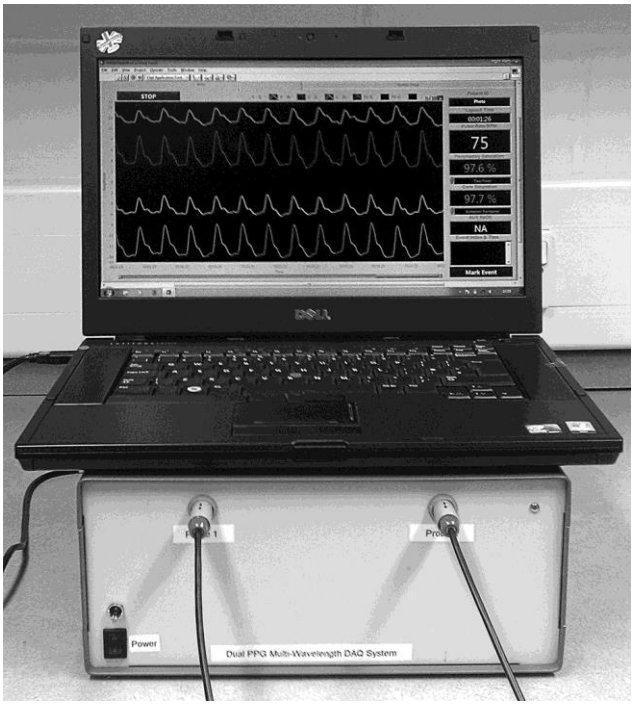

Fig.2: Photo of the fontanelle/foot PPG system

B. Clinical Measurements

Local research ethics committee approval and parental written consent was acquired prior to this study. A two day-old neonate, weighing 3kg was recruited for this study.

Both PPG sensors were taped into place, one on the fontanelle and the other on the foot. Prior to placement, both sensors were covered with clear medical patches (Tegaderm™, 3M, USA) to ensure sterility. A commercial pulse oximeter (Philips Intelliview MP70 Patient Monitor) was also placed on the foot of the neonate.

Continuous PPG measurements from both sensors took place for a total period of approximately 54 minutes. The acquisition of PPG measurements was separated into three distinct measurements periods (P1, P2, and P3). P1 is a baseline PPG measurement period, with FiO_2 set at 0.25 which lasted approximately 12 minutes. During P2 (approximately 12 minutes) FiO_2 was increased by 50% and during P3 (approximately 14 minutes) FiO_2 was brought back to baseline. The hypothesis underlying the changes in FiO2 was to enable the investigation of the behavior of PPGs and consequently SpO_2 under such changes. In this particular case there was also a P4 period (approximately 16 minutes) were the position of the fontanelle sensor was optimized further in order to achieve better quality PPG signals.

The stored PPG data was analyzed offline using MATLAB® software (The Mathworks USA). The signals were filtered to remove high frequency noise and breathing modulation and then split into AC and DC PPG components. The ratio of ratios (1) of the red and infrared signals was calculated for both sensors for every 2 seconds of data.

$$R=\frac{\mathrm{Red_{AC}}/\mathrm{Red_{DC}}}{\mathrm{Ird_{AC}}/\mathrm{Ird_{DC}}} \qquad (1)$$

Preliminary SpO_2 results were calculated using (2):

$$SpO2 = 110 - 25R \qquad (2)$$

The mean and standard deviation of the PPG amplitudes for both sensors across both wavelengths was also calculated across all four monitoring periods.

III. RESULTS

Good quality PPGs with large amplitudes were obtained from the foot sensor for both the red and infrared signals for the entire duration of the study, through all four periods (P1, 2, 3, 4). The estimation of

SpO_2 values from the acquired foot PPGs were in good agreement with the commercial foot SpO_2 sensor.

PPG amplitudes from the fontanelle were relatively small for the duration of the study, however after the sensors was repositioned, during period P4, the fontanelle PPG signals were of larger amplitudes and of better quality than those from the foot sensor. On average the increase in the amplitude of the AC infrared PPGs (IR) from the fontanelle was 33% from those from the foot and for the AC Red PPGs the increase in amplitude was 45%. Fig. 3 shows the amplitude analysis across all recording periods.

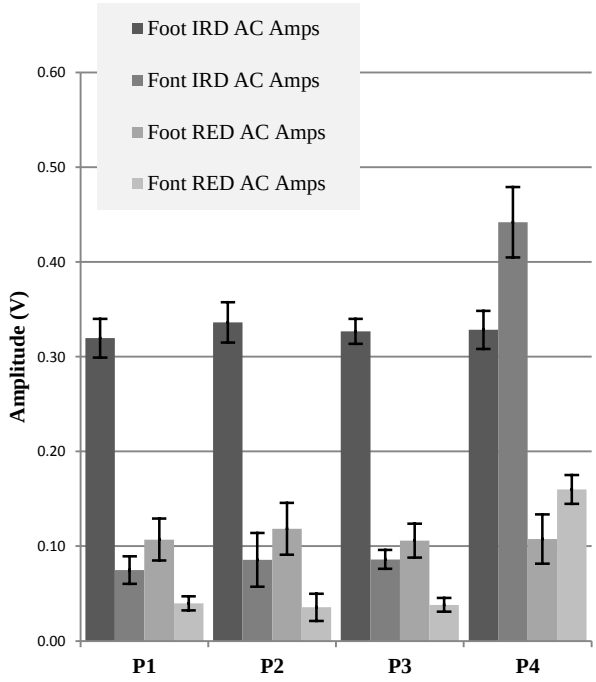

Fig. 3: Custom Sensor (foot and fontanelle (font)) PPG amplitudes for Red and Infrared Signals.

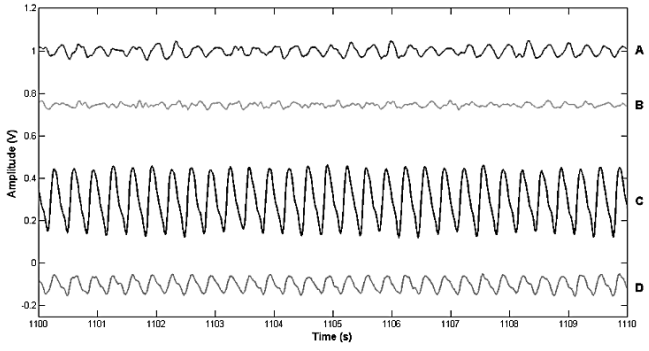

Fig. 4: PPG Amplitudes from the foot and fontanelle, simultaneously, before optimal placement was achieved, 10 Second Sample, HR = 180bpm. A – Font IRD AC, B – Font RED AC, C – Foot IRD AC, D – Foot RED AC.

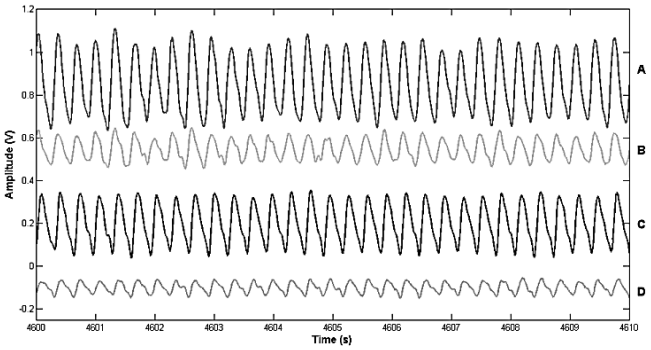

Fig. 5: PPG Amplitudes from the foot and fontanelle, simultaneously, after optimal placement was achieved, 10 Second Sample, HR = 186bpm. A – Font IRD AC, B – Font RED AC, C – Foot IRD AC, D – Foot RED AC.

Estimated SpO_2 values from the fontanelle were slightly lower than the custom foot sensor and the commercial sensor; however they were still in broad agreement. Table 1 shows a summary of the SpO_2 results.

The change of FiO_2 from period P1 to P2 had a direct effect on blood gas measurements such as SaO_2, PaO_2 and $PaCO_2$), as it was expected. During this change the commercial pulse oximeter exhibited no change in its SpO_2 readings as it was displaying saturation values around 100% for the duration of this study. The two custom made sensors (fontanelle and foot) did show a small change in this period which reflects the effects of FiO_2 on gas measurements and suggests that the developed fontanel sensor is sensitive to such changes (see Table 1).

Period	Com SpO_2 %	SaO_2 %	PaO_2 kPa	$PaCO_2$ kPa	Foot SpO_2 (±Com)	Font SpO2 (±Com)	SpO_2 diff Foot - Font
P1 FiO_2 (0.25)	100	98	14.8	5.86	100.3% (+0.3)	96.8% (-3.2)	3.5%
P2 FiO_2 (0.37)	100	100	25.4	5.93	99.7% (-0.3)	98.0% (-2.0)	1.7%
P3 FiO_2 (0.25)	100	98	15.10	5.60	101.1% (+1.1)	99.1% (-0.9)	2.0%
P4 Font Repos	100	---	---	---	101.2% (+1.2)	99.6% (-0.4)	1.6%
				MEAN	**100.6% (+0.6)**	**98.4 (-1.6)**	**2.2%**

Table. 1: Commercial SpO_2, Blood Gas Analysis and Custom Sensor SpO_2 results.

IV. CONCLUSION

This study has successfully demonstrated that it is feasible to acquire good quality PPGs from the neonatal fontanelle. The fontanel PPGs were of large amplitudes and at times where the position of the fontanelle probe was placed in a more optimal place the fontanelle PPGs were larger than the foot PPGs. This suggests that the placement of the sensor on the

fontanelle is of significance and it is something that needs further investigation in subsequent studies.

The developed system, despite being an un-calibrated SpO_2 system has produced fontanelle and foot SpO_2 values that were in broad agreement with the commercial foot pulse oximeter. Also, the fontanel sensor seems to be more sensitive in identifying changes in blood oxygen saturation caused by changes in FiO_2 than the commercial pulse oximeter used in this study.

Further trials are continuing, and a full exploration into the phenomena observed in this trial may yet reveal clues about the health of the neonate only obtainable from this unique anatomical feature.

REFERENCES

[1] D.L. Reich, A. Timcenko, C.A. Bodian, J. Kraidin, J. Hofman, M. DePerio, S.N. Konstadt, T. Kurki, and J.B. Eisenkraft, "Predictors of pulse oximetry data failure," Anesthesiology, vol. 84, Apr. 1996, pp. 859-864.

[2] J.T. Moller, N.W. Johannessen, K. Espersen, O. Ravlo, B.D. Pedersen, P.F. Jensen, N.H. Rasmussen, L.S. Rasmussen, T. Pedersen, and J.B. Cooper, "Randomized evaluation of pulse oximetry in 20,802 patients: II. Perioperative events and postoperative complications," Anesthesiology, vol. 78, Mar. 1993, pp. 445-453.

[3] P. Iyer, P. McDougall, P. Loughnan, R.B. Mee, K. Al-Tawil, and J. Carlin, "Accuracy of pulse oximetry in hypothermic neonates and infants undergoing cardiac surgery," Critical Care Medicine, vol. 24, Mar. 1996, pp. 507-511.

[4] S. Levene and S.A. McKenzie, "Pulse oximetry in children," Lancet, vol. 1, Feb. 1988, pp. 415-416.

[5] H. Gray, Gray's Anatomy, 1860th ed. London: Arcturus, 2008.

[6] A.C. Dassel, R. Graaff, M. Aardema, W.G. Zijlstra, and J.G. Aarnoudse, "Effect of location of the sensor on reflectance pulse oximetry," British Journal of Obstetrics and Gynaecology, vol. 104, Aug. 1997, pp. 910-916.

[7] J. M. May, P. A. Kyriacou, and A. J. Petros, 'Development of an optoelectronic sensor for the investigation of photoplethysmographic signals from the anterior fontanel of the newborn', Conf Proc IEEE Eng Med Biol Soc, vol. 2011, pp. 18–21, Aug. 2011.