

## Chapter 11. Physiological Measurement

### Dynamic Neural Network Analysis of Cerebral Blood Flow Autoregulation

Panerai R B<sup>1</sup>, Chacon M<sup>2</sup>, Pereira R<sup>2</sup>, Nuñez N<sup>2</sup> and Evans D H<sup>1</sup>

<sup>1</sup>*Division of Medical Physics, University of Leicester, Leicester Royal Infirmary, Leicester LE1 5WW, UK*

<sup>2</sup>*Department of Engineering Informatics, University of Santiago de Chile, Av. Ecuador 3659, Casilla 10233, Santiago, Chile*

**Introduction** The dynamic relationship between arterial blood pressure (ABP) and cerebral blood flow velocity (CBFV) has been used as an expression of the autoregulatory capacity of the cerebral circulation. Linear frequency- and time-domain techniques have been applied to model this relationship, but non-linear approaches remain relatively unexplored. We hypothesize that a recurrent neural network should provide superior results in terms of model performance.

**Methods** ABP (Finapres) and CBFV (Doppler ultrasound, 2MHz) have been recorded during six successive thigh cuff manoeuvres in 15 healthy volunteers ( $30 \pm 7$  years) and digitized at 200 samples/s. Mean beat-to-beat values were interpolated and resampled at 5 Hz. Signal duration was limited to 30 s. A time-lagged recurrent network (TLRN) with three taps for the ABP signal and eight non-linear hidden neurons was adopted. Laguerre memories were used for the input taps and for the output (CBFV) delayed feedback loops to the hidden layer. A cross-validation approach was adopted by training the network with the ABP drop from five manoeuvres and using the sixth one for validation, repeating this process six times. For comparison, a similar process was followed using Aaslid's second order model which gives an index of dynamic autoregulation (ARI) to grade cerebral autoregulation responses to thigh cuff manoeuvres.

**Results** Superior results ( $p < 0.005$ , sign test) were obtained with the TLRN in comparison with Aaslid's model as expressed by mean correlation coefficients of  $0.76 \pm 0.12$  and  $0.69 \pm 0.14$ , respectively, for the cross-validation procedure. The mean/SD of ARI was  $4.6 \pm 1.3$ . CBFV step responses can also be extracted from TLRN, resembling those obtained with linear methods, but their directional sensitivity confirms the TLRN ability to model non-linear behaviour.

**Conclusion** Non-linear modelling of the ABP-CBFV dynamic relationship using a recurrent neural network significantly improves model performance in comparison with classical methods.

### Comparison of Two Non-Invasive Methods for Measuring a Blood Pressure Waveform.

Birch A A and Morris S L

*Department of Medical Physics & Bioengineering, Southampton University Hospitals NHS Trust, Tremona Road, Southampton SO16 6YD.*

**Introduction** Cerebral blood flow autoregulation is often measured using transcranial Doppler to record flow velocity while a step change in blood pressure is induced by rapid deflation of thigh cuffs. To interpret the result a measurement of arterial blood pressure with high time resolution is required. A direct arterial line provides the optimal measurement but is more invasive than is usually acceptable. The finapres is a commercially available device that uses finger plethysmography with a rapid feedback control to follow changes in blood pressure. Although there is uncertainty about its reliability the finapres has been used by several groups assessing autoregulation. Radial artery tonometry has recently become commercially available as an alternative non-invasive

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measurement of blood pressure. The objective of this work was to determine if any systematic differences exist between the waveforms measured by the two non-invasive techniques.

**Methods** Nineteen healthy volunteers were recruited. Each volunteer lay supine through out the measurements. A finapres device was attached to a finger and the tonometry was attached to the opposite wrist. Data from both devices were sampled at 50Hz during six thigh cuff deflation procedures.

**Results** Average blood pressure waveforms measured with the finapres and tonometry were significantly different; the most striking difference being a much slower recovery time measured with the finapres (two tailed t test  $P=0.001$ ). The shape of the tonometry waveform is more in keeping with measurements described in the literature using alternative blood pressure measurements.

**Conclusion** A systematic difference does exist between the finapres and radial artery tonometry when used to measure blood pressure dynamics following thigh cuff deflation. Measurements with tonometry are closer to the expected waveform. Peripheral vasoaction may be distorting the measurement of blood pressure and hence autoregulation when using the finapres. Comparison with invasive techniques would confirm which measurement is the more accurate.

### Estimation of coherence between cerebral blood flow velocity and EEG activity in newborn babies

Simpson D M<sup>1</sup>, Botero Rosas D A<sup>2</sup> and Infantosi F C A<sup>2</sup>

<sup>1</sup> *Institute of Sound and Vibration Research, University of Southampton, Southampton, SO17 1BJ. e-mail: ds@isvr.soton.ac.uk*

<sup>2</sup> *Biomedical Engineering Program, Federal University of Rio de Janeiro (COPPE/UFRJ), C.P. 68510, 21945-970 Rio de Janeiro, Brazil. e-mail: afci@peb.ufrj.br.*

**Introduction** Blood flow to the brain is normally regulated by control mechanisms, whose failure has been linked to cerebral ischaemia and intracranial haemorrhage. We have been investigating this control in neonates using transcranial Doppler measurements of cerebral blood flow velocity (CBFV), and have shown correlation between CBFV and the power of the EEG. The aim of the current work is to identify the frequency range in which the EEG activity is most strongly linked to CBFV, using coherence estimates.

**Methods** CBFV and EEG were simultaneously recorded in normal neonates. In 12 recordings (from 9 neonates), the normal neonatal EEG pattern of Tracé Alternant was identified. Mean CBFV and the RMS value of the EEG were calculated in one-second intervals. The coherence between the resulting signals was estimated using an algorithm developed for signals with missing samples (excluding signal segments with noise or artefact), followed by Monte Carlo statistical tests of significance.

**Results** It was found that coherence peaked at approximately 0.1 Hz, with a median value of the coherence-magnitude of 0.57. Coherence was significant in 8 of the 12 records. The RMS value of

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the EEG also showed a spectral peak at 0.1 Hz, but the mean CBFV generally did not.

**Conclusions** The algorithm developed for estimating coherence and testing its significance performed well. The results suggest that the EEG activity at 0.1 Hz is the main source of correlation between CBFV and the EEG during Tracé Alternant activity.

### Effect of Caffeine on Cerebral Blood Flow

#### – Why do Xenon Clearance and Transcranial Doppler give Different Results?

Lunt M J<sup>1</sup>, Ragab S<sup>2</sup>, Birch A A<sup>3</sup> and Jenkinson D F<sup>2</sup>

*Departments of <sup>1</sup>Medical Physics and <sup>2</sup>Medicine, Royal Bournemouth and Christchurch Hospitals.*

*<sup>3</sup>Department of Medical Physics and Bioengineering, Southampton General Hospital.*

**Introduction** Changes in cerebral blood flow (CBF) can be assessed either directly with xenon clearance or indirectly with transcranial Doppler (TCD), which measures middle cerebral artery blood velocity (Vmca). We used both techniques to examine the effect of 250mg caffeine on 9 control subjects and 14 patients recovering from a stroke [1]. Caffeine reduced CBF by 22% and Vmca by 13%. The fall in Vmca was significantly less than that in CBF ( $p = 0.0016$ ), and there was low but significant correlation between the two ( $r = 0.42$ ,  $p = 0.045$ ). This paper describes a simulation to establish whether these results are consistent with perfect inherent correlation degraded by random variations in the measurements.

**Methods** A set of measurements of CBF and Vmca on 23 subjects was simulated using a spreadsheet. For each subject, baseline CBF, baseline Vmca and percentage caffeine-induced reduction in CBF were

selected at random from the distributions of these parameters found in the clinical study. In every subject, the percentage reduction in Vmca was assumed to be 0.6 that in CBF, giving perfect inherent correlation. Simulated measurements were then taken at random from distributions with the selected mean values and the same variances as those found in the clinical study. The correlation coefficient  $\rho$  was calculated and this was repeated for 200 studies to establish the distribution of  $\rho$ .

**Results** The correlation coefficient obtained from the clinical study was exceeded in only 40% of the simulated studies.

**Conclusions** The clinical results are consistent with perfect inherent correlation between changes in Vmca and CBF, reduced through random variability in the measurements.

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### Influences on the interaction between heart rate and blood pressure

Bowers E and Murray A

*Regional Medical Physics Department, Freeman Hospital, High Heaton, Newcastle upon Tyne NE7 7DN*

**Introduction** Heart rate and blood pressure are held in balance by the baroreflex, which is one of many autonomic reflexes that the body uses to maintain homeostasis. Although heart rate is easy to appreciate, when determining how well the baroreflex is functioning, the instantaneous time between each

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R-wave in the electrocardiogram (RR-interval) is used instead. Two components need to be considered. One is the time delay between change in RR-interval and blood pressure; the other is the baroreflex sensitivity which is the ratio of increase in RR-interval to increase in blood pressure, measured in ms/mmHg.

Baroreflex sensitivity is clinically important for determining prognosis after myocardial infarction [1]. NICE has also stated that it is an important test for determining suitability of patients to receive implantable cardioverters [2].

Baroreflex sensitivity was first measured in 1969 by administering a drug that dramatically increased blood pressure, and determined by linear regression [3]. Today it is measured and determined using a variety of non-invasive techniques and mathematical algorithms in both the time and frequency domains [4 and 5]. The problem that has always occurred when measuring baroreflex sensitivity has been poor repeatability.

**Aim** We aim to understand what influences time delay and baroreflex sensitivity both internally and externally so that we can ultimately improve the repeatability of baroreflex measurements. This study investigated the influence of breathing frequency and posture.

**Methods** Six subjects (2 female, 4 male) with a mean age of 32 years (standard deviation 12 years), mean resting heart rate of 61 beats per minute (standard deviation 8 beats per minute) and mean systolic pressure of 128 mmHg (standard deviation 25 mmHg) were studied.

Each subject was asked to breathe following a scrolling triangular waveform on an oscilloscope

screen, for three minutes each, at 6, 8, 10 and 12 breaths per minute in a supine, sitting and standing position. RR-intervals were derived from the ECG, and the beat-by-beat change in systolic blood pressure was derived from a Finapres signal. A Finapres measures continuous non-invasive blood pressure.

The datasets containing RR-interval and systolic pressure data related to sequential heart beats. A linear interpolation algorithm [6] was used to convert the datasets so that they were regularly re-sampled in the time domain. To calculate the time offset the regularly sampled RR-interval and systolic pressure data were bandpass filtered at the breathing frequency. The two datasets were then cross correlated and the position of the maxima and minima calculated, as they represent the time offset between the two datasets. Baroreflex sensitivity was calculated from the frequency domain representation of the regularly sampled RR-interval and systolic pressure data. The ratio of the height of the peaks of the RR-interval to systolic pressure that occurred at each breathing frequency was used as the baroreflex sensitivity measure.

An analysis of variance was performed to look for consistent effects with changes in posture and breathing frequency. The combinations from this analysis that were significant were explored further with paired t-tests.

**Results** From the 72 recordings only 8 recordings (11%) could not be used to determine the time offset between RR-interval maxima and subsequent systolic pressure minima. They had an irregular correlation signal. The relationship between time offset and breathing frequency showed time offset reduced as breathing frequency increased ( $p < 0.001$ ). There was no relationship with posture.

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From the 72 recordings only 4 recordings (5.5%) could not be used to determine baroreflex sensitivity. Three did not have the expected peak at the breathing frequency in the frequency domain of the systolic pressure signal and one did not have the peak in the frequency domain of the RR-interval signal. The relationship between baroreflex sensitivity and posture showed baroreflex sensitivity reduced as posture became more upright ( $p < 0.01$ ). There was no relationship with breathing frequency.

The components that make up baroreflex sensitivity showed that the heights of the RR-interval peak and systolic pressure peak reduced with increased breathing frequency ( $p < 0.05$ ). Changes in posture showed a significant increase in systolic pressure peak height from supine to sitting ( $p < 0.001$ ) and supine to standing ( $p < 0.001$ ). There was a small effect of posture change on RR-interval peak heights.

**Discussion** In this study, we asked six normal subjects to follow each of the 12 breathing signals for 3 minutes, which requires subject compliance. The subjects were able to follow the breathing signals well. Baroreflex sensitivity tests are usually carried out on patients whose compliance may not be as good and hence this technique may not be as effective in a clinical environment, although further investigations will need to follow.

How the test is performed to measure baroreflex sensitivity and the time offset between heart rate and blood pressure influences the results considerably. Baroreflex sensitivity is affected more by posture than breathing frequency and time offset is affected more by breathing frequency than posture.

Baroreflex sensitivity reduced mainly because of the increase in systolic pressure peak height. This was apparent with the significant changes in systolic

pressure peak height due to posture change. RR-interval and systolic pressure peak heights both reduced with breathing frequency, and hence baroreflex sensitivity remained invariant to breathing frequency.

Usually baroreflex sensitivity is recorded in the supine position [7 and 8]. This study suggests that the supine position may not be the best. This is because significant changes occur in systolic pressure peak height when moving from supine to sitting or supine to standing.

**Conclusion** Baroreflex sensitivity has been measured since 1969. This study shows that we still need to understand what external and internal factors influence the measurement. Breathing frequency strongly influences the time offset, and posture strongly influences baroreflex sensitivity. There are many other influencing factors that need to be investigated

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### The Mathematical Modelling of Blood Gas Variation in the Ventilated Neonate

Evans C J<sup>1</sup>, Smye S W<sup>1</sup>, Snowden S<sup>1</sup>, Tan K<sup>2</sup>, Newell S<sup>2</sup> and Dear P R F<sup>2</sup>

<sup>1</sup> Dept. of Medical Physics and Engineering, St James's University Hospital, Leeds, LS9 7TF

<sup>2</sup> Dept. of Paediatrics, St James's University Hospital, Leeds, LS9 7TF

**Introduction** A mathematical model of the variation of partial pressure of carbon dioxide and oxygen in the arterial blood of a ventilated neonate is developed. The model predicts changes in the blood gas partial pressures that occur following abrupt changes in the ventilation settings, and have been compared to clinical data obtained using novel sensor technology.

**Methods** The model comprises alveolar, arterial, pulmonary, venous and tissue compartments, with gas exchange in the lung determined by inspiration and expiration terms as well as diffusion to/from the

arteries. Oxygen is consumed and carbon dioxide is produced in the tissue by a metabolic term.

The mathematical model was implemented using Maple software. Clinical data was obtained using a multi-parameter intra-arterial sensor (MPIAS) which has recently been developed by Diametrics Ltd. It uses fibre optics and passes through the umbilical arterial catheter into the infant's aorta where it is able to measure the partial pressures of oxygen and carbon dioxide in the blood as well as the pH.

**Results and Conclusions** The method has been applied to several different data sets and estimates of model parameters for the particular infant obtained. Following an abrupt change in ventilator settings the model typically predicts a short-term transient change (over a period of 30 seconds or so) followed by a gradual transition to the new steady state over a time scale of several minutes. Determination of the model parameters and subsequent modelling may permit the status of a ventilated neonate to be described quantitatively and ultimately managed more effectively.

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### Automatic Repolarisation Measurements using Magnetocardiography

Smith F E<sup>1</sup>, Langley P<sup>1</sup>, Steinhoff U<sup>2</sup>, Trahms L<sup>2</sup>, Bourke J P<sup>1</sup> and Murray A<sup>1</sup>

<sup>1</sup>Freeman Hospital, Newcastle upon Tyne, UK

<sup>2</sup>Physikalisch-Technische Bundesanstalt (PTB), Berlin, Germany

**Introduction** Magnetocardiography is a non-invasive measure of cardiac magnetic field strength. Compared to conventional electrocardiography, multichannel magnetocardiograms (MCGs) allow easy evaluation of repolarisation interval at many positions on the torso, increasing information about cardiac repolarisation. However, the large number of channels makes manual analysis laborious. The aim of this study was to assess the influence of MCG filtering on the measurements of an automatic algorithm for repolarisation interval detection.

**Methods** Automated analysis of repolarisation interval was developed in MATLAB from MCGs obtained using the Berlin PTB magnetometer at 49 sites over the heart from 23 healthy volunteers. A technique for automatic analysis of ECG signals, which used modelling of the terminal T-wave section to determine the end point, was extended and applied to the MCG recordings. Automatic repolarisation interval measurements were made following the addition of different high and low pass filters. An experienced analyst also manually measured repolarisation intervals of unfiltered data.

**Results** Mean (standard deviation) of the differences between manual and automatic repolarisation measurements were compared for unfiltered data. The automatic technique underestimated repolarisation interval by 32.4 ms (9.4 ms). This was because manual measurement attempts to identify an ill-defined T-wave end, whereas automatic methods

use features of T-wave shape to determine end point. Filtering modifies the slope of the T-wave, which was reflected in the results. Low pass filtering tended to increase repolarisation interval relative to unfiltered measurements by 5.8 ms (3.3 ms) for a 40 Hz cut-off. High pass filtering decreased the mean value by 3.1 ms (10.5 ms) for a 0.25 Hz cut-off.

**Conclusion** Automatic repolarisation intervals were different to manual measurements and were influenced by filtering.

### Reconstruction of Respiratory Signals from Bed ECG Measurement Using Wavelet Transform

Yi W J and Park K S

Dept. of Biomedical Engineering, College of Medicine, Seoul National University, Seoul, Korea

**Introduction** It is possible to extract the respiratory signals from the ordinary ECG signals[1]. To monitor the ECG without the subject's awareness during sleep, a system was developed to measure the ECG with electrically conductive textiles on a bed sheet[2]. In this work, we developed a system to measure ECGs on a bed and derived respiration from the ECGs using wavelet transform.

**Methods** The bed sheet electrodes consisted of three pieces of conductive textiles, which were under left, right shoulders and legs. The ECGs were recorded by standard lead configurations of I, II and III. The airflow at the nose was measured using a thermistor. All the signals were collected at the sampling rate of 200Hz. A wavelet transform was applied to the ECG signals. Respiratory signal was derived by reconstructing the detail signal of 9th decomposition which corresponded to 0.2~0.4Hz. The

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respiration periods were calculated by detecting the zero-crossing of the respiratory signals.

**Results** In Fig.1, the solid line represents interpolated series of respiration period extracted from the airflow and the dotted line from the EDR. Correlations between these two series were high for all subjects (above 0.9).

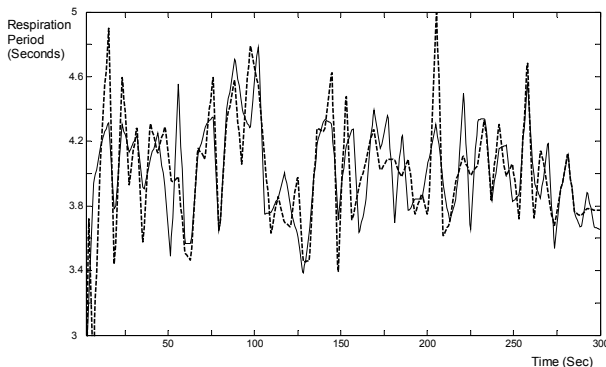


Fig 1. Interpolated respiration period from ECG derived respiration signals

**Conclusion** The results show that EDR from bed textile electrodes can be used as a reliable monitoring tool of respiration. This may be applied to screening apnea during sleep without causing discomfort to patients.

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## Thermographic imaging and skin oxygen saturation measurements applied to amputation level viability prediction

Harrison D K<sup>1</sup>, Hanson J M<sup>2</sup> and Hawthorn I E<sup>2</sup>

<sup>1</sup> *Regional Medical Physics Department and*

<sup>2</sup> *Directorate of General Surgery, University Hospital of North Durham, Durham DH1 5TW.*

**Introduction** About 5% of British males over 50 years contract peripheral arterial occlusive disease. Of these about 2% ultimately require lower limb amputation. In 1995 we proposed a new technique using lightguide spectrophotometry to measure the oxygen saturation level of haemoglobin (SO<sub>2</sub>) in the skin as a method for predicting tissue viability [1]. This technique, in combination with thermographic imaging, gave a sensitivity and selectivity of 1.0 for the prediction of successful outcome of a below knee amputation compared with a specificity of 93% using the “traditional” (<sup>125</sup>I) 4-Iodoantipyrine (IAP) clearance technique at a below knee to above knee amputation ratio (BKA:AKA) of 75%.

**Methods** The present study assesses the routine clinical application of the above two techniques to the assessment of amputation level viability in patients with critical limb ischaemia. An MCPD-1000 (Otsuka Electronics, Osaka) lightguide spectrophotometer was used for the oxygen saturation measurements using the protocol described previously [1]. Thermographic images were recorded using an 80 series STARSight infrared camera (Insight, Malvern).

**Results** The study is ongoing, but the data to date comprise 22 patients. 4 patients were recommended for above knee amputation (AKA) and 18 patients for below knee amputation on the basis of thermographic and tissue SO<sub>2</sub> measurements. All but one of the predicted BKA amputations healed, giving a 94% healing rate (specificity) for a BKA:AKA ratio of 82%.

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**Conclusion** The results from this study compare very favorably with those from our first study [1] and confirm the value of these two techniques for the assessment of amputation level in routine clinical practice.

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### Oesophageal Pulse Oximetry: A New Monitoring Site

Kyriacou P A<sup>1</sup>, Langford R M<sup>2</sup>, Powell S<sup>2</sup> and Jones D P<sup>1</sup>

<sup>1</sup>*Medical Electronics & Physics, Department of Engineering, Queen Mary College, University of London, London E1 4NS, UK*

<sup>2</sup>*Anaesthetic Laboratory, St Bartholomew's Hospital, Barts and The London NHS Trust, London EC1A 7BE, UK*

**Introduction** Pulse oximeter probes placed peripherally may fail to give accurate values of arterial blood oxygen saturation (SpO<sub>2</sub>) when peripheral perfusion is poor. Since central blood flow may be preferentially preserved, the oesophagus was investigated as an alternative monitoring site.

**Methods** A miniature opto-electronic reflectance pulse oximetry probe was constructed to allow SpO<sub>2</sub> measurements within the whole depth of the oesophagus [1]. A processing system was developed to detect and display the oesophageal photoplethysmographic (PPG) signals on a laptop computer. Software was implemented in *LabVIEW* to make continual estimations of oesophageal SpO<sub>2</sub>. The system was evaluated on clinical measurements

performed on 50 critically ill patients undergoing thoracic surgery, mainly cardiothoracic bypass. Oesophageal SpO<sub>2</sub> values were systematically compared with both conventional finger SpO<sub>2</sub> measurements and arterial blood oxygen saturation (SaO<sub>2</sub>) values obtained from laboratory blood analysis.

**Results** It was found that the oesophageal pulse oximeter was in good agreement with SaO<sub>2</sub> measurements obtained by a blood gas analyser and a CO-oximeter and with SpO<sub>2</sub> values from a commercial finger pulse oximeter. The means ( $\pm$  SD) of the differences between the oesophageal SpO<sub>2</sub> and SaO<sub>2</sub> results from blood gas analysis and CO-oximetry were  $0.02 \pm 0.88\%$  and  $-0.73 \pm 0.72\%$ , respectively. A Bland and Altman statistical analysis showed that the oesophageal and finger pulse oximeters agreed sufficiently to allow them to be used interchangeably. In five patients SpO<sub>2</sub> readings from the commercial finger pulse oximeter probe failed for at least ten minutes while the oesophageal readings remained stable and reliable.

**Conclusion** The results from the clinical measurements suggest that oesophageal pulse oximetry may be used as an alternative for patients with compromised peripheral perfusion.

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### Obtaining an auditory evoked potential index for the assessment of depth of anaesthesia

Taktak A F G<sup>1</sup>, Fisher A C<sup>1</sup>, Jones A G<sup>2</sup>, Mustafa F<sup>2</sup> and Sidaras G<sup>2</sup>

<sup>1</sup> Department of Clinical Engineering, Royal Liverpool University Hospital

<sup>2</sup> Department of Anaesthesia, Royal Liverpool University Hospital

**Introduction** Measures of depth of anaesthesia range from observations of heart rate, blood pressure, EMG monitoring, eye movement and sweating. Awareness during anaesthesia may not be identifiable from these parameters particularly with neuromuscular blockade and may cause major psychological trauma during surgery. In a recent study, the incidence of awareness in 12,000 cases was as high as 2 per 1000 [1]. Monitoring brain activity during anaesthesia is one method which may provide an objective measure of the level of anaesthesia. This paper describes the development of a monitor based on Auditory evoked potential (AEP) [2].

**Method** The instrument applied auditory stimuli and the mid-latency response (15 – 110 ms) was measured. A PIC microcontroller was used to handle the low level control and the data was sent to a PC via a serial link. Data processing was carried out using programmes written in Matlab. Mixed language programming under MS Windows using Dynamic Link Library (DLL) and ActiveX was employed. The user interface plotted the signal, stored the data and obtained a level of arousal score (LivLAS) from 256 stimuli in less than 1.5 seconds

**Results** Clinical trials of the system were carried out on 20 patients undergoing general anaesthesia. The anaesthetist was blind to these figures so that it did

not influence clinical judgement. None of the patients recalled any awareness after the operation. LivLAS was also measured in ten controls. Results showed significant difference ( $p < 0.05$ ) between the awake and asleep LivLAS values.

**Conclusion** Auditory-evoked potential (AEP) is a useful technique for measuring depth of anaesthesia and can be implemented relatively easily using distributed processing. Further work is needed to establish normative values for anaesthetic agents.

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### Assessment of the Physical Properties of Endoscopic Retrieval Systems

Allan W<sup>1</sup>, Williams E D<sup>1</sup>, Singhvi S K<sup>2</sup> and Small P K<sup>2</sup>

<sup>1</sup> Regional Medical Physics Department, Sunderland Royal Hospital, Kayll Road, Sunderland, SR4 7TP

<sup>2</sup> Department of General Surgery and Urology, Sunderland Royal Hospital, Kayll Road, Sunderland, SR4 7TP

**Introduction** Laparoscopically resected organs require a reliable method of retrieval. We have examined the physical properties of three commercial systems available for clinical use (two plastic, one woven fabric).

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**Method** Pig abdominal walls and gallbladders containing steel balls to represent gallstones were used to simulate organ retrieval on 60 occasions. The performance of retrieval bags was measured in terms of the temporal profile of pressure developed inside the bag, the force on the bag during withdrawal, and whether or not the bag could be retrieved intact. The force versus elongation relationship was also determined for each bag.

**Results** Although there was a wide range of maximum pressures recorded (range 14 to 320 mmHg) with each retrieval system, the mean pressures in the plastic systems were significantly higher. The forces recorded during attempted withdrawal of both plastic bags were significantly lower compared with the fabric system - BERT fabric: 87 N (25 - 165 ) [ mean (range) ]; Endocatch: 40 N (7 - 123 ); Endopouch : 40 N (14 - 68) [  $p = 0.005$  Endocatch vs BERT,  $p = 0.004$  Endopouch vs BERT]. The BERT bags tore more easily at the site of the grasper.

**Conclusion** Plastic retrieval systems are less likely to burst than fabric systems when subjected to simulated retrieval, and required less force for withdrawal. Plastic systems may therefore be associated with less tumour seeding or gallstone spillage as a consequence of bag disruption.

### **Detecting changes in intracranial pressure using tympanic membrane displacement measurement.**

**Banister K R<sup>1</sup>, Cowie C R<sup>1</sup>, Mendelow A D<sup>2</sup> and Chambers I R<sup>1</sup>**

<sup>1</sup> *Regional Medical Physics Department, Newcastle General Hospital, Newcastle upon Tyne*

<sup>2</sup> *Department of Neurosurgery, Newcastle General Hospital, Newcastle upon Tyne*

**Objectives** Measurement of intracranial pressure (ICP) is valuable in assessing the function of an implanted hydrocephalus shunt system. However, it is highly invasive and precludes repeated measurements. A non-invasive ICP assessment technique (Marchbanks Measurement Systems) measures tympanic membrane displacement (TMD) after stimulation of the acoustic reflex [1] and is easily repeated. The purpose of this study was to establish if repeat TMD measurements could determine changes in ICP.

**Methods** Hydrocephalus patients requiring surgical intervention to alter ICP were studied. Tympanic membrane displacement was measured pre and post intervention with the patient supine. Patients were excluded if a postural test indicated that ICP was not transmitted to the perilymph.

**Results** Tympanic membrane displacement readings were compared in 10 patients. Intervention reduced ICP in 9 patients (lumbar puncture, shunt insertion or revision) and increased ICP in 1 patient (insertion of antisiphon device). In 4 patients, TMD was measured bilaterally; in 6 patients, TMD was measured in only one ear. Where TMD was measured bilaterally the mean TMD was used. Reduced ICP was associated with increased TMD in 8 out of 9 patients. Conversely, when ICP was increased, TMD decreased. In 1 patient, decreased ICP was

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associated with decreased TMD. Given an inverse relationship between TMD and ICP, correct diagnoses of ICP changes were made in 90% of cases.

**Discussion** These preliminary results suggest that TMD measurement may be useful to detect ICP changes when a baseline asymptomatic measurement has been performed. However, in three cases where both ears were measured, TMD changes in each ear were not in good agreement and in one case, although TMD increased on average, TMD increased in one ear and decreased in the other. The cause of these discrepancies requires further investigation and a larger series of measurements is underway to define more accurately the sensitivity and specificity of this technique.

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### Gender-related differences in multi-site photoplethysmographic pulse timing characteristics

**Allen J and Murray A**

*Regional Medical Physics Department, Freeman Hospital, Newcastle upon Tyne NE7 7DN*

A multi-site photoplethysmographic (PPG) pulse waveform measurement and analysis system has been developed to study the peripheral pulses in normal subjects and patients with vascular disease

[1]. The aim of this study was to quantify any gender-related differences in timing characteristics for PPG pulse waveforms from the ears, fingers, and toes.

PPG pulses were measured simultaneously from the ears, fingers and toes whilst subjects lay supine on a measurement couch. A total of 116 normal healthy subjects were studied (median age 42 years, range 13-72). An electrocardiogram (ECG) was also recorded and provided a cardiac timing reference. All waveforms were captured to computer for 2.5 min at 2500 Hz for subsequent beat-to-beat analysis. Subject age, height, heart rate and systolic blood pressure were also recorded. For each subject and measurement site the time between the ECG R wave and the foot of the pulse (pulse transit time, PTT) was calculated. Comparisons between male and female PTT were made using an analysis of covariance model with age, height, heart rate, and systolic blood pressure as covariates. When PTT was adjusted for these factors it gave the following results:

Male subjects were found to have small but significantly lower values of PTT than females at the finger and toe sites. No significant differences were found at the ear site.

	Number	Ear PTT (ms)	Finger PTT (ms)	Toe PTT (ms)
Males	68	136.6	194.1	289.0
Females	48	139.5	200.8	299.4
PTT Difference (male-female)		-2.9	-6.7	-10.4
Significance		P=0.271 (NS)	P<0.02	P<0.02

### Reference

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### Terahertz Pulsed Imaging in Medicine: The Optical Properties of Tissue

Berry E<sup>1</sup>, Fitzgerald A J<sup>1</sup>, Zinov'ev N N<sup>2</sup>, Miles R E<sup>2</sup>, Chamberlain J M<sup>2</sup> and Smith M A<sup>1</sup>

<sup>1</sup> Academic Unit of Medical Physics and Centre of Medical Imaging Research, University of Leeds, Wellcome Wing, Leeds General Infirmary, Great George Street, Leeds, LS1 3EX.

<sup>2</sup> School of Electronic and Electrical Engineering and Institute of Microwaves and Photonics, University of Leeds, Leeds, LS2 9JT

**Introduction** Imaging in medicine using microwaves and infrared radiation is well established, but the region of the electromagnetic spectrum lying between has not been utilised. However, advances in laser and electro-optical technologies have made the terahertz band (0.1 THz to 10 THz) accessible. Generated pulses of terahertz radiation may be detected coherently, so the electric field amplitude, after reflection or transmission through a sample, may be recorded as a time series. Fourier transformation then allows spectroscopic analysis of both amplitude and phase changes. Refractive index and linear attenuation of a medium may be estimated: (i) broadband (ii) as function of frequency. Image data sets are acquired by raster scanning with a time series for each pixel. Demonstrations of terahertz imaging in biomedicine were made several years ago, but few data are available regarding the optical properties of tissue at terahertz frequencies. Our aim was to begin to catalogue these, to estimate variability and to provide information about the practicality of proposed applications in terms of penetration depth, image contrast and reflection at boundaries.

**Methods** Transmission measurements through tissue slices, thickness 80  $\mu\text{m}$  to 1 mm, were made (59 cortical bone, 72 tooth dentine and 44 tooth

enamel, plus blood, skin, muscle and adipose tissue). Mean and standard deviation of broadband and spectral refractive index ( $n$ ) and linear attenuation coefficient ( $\mu$ ) were calculated. The Fresnel relation was used to estimate percentage reflection ( $R$ ) at the boundary between tooth enamel and dentine.

**Results** Preliminary broadband results (system bandwidth 0.5-2.5 THz) are in the table.

	Cortical bone	Tooth enamel	Tooth dentine
$n$	$2.41 \pm 0.09$	$2.9 \pm 0.2$	$2.5 \pm 0.1$
$\mu / \text{cm}^{-1}$	$68 \pm 10$	$53 \pm 32$	$60 \pm 31$
$R / \%$	-	-	7
N	59	44	72

**Conclusion** Reflection imaging shows the most promise for clinical application, particularly for dental and dermatological applications.

### Adaptive Mains-interference and a Near Real-time FIR Filter Techniques for EEG Recording in Theatre

Fisher A C<sup>#</sup>, Taktak A F G, Hagan R, Sidaras G\* and Jones A G\*

Departments of Clinical Engineering and \*Anaesthesia, Royal Liverpool University Hospital, Liverpool L7 8XP (#a.c.fisher@liv.ac.uk)

**Introduction** The detail of the eeg measured from surface skin electrodes is described at the precision of 10's of *nanovolts*. However, in the operating theatre electrical noise from the mains and other sources can sum to the order of volts. This implies a signal-to-noise (voltage) ratio of -140dB. Whilst most of this noise is *common-mode* and will be rejected at the *differential mode* inputs of the amplifier, sub-100Hz contamination from the mains and other

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electrical equipment, particularly computers, remains a major challenge. In Liverpool we are presently developing a *level of consciousness monitor* for general anaesthesia based on the dc-to-45Hz component of the middle latency auditory evoked potential AEP. Here we describe 2 noise minimisation strategies that have been shown to be useful in this work.

**Method** First we describe a *practical* near-real-time mains noise cancellation algorithm implemented on a PC that does not require a reference noise source (as do the majority of adaptive noise cancellers). Secondly, we describe a variable length FIR filter which executes in essentially real time by exploiting FIFO buffering of serial input data at the standard PC UART.

A demonstration will be given for continuous signals (eg. eeg) and discrete-repetitive signals (eg. middle latency auditory evoked potentials).

**Results** The above algorithms are implemented in Matlab. The use of *wrapper* techniques enables the construction of *objects* containing these sub-programmes which are easily embedded within Visual BASIC and other Microsoft programming languages.

**Conclusion** The above techniques have enhanced the quality of the signal and their near-real-time implementation has made their use possible for clinical monitoring.

### Acoustic Emission from Stenosed Blood Vessels

Lunt M J<sup>1</sup>, Aindow J D<sup>1</sup>, Grant L J<sup>3</sup>, Robins P A<sup>1</sup> and Winterton S J<sup>2</sup>

<sup>1</sup>Medical Physics & <sup>2</sup>Cardiology Departments, Dorset County Hospital, Williams Avenue, Dorchester, DT1 2JY

<sup>3</sup>Medical Physics Department, Royal United Hospital, Combe Park, Bath, BA1 3NG.

**Introduction** It is well known that blood flowing through a tightly stenosed blood vessel emits a characteristic sound (bruit) that can be heard with a stethoscope. However, stethoscopes have a poor high frequency response and may lose high frequency signals. This paper describes an analysis of the higher frequency components of arterial bruits.

**Methods** We used a pulsatile flow rig to investigate bruits from 50, 70 and 80% stenoses. The components between 1 and 50kHz were detected with a piezoelectric transducer and separated using Fourier analysis. We have also investigated a bruit from a patient with a tight femoral stenosis which had already been assessed by duplex scanning.

**Results** The bench experiments confirm that bruits from the 80% stenosis had components above 10kHz. The initial clinical study did not show such high frequencies but the stenosis was not as tight. Results from further clinical studies will be presented.

**Discussion** The aim of this project is to establish whether high frequency sound can be used to detect coronary artery stenosis. Results from bench experiments are encouraging, and clinical studies have been started. Results from carotid and femoral arteries will be used to assess the prospects for detecting coronary stenosis.

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### In Vivo Impedance Characterisation of Acupuncture Points in Healthy and Unhealthy Individuals

Prokhorov E<sup>1</sup>, Prokhorova T<sup>1</sup>, González-Hernández J<sup>1</sup>, Kovalenko Y<sup>1</sup>, Moctezuma S<sup>2</sup>, Romero H<sup>2</sup> and Llamas F<sup>2</sup>

<sup>1</sup> CINVESTAV del IPN, México.

<sup>2</sup> Universidad Autónoma de Querétaro, México.

**Introduction** According to electroacupuncture methodologies dc resistance of acupuncture points (APs) depends on condition of internal organ to which these points are connected. The aim of this report is to compare *in vivo* impedance characteristics of Aps, which connect with pathological internal organs, with corresponding characteristics of another APs and the surrounding human skin in the same participant patients.

**Methods** The impedance measurements (from 3 Hz to 1 MHz) of the APs and of the surrounding human skin (at a distance 5-10 mm from the former) with the method of measurements offered by Voll [1] were carried out *in vivo* on 50 patients with clinical diagnose: gastritis, bronchitis and neurological damage.

**Results** The results of the measurements have shown that real and imaginary parts of APs impedance, which according to Volls method are connected with pathological organs in the frequency range of 3-1000 Hz, are about 5-10 times higher than real and imaginary parts of impedance of skin. On the other hand, the real and imaginary parts of impedance of APs, which are connect with healthy

organs are only about 2-4 times higher than the correspondent characteristics of skin.

**Conclusion** The data obtained show that the impedance characteristics of human body measurement *in vivo* in different body region, especially in ill people, depend on APs, which can be present under electrodes' surface. Impedance measurements of APs can be use as an efficient and prompt non-invasive analysis for diagnostics purposes.

### Reference

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### A critical appraisal of visual acuity

Walton S C<sup>1</sup>, Davies N P<sup>2</sup>, McMaster R S<sup>1</sup> and Johnston R<sup>3</sup>

<sup>1</sup> Cranfield University

<sup>2</sup> University College Hospital, London

<sup>3</sup> Cheltenham General Hospital

To assess visual function the most common approach is to perform a letter recognition visual acuity test. This is usually carried out with aid of the Snellen chart. However, the Snellen chart suffers from many disadvantages resulting in inaccurate assessments of visual acuity. For example [1]:

- Different number of letters on each line
- Different increments of letter size from line to line
- Different letter recognisability on each line (due to different shapes, stroke widths, stroke angles etc).

An alternative chart, based on a logarithmic progression of letter size was developed in the 1970's

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to address these problems [1 & 2]. The logMAR (logarithmic Minimum Angle of Resolution) chart has 5 letters per line and the letter sequence used on each line is chosen such that the recognisability of the lines is approximately equal. This chart has become the gold standard for visual acuity testing.

However all chart-based tests, including the logMAR chart, still have other problems. The most obvious of these is the 'memory effect' on subsequent testing.

Others include:

- A low resolution due to the relatively large decrease in letter size between each line
- No control over the length of time that each letter is presented to the subject
- No opportunity to estimate measurement error since it is a single measurement approach
- Letter charts use a method of descending limits to assess the threshold of acuity which is one of the weakest techniques used to measure human psychophysical thresholds and is prone to motivational bias

This paper critically examines the above tests and presents in conceptual terms, attributes and methodologies needed in order to address these shortcomings. This research work is a collaboration between Cranfield University Postgraduate Medical School, Clement Clarke International and the Ophthalmology Department at Cheltenham District General Hospital.

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