ASSESSMENT OF AUTONOMIC RESPONSE AND HAEMODYNAMIC PARAMETERS USING HEART RATE VARIABILITY AND PULSE SIGNALS

VEERABHADRAPPA S. T.

INSTRUMENT DESIGN DEVELOPMENT CENTRE

INDIAN INSTITUTE OF TECHNOLOGY DELHI

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by

VEERABHADRAPPA S. T.

INSTRUMENT DESIGN DEVELOPMENT CENTRE

Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

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Dedicated to

My Beloved Teachers

&

Family

Certificate

This is to certify that the thesis entitled **“Assessment of Autonomic Response and Hemodynamic Parameters using Heart Rate Variability and Pulse Signals”**, submitted by **Mr. Veerabhadrappa S. T.** to the Indian Institute of Technology Delhi, for the award of the Degree of **Doctor of Philosophy**, is a record of the original bona fide research work carried out by him under our supervision and guidance. The thesis has reached the standards fulfilling the requirements of the regulations relating to the degree.

The results contained in this thesis have not been submitted in part or full to any other university or institute for the award of any degree or diploma.

. . . .
Prof. Anoop Lal Vyas
Instrument Design Development Centre
Indian Institute of Technology Delhi
New Delhi - 110016, India

. . . .
Prof. Sneh Anand
Centre for Biomedical Engineering
Indian Institute of Technology Delhi
New Delhi - 110016, India

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Veerabhadrappa S. T.

Abstract

The quantification of the variability in heart rate and pulse signals provide information about the autonomic neural regulation of the heart and the circulatory system. Both heart rate variability and pulse signals are influenced by diseases, vascular ageing and several underlying mechanisms involved such as respiratory rhythm, blood pressure regulation and inflammatory responses. Heart rate variability (HRV) and pulse wave results from the sum of all these processes response and provide a rapid measure of vascular tone and arterial stiffness. In addition to autonomic nervous system (ANS) activity, the contour analysis of pulse wave measures provides a noninvasive means to study the characteristic change relating to haemodynamics. This present study focuses on the study of the HRV and pulse signals for cardiovascular assessment and haemodynamic changes during pregnancy and third molar tooth extraction.

The ECG and pulse signals are recorded during pregnancy and postpartum considering factors like maternal age, body mass index, blood pressure. The studies were carried out to investigate autonomic response through the HRV and classification of three trimesters during pregnancy and postpartum. The spectrum analysis, approximate entropy, correlation dimension and bispectrum methods were used to carryout HRV analysis as all these approaches can quantify the balance between the autonomic nervous activities. These findings are compatible with reduced HRV complexity and pregnancy is characterized by a reduction of parasympathetic activity. The HRV features are significant during various stages of pregnancy and enables to distinguish three trimester of pregnancy and postpartum.

Extensive experiments were carried out regarding the overall usefulness of the features with linear and non-linear methods. In addition, an expert system has been designed for the classification of different stages of pregnancy. The features extracted from the HRV are fed to a K-Nearest Neighborhood (KNN), Gaussian Mixture Model (GMM) and Probabilistic Neural Network (PNN) classifiers. Results are very promising for classification of three trimesters during pregnancy and postpartum with accuracy of 85.89%, 85.89% and 89.74% using KNN, GMM and PNN classifiers respectively using bispectrum features.

In addition to HRV analysis, the contour analysis of pulse wave is carried out to assess the haemodynamic changes and autonomic response. Normotensive pregnancies were associated with a reduction of the vagal tone and a reduction of pulse interval. The increase in pulse amplitude and pulse transit time during all the three trimesters were observed. These parameters are observed to be more sensitive to vascular compliance and peripheral resistance. These results suggest that arterial compliance and volume of expansion increase due to sympathetic activity throughout the pregnancy. The findings also indicate that normal pregnancy is associated with an increase in stroke volume, cardiac output, heart rate and arterial compliance. This study establishes the normal ranges of pulse wave characteristics during normal pregnant and postpartum group.

In another study, which includes the complex mix of physiological, emotional and cognitive factors associated with anxiety and fear during tooth extraction has been carried out. This study presents the ongoing short-term changes in autonomic activities and haemodynamics of patients during tooth extraction. It is observed that amplitude, slope

and heart rate increased by 40%, 35% and 10% respectively after injection of local anesthetic which causes vasoconstriction induced by the stimulation of the smooth muscles of arterioles. The results suggest that the sympathetic modulation of the heart would be increased during the tooth extraction procedure due to psychological stress, epinephrine contained in the local anaesthesia and/or painful stimuli. The studies suggest that HRV and pulse parameters are sensitive to detect the onset of increase in sympathetic activity and can also be used to assist dentists in the monitoring of volume and duration of the local anesthesia.

The present findings of thesis basically suggest that overall responses of HRV and pulse parameters can be used to quantify the sympathetic activity and haemodynamic changes during normal pregnancy and third molar tooth extraction procedure. This study concludes that the contour analysis of pulse and HRV together could be useful in finding the arterial compliance and autonomic balance due to maternal adaptations and effect of local anesthesia during tooth extraction.

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Abbreviations

Symbol	Meaning
ANS	Autonomic nervous system
ApEn	Approximate entropy
AV	Atrio-ventricular
BMI	Body mass index
BP	Blood pressure
CD	Correlation dimension
CNS	Central nervous system
CO	Cardiac output
DBP	Diastolic blood pressure
ECG	Electrocardiogram
EEG	Electroencephalogram
GMM	Gaussian mixture model
HF	High frequency component of HRV: $0.15 - 0.4$ Hz
HFnu	HF expressed in normalised units
HOS	Higher order spectrum
HOSA	Higher order spectral analysis
HR	Heart rate
HRV	Heart rate variability

KNN	K-nearest neighborhood
LF	Low frequency component of HRV: $0.04 - 0.15$ Hz
LF/HF ratio	The ratio between LF and HF components
LFnu	LF expressed in normalised units
LMS	Least mean square
NN	Normal-to-normal
NN50	Number of interval differences of successive NN intervals greater than 50 *ms*
PIH	Pregnancy induced hypertension
PNN	Probabilistic neural network
PNS	Parasympathetic nervous system
PostLA	After injection of local anaesthesia
PPG	Photoplethysmography
PreLA	Before injection of local anaesthesia
PSD	Power spectral density
PTT	Pulse transit time
PW	Pulse wave
PWV	Pulse wave velocity
QPC	Quadrature phase coupling
RMSSD	Square root of the mean squared differences of successive NN intervals
RR	R-wave to R-wave
RSA	Respiratory sinus arrhythmia
SA node	Sino-Atrial
SBP	Sytolic blood pressure
SD	Standard deviation
SDNN	Standard deviation of NN interval

SNS	Sympathetic nervous system
SPO_2	Oxygen saturation
SVR	Systemic vascular resistance
ULF	Ultra low frequency component of HRV: < 0.003 Hz
VLF	Very low frequency component of HRV: $0.003 - 0.04$ Hz