Wavelet analysis of pulse oximeter waveform permits identification of unwell children

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Background: Children who are unwell often display signs of circulatory compromise. It has been observed that pronounced changes occur in the appearance of the photoplethysmogram (pulse oximeter tracing) in these children. The aim of the study was to discover if wavelet transforms can identify more subtle changes in the photoplethysmogram of children who are unwell.

Methods: Photoplethysmograms were obtained from children attending a paediatric accident and emergency department with clinical features suggestive of significant bacterial illness or circulatory compromise. Photoplethysmograms were also obtained from a control group of well children. Wavelet transforms were applied to the traces in an attempt to separate the two groups.

Results: 20 traces were obtained from unwell children and 12 from controls. Analysis of the entropy of the wavelet transform of the photoplethysmogram allows the differentiation of unwell children from controls ($p = 0.00002$).

Conclusions: Wavelet transform of the photoplethysmogram offers the possibility of a rapid non-invasive method of screening children for significant illness.

METHODS

Children attending the accident and emergency department of a busy paediatric hospital were eligible for inclusion in the study if they displayed clinical features suggestive of significant bacterial illness or circulatory compromise (box). Prior ethical approval had been obtained from the local regional ethics committee, and informed consent was obtained from the parents of all enrolled children, and where applicable from the child themselves.

All children had pulse oximetry performed simultaneously at two sites (lobe of ear and either a finger or a toe as tolerated by the child) using paired Nellcor 100 pulse oximeters, which were connected to a standard Dell Pentium PC via a Computer Boards PCI-DS1602/16 analogue to digital converter board. This enabled the plethysmogram to be captured and stored for analysis. Monitoring took place over a period of an hour or until the child left the department. Clinical care for the child was not interrupted and continued as per departmental protocol.

A control group of well children was recruited from the siblings of patients attending the department with minor trauma. These children were monitored for a period of five minutes using the same equipment in the same environment as the study group. This shorter monitoring period for the control group was chosen to enable capture of an adequate length of plethysmogram for analysis without causing undue distress to the child.

All traces were analysed using wavelet techniques, first to remove the effects of noise and drift, and then to determine the wavelet based features that permit separation of the control group from the unwell children. Maximal separation was achieved when the wavelet power across the 1 Hz frequency band was plotted against the entropy at the 7 Hz band. Entropy is a measure of data spread or clumpiness, with the lowest entropy having all the signal in one place and the highest having an even spread. Statistical analysis was performed using a Wilcoxon rank sum test.

RESULTS

Photoplethysmograms were obtained from 20 children fulfilling the study entry criteria. Twelve control traces were obtained.

Figure 1 shows that it is possible to differentiate the control group from the unwell children using wavelet analysis. The probability that the two samples come from populations that are identical is $p = 0.00002$.

There was some suggestion that these features can further stratify the children into groups based on illness severity, although numbers are too small to reach statistical significance.
DISCUSSION

Pulse oximeters use the differential absorption of red and infrared light by haemoglobin in its oxygenated and deoxygenated forms to calculate the ratio of these two molecules in pulsatile capillary flow. The photoplethysmogram is a plot of the absorption of light at one of these wavelengths (usually the infrared) against time. In the past the photoplethysmogram has traditionally been thought to be of no value except to determine if a pulse oximeter is picking up a good signal and thus giving an accurate reading. However, recent work has shown that other cardiorespiratory variables influence the waveform. It is currently unclear which variable, or combination of variables gives rise to our findings and further work is required to investigate this.

The traditional method of analysing waveforms is Fourier analysis. However, this technique produces only globally averaged spectral-only information, leading to location specific features in the signal being lost. The complete analysis of a signal requires the deduction of both the frequency make up and temporal location of the signal components. This limitation can be partly overcome by introducing a sliding time window, which localises the analysis in time (short time Fourier transform (STFT)) and provides a degree of temporal resolution by highlighting changes in spectral response with respect to time. However, this method is always a compromise between temporal and frequency resolution, which is set by the pre-defined fixed window width. Wavelet transforms differ from the STFT as they permit arbitrarily high localisation in time of high frequency signal features. They do this by having a variable window width that is related to the scale of observation. This flexibility allows for the isolation of the high frequency features obscured by STFT analysis and make them a useful tool for the analysis of biological signals as demonstrated in this and other recent studies.

![Figure 1 Scatter plot of wavelet power at 1 Hz against entropy at 7 Hz showing differentiation of well children from unwell children.](image)

In conclusion, our study shows that wavelet transforms can be applied to the photoplethysmogram and permit the identification of features that differentiate control children from children with clinical markers of significant illness. Further work with larger numbers of children needs to be undertaken to determine the physiological basis and clinical application of this technique. However, the potential exists to improve the identification of children with serious disease using a simple, real time, non-invasive monitoring system that would also provide standard pulse oximetry.

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REFERENCES