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The enhancement of intra-operative diagnostics and decision-making using computational methods

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MB, BS (Newcastle upon Tyne), FRCA, FANZCA

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Medicine.
The University of Auckland, 2005
ABSTRACT

The data presented and views expressed in this document are the result of multiple published and unpublished studies over the last 25 years. My over-arching goal in this research was to use modern computing power to create functionally useful diagnoses, in real time, from the monitoring systems used during routine anaesthesia and to present these diagnoses in an ergonomic manner. In addition it was intended to incorporate into the anaesthetic monitor, expert systems that help with the management of uncommon situations.

The Australian and New Zealand College guidelines on monitoring during anaesthesia dictate those measurements that should be made during every anaesthetic; from these data evidence can be gathered, integrated, and presented to the clinician. Constraints in this field of research include the inability of the monitors to see, hear or understand the context of operating theatre activities, and computer processing time.

Because many studies are involved the methods are detailed in the main text, and are not summarized here.

Physiological ‘envelopes’ have been developed, in which the ‘normal’ variation in physiological variables, during anaesthesia, are enclosed. They have enabled the creation of intelligent alarm systems that can suggest diagnoses. A retrospective off-line study showed that it was possible to diagnose the onset of malignant hyperpyrexia, using fuzzy logic templates, about 10 minutes earlier than the clinician. Some variables may be more important than others in making a diagnosis, and the strength of a diagnosis depends on the amount of supporting evidence, the amount of evidence not against the diagnosis and the amount of missing data.

Decision-making (for example to transfuse or not transfuse blood) can also be mathematically modelled so that decision making is more consistent.

Finally, investigation of the ways of displaying data indicates that the output can be very explicit.

My overall conclusion is that real time decision support systems for the management of clinical dilemmas are possible. They can be instantly and easily accessible and can sit discretely in the background of anaesthetic monitors to be activated at will by the anaesthetist.
The work for this thesis has been carried out over twenty-five years. It began whilst I was working as a Consultant Anaesthetist and Senior Lecturer in Anaesthesia in the city of Nottingham, in the UK. The work was continued in Auckland, at Auckland Hospital, and as an honorary Senior Lecturer and Associate Professor in the Department of Anaesthesiology, Faculty of Medical and Health Science, University of Auckland, New Zealand.

The majority of the work has been at my instigation but much of the work has been co-authored with past and present colleagues.
ACKNOWLEDGEMENTS

I would like to give thanks to the following friends who have contributed to my fumbling attempts at seeing through the fog of uncertainty.

Frank Johnson, Andrew Lowe, Phil Guise, Nigel Robertson, Michal Kluger, Brian Mace, Guy Warman, Brian Pollard, Ron Jones, Tom Healy, Alan Merry, Doug Campbell, Richard Jones, David Kabel, Jim Hunter and many more.

Much praise and thanks must be given to my wife, Penny, who has valiantly put up with my computing over the years.

“I heartily beg that what I have done here may be read with candour; and that the defects I have been guilty of upon this difficult subject may be not so much reprehended as kindly supplied, and investigated by new endeavours of my readers.”

Isaac Newton
The Mathematical Principles of Natural Philosophy
Cambridge, Trinity College,
May 8, 1686.

It is likely that this work will expose my ignorance more than my knowledge. Being pragmatic I hope the end result may be of use to someone with greater skills.

Michael Harrison
September 22nd, 2005
PUBLICATIONS AND PRESENTATIONS

The following publications arose from this work:

My contribution to these publications is tabulated in detail in APPENDIX H

Harrison MJ, Johnson F. Computer assisted decision making in anaesthesia. Br J Anaes 1980; 629P


Harrison MJ. Preoperative computer generated advice – is it helpful? Computers and Medicine 1983;2:3-8


Harrison MJ. The computer in the Intensive Care Unit. Care of the Critically Ill 1984;1,15-18 (reproduced in Medicine Digest 1985;11:12-20

Harrison MJ, Slater EJ. Remote monitoring using an induction loop. Anaesthesia 1986;41:71-72


Lowe A, Harrison MJ, Jones RW. Diagnostic monitoring in anaesthesia using fuzzy trend templates for matching temporal patterns. Artificial Intelligence in Medicine, Special Issue on Fuzzy Diagnosis (page refs)


Harrison MJ, Kluger M, Robertson NN. Physiological changes during induction of anaesthesia. Aust. and NZ College of Anaesthesia and Intensive Care 1998 Annual Scientific Meeting, Newcastle (Abstract)


**BOOKS**


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FIGURE 82  Hierarchy of display data; face icon always visible, strength of diagnosis determines switch to more detailed information using the user's choice of display.

FIGURE 83  Development of data display
LIST OF ABBREVIATIONS

AI  Artificial intelligence
ASA  American Society Anaesthesiologists' assessment score (1 – V E)
BIS  Bi-spectral index
BLR  Binary logistic regression
BP  Blood pressure
BPV  Blood pressure variability
CHF  Congestive heart failure
CJA  Clinical judgment analysis
CO  Cardiac output
COPD  Chronic obstructive pulmonary disease
COR  Cardiac output reserve
CORE  Clinical operating range (for physiological variables)
CVP  Central venous pressure
Des  Desflurane
DSS  Decision Support System
ECG  Electrocardiogram
$E_{T}\text{AA}$  End-tidal concentration of anaesthetic agent
$E_{T}\text{CO}_2$  End-tidal concentration of carbon dioxide
$F_{E}\text{O}_2$  Fractional expired concentration of oxygen
FFT  Fast Fourier Transform
$F_{I}\text{AA}$  Fractional inspired concentration of anaesthetic agent
$F_{I}\text{CO}_2$  Fractional inspired concentration of carbon dioxide
$F_{I}\text{O}_2$  Fractional inspired concentration of oxygen
FN  False negative
FP  False positive
gdL$^{-1}$  Grams per decilitre
Halothane
$H_b$  Haemoglobin or haemoglobin concentration
HF  High frequency
HRV  Heart rate variability
IABP  Intra-arterial blood pressure
IPPV  Intermittent positive pressure ventilation
Isocyanurane
kPa  kilo Pascal
LF  Low frequency
LRE  Logistic regression equation
MAC  Minimum alveolar concentration
MAP  Mean arterial blood pressure
MOV  Mode of ventilation
$N_2\text{O}$  Nitrous oxide
NIBP  Non invasive blood pressure
NMT  Neuromuscular transmission monitor
NN  Neural networks
NPV  Negative predictive value
NZ  New Zealand
OGH  Ongoing haemorrhage
ON  Oxygen need
P1  Invasive arterial pressure channel on Datex-Ohmeda monitor
Preface

P(E) Probability of the individual being in a subset
P(H) Unconditional probability of event H
PA Pulmonary artery
PCF Patient condition factor
PCWP Pulmonary capillary wedge pressure
PE(H) Probability of the event occurring if patient was in subset
PH(E) Fraction of events in a set of patients
Pleth Plethysmographic trace from pulse-oximeter
PPNT Peer pressure not to transfuse
PPT Peer pressure to transfuse
PPV Positive predictive value
PR Pulse rate
Pt Patient
PVD Peripheral vascular disease
RAPV Respiratory-related arterial pressure variability
ROTH Risk of tissue hypoxia
RR Respiratory rate
RRV Respiratory rate variability
SBP / SABP Systolic blood pressure / Systolic arterial blood pressure
SNA Sympathetic nervous activity
SpO2 Oxygen saturation of Hb measured using pulse-oximetry
SPV Systolic pressure variability
SQL Structured Query Language
TIA Transient ischaemic attack (transient cerebral ischaemia)
TN True negative
TP True positive
TSW Time series workbench
TTS Trigg’s tracking signal
TURP Transurethral resection of prostate
Tx Transfusion
V (max, min, ave) Variable (maximum, minimum, average)
VAS Visual analogue scale
Xt Value of variable X at time t
y ‘year old’ as in ‘80y’
The work for this thesis has been carried out over twenty-five years. It began whilst I was working as a Consultant Anaesthetist and Senior Lecturer in Anaesthesia in the city of Nottingham, in the UK. The work was continued in Auckland, at Auckland Hospital, and as an honorary Senior Lecturer and Associate Professor in the Department of Anaesthesiology, Faculty of Medical and Health Science, University of Auckland, New Zealand.

The majority of the work has been at my instigation but much of the work has been co-authored with past and present colleagues.
ACKNOWLEDGEMENTS

I would like to give thanks to the following friends who have contributed to my fumbling attempts at seeing through the fog of uncertainty.

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Much praise and thanks must be given to my wife, Penny, who has been an inspiration in the search of truth.

“...I heartily beg that what I have done here may be read with candour; and that the defects I have been guilty of upon this difficult subject may be not so much reprehended as kindly supplied, and investigated by new endeavours of my readers.”

Isaac Newton
The Mathematical Principles of Natural Philosophy
Cambridge, Trinity College,
May 8, 1686.

It is likely that this work will expose my ignorance more than my knowledge. Being pragmatic I hope the end result may be of use to someone with greater skills.

Michael Harrison
September 22nd, 2005