ARRES: Computer-Assisted Decision Support System for the Post-Anaesthesia Care Unit

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TABLE OF CONTENTS

Page #

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES & ILLUSTRATIONS

Page #

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ABSTRACT

The routine use of pulse oximeters, non-invasive blood pressure monitors and electrocardiogram monitors has considerably improved patient care in the post anaesthesia period. Using an automated data collection system (ARRES), the occurrence of several adverse events frequently revealed by these monitors has been investigated. The ARRES is an on-line Post Anaesthesia Care Unit clinical management system designed to minimise artifact, demonstrate the feasibility of collecting and processing data, and identify variables that predict adverse events. Results indicated that the overall incidence of hypoxia was 35%, hypertension 12%, hypotension 8%, tachycardia 25% and bradycardia 1%. Discriminant analysis was able to correctly predict classification of about 90% of patients into normal *versus* hypertensive or hypotensive groups. Use of the ARRES system, increased the yield of adverse physiological events to 50%, up from 20% in our retrospective study in which data were collected manually. The ARRES system minimised artifact through the use of data validation rules, collected continuous on-line data, and was able to identify variables that predict adverse events. It is anticipated the PACU clinical management system designed in this project would become a part of a larger process which consists of collecting information about the patient, identifying adverse events and suggesting a course of action.

1.0 INTRODUCTION

1.1 Background of the Problem

In the 1950s, the risk associated with anaesthesia considerably exceeded the risk of surgery. During the last several decades, as surgical and anaesthetic techniques have improved, intraoperative morbidity and mortality have decreased. These achievements have directed more attention toward the problems and dangers in the post-anaesthetic period.

In order to achieve the objectives of anaesthesia (freedom from pain and anxiety, profound muscular relaxation, amnesia, near normal physiological parameters), drugs which are potentially lethal are administered to patients. Many drugs utilised for anaesthesia depend on the cardiovascular system to produce their effects. Other anaesthetic agents, such as intravenous narcotic agents, may depress respiration [Drain & Christoph, 1987].

In addition to each drug's potential impact on a patient, drug interactions may be important to consider. Surveys indicate that an average of more than eight drugs is prescribed for a hospitalised patient [Morrow et al., 1970; May et al., 1974; Fraulini, 1987]. Surgical patients may receive an additional five to ten drugs during anaesthesia and surgery, thus increasing the potential for drug interactions.

At the end of surgery, patients remain under the influence of these drugs and must also recover from the trauma of the surgical procedure. The duration and severity of post anaesthetic risk are dependent on the patient's original condition,

nature of the surgical procedure, length of the procedure, drugs used, blood and other vital fluid loss, and individual patient responses. Some of the adverse post-operative events like total airway obstruction with attendant hypoxaemia or severe hypotension, can be life threatening. During the immediate post-operative period, patients are at considerably increased risk for adverse circulatory (cardiac arrest, arrhythmias, hypotension) and respiratory events (airway obstruction, hypoxaemia). Other adverse events, like mild hypertension or hypoventilation, are associated with only slightly increased risk of mortality [Cullen & Cullen, 1975; Duncan & Cohen, 1987; Gewolb et al., 1987].

In order to minimise risk of adverse events during recovery, a nursing unit with specialised equipment and specially-trained personnel has evolved, the Post Anaesthesia Care Unit (PACU). The purpose of the PACU is to provide concentrated and comprehensive care in the immediate post-anaesthetic period. PACU nurses are responsible for assisting and monitoring patients as they re-establish consciousness and physiological stability. The more irregular this path, the longer the recovery, and the greater the possibility of morbidity or fatal injury to the patient.

Farman (1978) reports that 1 in 5.5 patients showed problems after anaesthesia and surgery. Atkinson (1982) reports that about 20% of deaths associated with anaesthesia occur in the 30 minutes following the operation. Recent studies have demonstrated that the overall incidence of complications occurring during the post-anaesthesia recovery room stay may be higher than previously expected [Eltringham et al., 1982; Cohen et al., 1986].

Treatment in the PACU is determined based on information extracted from the patient chart, operating room record, anaesthesia record, automatic monitors and clinical observations. The introduction of new monitoring equipment and techniques has made a major contribution to PACU efficacy by providing nurses with accurate and reliable information on which to base clinical decisions. Current standards call for physiological variables including blood pressure, heart rate, oxygen saturation and temperature to be continuously monitored. Physiological monitoring was developed on the premise that if clinicians knew more, they would be able to take better care of patients [Osborn, 1982].

The tremendous growth of medical information contributed by new tests, procedural innovations, and advanced monitoring techniques has produced an extraordinary increase in the volume of data to record and interpret. Clinical personnel have been overwhelmed by the quantity of data and its arrival from multiple sources [Stafford, 1982; Ozbolt, 1983; Lagler, 1986]. Furthermore, nurses need to reach their decisions without expending time collecting unnecessary or redundant data that can confuse rather than enlighten an already overloaded decision maker. The problem is further compounded because data presentation varies in format among devices, and the relationships between the monitored variables are very complex, requiring highly skilled integration and interpretation. Unless appropriate variables are monitored continuously, it is impossible to determine if the patient is having difficulty and perhaps developing a life threatening condition [Calkins, 1981].

In summary, nurses must remember large quantities of patient data, and relate the data to an up-to-date nursing knowledge base before they can make rational decisions which will enhance patient care. All this must be done quickly and at the appropriate time, so that the nurse can take action to promote recovery and to prevent potential complications before they occur [Ozbolt, 1983].

Research indicates that humans have limitations regarding the number of pieces of information they can consider simultaneously and apply towards decision making [Edwards, 1968; Garfinkel, 1980]. An approach to the need for continuous assessment of data from multiple sources in medical decision making is to make appropriate use of computers. Computers provide the opportunity to integrate, evaluate and simplify data management in such ways that are difficult to perform manually. Computers have the ability to acquire and process large quantities of data quickly, consistently, and can be of great assistance in decision making. The following improvements in patient care may be achieved by computers:

* collect patient data more efficiently
* perform tedious calculations
* undertake analytical procedures (data analysis)
* suggest diagnosis (process control)
* test to confirm the diagnosis

Some prototype computer-assisted decision making systems have been developed in the critical care areas but these have not been exploited in the PACU.

An intelligent computer-based system which logically organises and presents essential variables could be of great value to assist the PACU nurse in rapid clinical decision making and more timely patient management. After reviewing monitoring activities in our PACU, four areas were identified in which computerisation could make a contribution and reduce the demands placed on the already overburdened nurses:

* automation of record keeping
* elimination of artifactual data
* consolidation of data displays
* centralisation of alarm messages.

1.2 Objective & Goals of the Study

The objective of this project is to design and develop a PACU clinical management system that detects common adverse events and provides advice to the nurse regarding PACU patients experiencing these events. It is anticipated the PACU clinical management system designed in this project would become a part of a larger process which consists of collecting information about the patient, identifying adverse events and suggesting a course of action. The goals of this project are to:

* minimise artifact in our data base;
* demonstrate the feasibility of collecting on-line continuous monitoring data for epidemiological studies;
* identify variables that predict adverse events through application of appropriate statistical and artificial intelligence (AI) techniques.

This system is intended to aid in the creation of AI rules for the identification and classification of untoward events. The nurse can then be alerted to potentially harmful situations. It is anticipated that this system should contribute to:

* delivery of better PACU patient care
* more efficient management of limited PACU resources, and
* effective data-gathering for research purposes.

1.3 Organisation of the Study

The thesis is organised into seven chapters including this introductory one.

Chapter Two introduces Artificial Intelligence and discusses why medical care is a challenging domain for applying artificial intelligence techniques. It also provides a critical overview of several research projects that apply AI techniques.

Chapter Three presents a basic review of respiratory and cardiovascular physiology, a description of anaesthetic agents, together with an account of complications commonly occurring in the post-anaesthetic period.

Chapter Four describes the purpose of a retrospective study, the environment in which it was carried out, methods used for data analysis and the results obtained from the study.

Chapter Five presents some of the technological developments in clinical monitoring, along with a brief background of computer-assisted monitoring. A discussion is presented of the advantages and disadvantages of invasive and non-invasive techniques, alarms and physiological monitoring in the PACU.

Chapter Six describes the purpose of the prospective study. Included is an overview of previous work in which multivariate techniques have been used to aid medical decision making, a description of the methods used for data analysis and the results obtained from the study.

Chapter Seven presents the main findings of this project, their significance and suggestions for future research on the topic.

1.4 Summary

The patient entering the PACU has just undergone an acute potentially lethal but reversible intoxication for the purpose of achieving the objectives of anaesthesia. Because of the nature of the transition period and the frequent inability of the patient to communicate with those caring for him, it is very important that physiological monitoring be performed. Unless appropriate factors are monitored continuously, it is impossible to determine if the patient is about to experience an untoward event. The information required comes from multiple sources. An approach to the need for continuous assessment of data from multiple sources is to make appropriate use of computers as aids in the task of medical decision making. Computers can integrate, evaluate and simplify data management. The objective of this study is to design and develop a PACU clinical management system to provide advance warning of adverse respiratory and circulatory conditions in PACU patients.

In this chapter the reader has been introduced to the issues of untoward physiological events in the PACU, and objectives of the study. The next chapter will review AI medical models that can be effectively incorporated into a computer along with several research projects that were based on these models.

2.0 CRITICAL REVIEW OF EXPERT SYSTEMS IN MEDICINE

2.1 Historical Background

In the late 1950s scientists first began to suggest that computers were especially suited to assist medical personnel in clinical decision making and alert them of diagnoses which they may have overlooked. In 1959 Ledley and Lusted proposed that computer-based statistical models could enhance the diagnostic and therapeutic skills of the physician [Ledley & Lusted, 1959]. Research on computer-aided diagnosis began with the hope that difficult clinical problems might yield to mathematical formalisms. Most AI work of the next 20 years was mathematical, centred on the application of flow charts, statistical pattern recognition, and decision analysis to the diagnostic process. Artificial Intelligence (AI) was born in the 1956 at the meeting at Dartmouth College (Hanover, CT) where leading computer scientists first articulated notions of machine intelligence. Alan Turing, the famed British mathematician, had suggested an operational definition for computer-based "intelligent behaviour", but it was at the Dartmouth conference that a computer scientist first decided to begin active research in the area [Shortliffe, 1986].

Expert systems in medicine began to be used in the 1960s and focused on the diagnosis part of consultation. These early systems used methods such as pattern recognition through discriminant functions (statistically predicting that a particular pattern would, or would not, occur). Bayesian decision theory (Bayes' theorem

permits us to use personal conditional probabilities to combine evidence with prior information in order to reach a differential diagnosis), and decision tree techniques, the simplest decision making tool (division of a central construct into categories via yes, no branching technique), were based on the assumption that had only one disease category and were unsatisfactory.

In the early 1970s, four experimental systems are generally regarded as having started the research field of artificial intelligence in medicine (Szolovits, 1982).

Present Illness Program: The Present Illness program (PIP) system, uses a frame-system formalism for knowledge representation. Its goal was the acquisition of a present illness and the formalisation of a diagnosis in the domain of renal diseases [Szolovits & Pauker, 1978].

INTERNIST-1: The INTERNIST-1 represents disease knowledge in a taxonomic semantic net format, and the program is capable of discriminating between disease hypotheses [Miller et al., 1982].

MYCIN: The MYCIN program designed to provide consultative advice in the diagnosis and treatment of infections [Shortliffe, 1976], and

CASNET: The Casual Associational Network (CASNET) system is an ophthalmology advisor designed to access diseases states and recommend management for patients with glaucoma. In CASNET, knowledge representation is in the form of a semantic net of nodes, links, and tests [Kulikowski & Weiss, 1982].

2.2 Expert Systems and Knowledge-Based Systems

The term "expert-system" originally implied a computer-based consultation system using Artificial Intelligence techniques to emulate the decision-making behaviour of an expert in a specialised knowledge-intensive field [Duda & Shortliffe, 1983]. The term expert system seems to have had its origin at Stanford University in the development of DENDRAL [Feigenbaum et al., 1971]. The DENDRAL program was able to help identify unknown compounds from their mass spectral data. The program first had to be provided with certain rules of chemistry in order to eliminate impossible structures. The procedure for developing an expert system is essentially as follows. A "knowledge engineer" interviews a human expert representing a particular field, and attempts to extract the specific knowledge the expert needs and uses at work. This process is called knowledge acquisition and the objective is to develop a series of rules ("If-then" rules) that will fully capture the expert's performance if adequately coded in the program (this is known as knowledge representation). When case-specific data are entered (the "if" part is supplied), then the logic program (or inference engine) goes to work and generates the "then" consequences.

Knowledge-based systems are used for interpretation of data about a specific problem, in the light of knowledge represented in the knowledge base, to develop a problem specific model and then to develop plans for problem solution [Williams, 1982]. The knowledge-based system is comprised of two components. The first

component is the descriptive or factual knowledge base. The second is the normative knowledge. Normally the term knowledge refers to a body of information about a particular topic that is organised to be useful.

One of the earliest "knowledge-based" information system is available to us [Saggs, 1962]. During the reign of Ashurbanipal (ca. 650 B.C.), his library at Nineveh contained up to 10,000 clay tablets devoted to a collection of "omen literature". These documents consist of advice represented in the form of "if-clauses", followed by appropriate "then-clauses". These "if-then" statements purported to provide expert advice about the future given current circumstances or portents. For example: "If a man unwittingly treads on a lizard and kills it, he will prevail over his adversary" [Blois, 1987].

Two knowledge-based systems are the most common and best understand approaches:

Rule-Based Systems

Frame-Based Systems

Rule-based systems are the most common form of knowledge representation technique. They are a collection of if-then prepositions for storing strategies or directions. In a medical diagnosis expert system, the findings for a particular patient

would be compared with several "if" propositions. When a match is found, the then "portion" would execute and a diagnosis or resulting plan would be recommended. Inference chains can be directed either backward, forward or a mixture of both, depending on the nature of the task that the expert system is performing. In backward chaining, the system starts with the goals the user has listed in the knowledge base and works backward via rules to determine what initial data are required to determine if that goal can be recommended. Forward chaining systems must be provided initial data before they begin to examine their rules. The system keeps cycling until it has made all the inferences it can. Generally, backward chaining systems are most commonly used in consultation systems and for diagnostic and monitoring problems. Forward chaining systems are most commonly used for signal processing systems (i.e. systems that derive their data from sensors rather than by asking questions to users) [Harmon & Maus, 1988].

Frame-based systems capture prototypical situations and reason primarily by matching those prototypes against specific instances. Each frame contains facts and rules that address a piece of the overall problem. They are related to each other by a frame tree that describes their hierarchical structure. Frames have become to mean a number of different things and have been used in many different ways, since first suggested by Minsky [Minsky, 1975]. According to Davis (1987), four basic concepts appear common to the different conceptions.

1. A frame contains information about a prototypical instance. In medical applications, for example, a frame is used to describe a prototypical or "classic" case of a disease.

2. Reasoning with frames is a process of matching prototypes against specific individuals. For example, a specific patient is matched against a collection of disease prototypes to find the closest match.

3. Frames are often organised into taxonomic hierarchies, providing an economy of knowledge representation and reasoning mechanism.

4. The information within a single frame is typically expressed as a collection of slots, each of which has one or more values in it.

2.3 Models for Medical Reasoning

2.3.1 Critiquing Model

In the critiquing model, a user states his or her own management plan, or diagnosis, and the program interrupts only if the plan is judged to the significantly inferior to what the program would have recommended [Langlotz & Shortliffe, 1983]. The system critiques that plan, discussing the risks and benefits of the proposed approach and leaves the primary decision making with the physician. Miller (1985) points out that critiquing may be particularly well-suited to domains where decisions involve a significant amount of subjective judgment. Prototype systems such as ATTENDING (Miller, 1983) and VQ-ATTENDING (Miller, 1985) use the critiquing approach to provide computer-based advice.

2.3.2 Causal Model

In ordinary human terms, we understand a problematic situation when we have a causal explanation. To capture the richness of medical knowledge and clinical reasoning a causal model approach was adopted by the computer in reasoning about medical problems. The causal knowledge in the program is organised at several levels of detail. This knowledge at each level of detail is organised in terms of nodes

and links. Nodes are clusters of information that describe physiological and clinical states. Causal links may connect a node describing a disease or a clinical state to one or more nodes which describe the effects [Patil, 1987]. A pioneering AI system that explores causal modeling is the Acid-Base and Electrolyte Consultant system (ABEL) which consists of hierarchical representations of physiological, anatomical, aetiological and temporal knowledge [Patil, 1987]. An interesting aspect of ABEL's design is that it views diagnosis as a process of constructing a model or a theory that can explain a given patient's illness.

2.3.3 Qualitative Causal Model

People seem comfortable thinking about many problems in qualitative terms. A qualitative causal model is one which the various quantitative values are expressed into qualitative judgments. The relevant characterisation of blood pressure, heart rate might be low, normal or high rather than numerical. For example a heart rate of 120 beats/min may be considered normal if blood pressure has recently fallen to abnormally low values, but considered abnormal in other clinical settings [Rennels & Miller, 1988].

2.3.4 Temporal Reasoning

Many expert systems gather information and offer recommendations at a single moment in the patient's clinical course. Projects such as INTERNIST-1 and MYCIN followed the temporal modelling approach recommending diagnosis for a given moment in time. MYCIN gathers data, diagnoses the cause of infection, and recommends antibiotics for a given moment in time. Rennels points out that it is desirable to develop computer systems in the areas like operating rooms and intensive care unit (since medical care takes place over time), that can evaluate patient's clinical status and response to treatment over time. The authors also proposed that a related research project is how to design a computer system to scan a clinical time-ordered database (such as an operating, anaesthetic record) and summarise the clinical course, as the physician might do [Rennels & Miller, 1988].

2.3.5 Rule-Based Explanation

A computer program that models an expert in a given domain is more likely to be accepted by experts in that domain, and by non experts seeking its advice, if the system can explain its actions. The process of trying rules and taken actions can be compared to reasoning, and explanations require displays of how the rules use the information provided by the user to make various intermediate deductions and finally to arrive at the answer. The purpose of explanation capability (EC) is to give the

user access to as much of the system's knowledge as possible [Carlisle et al., 1984]. Explanation capability from projects such as MYCIN and XPLAIN [Swartout, 1981], allows the user to analyse the process by which the program arrived at a therapy recommendation.

2.4 Prototype Expert Systems

2.4.1 ATTENDING System

As described by Miller (Miller, 1983) the ATTENDING computer system is designed to critique an anaesthetist's preoperative plan for anaesthetic management. To use ATTENDING the anaesthetist first inputs the following:

* list of the patient's medical problems;
* the planned surgical procedure;
* the anesthetist plan for preanaesthetic medication, induction, intubation and maintenance of anaesthesia.

The ATTENDING system then critiques this plan discussing the risks and benefits of the proposed approach and other reasonable approaches. The system serves as feedback to help the anaesthetist evaluate and optimise his proposed approach. ATTENDING uses "Augmented Decision Networks" (ADNs) to represent alternative approaches to anaesthetic management. In ATTENDING each risk is assigned a rough estimate of its magnitude (LOW, MODERATE, HIGH or

EXTREME), instead of reducing anaesthetic risks to numbers to allow precise comparison. ATTENDING is implemented in the LISP programming language. In summary ATTENDING is designed to critique the anaesthetic management and primarily to outline the pros and cons to the physician's attention. It is left up to the physician to select the final plan.

2.4.2 VQ-ATTENDING

VQ-ATTENDING is a prototype expert system designed to critique aspects of a physician's ventilator management of a patient receiving mechanical respiratory support (Miller, 1985). VQ-ATTENDING implementation explores how underlying treatment goals might be made explicit. According to Miller (1985), VQ-ATTENDING separates its knowledge of ventilator management in two parts:

* strategic treatments about treatment goals
* tactical knowledge about management choices

To use VQ-ATTENDING the physician inputs the following information:

* a small amount of basic medical information describing the patient who is receiving mechanical respiratory support;

* a current set of Arterial Blood Gas (ABG) data;

* current ventilator settings, and

* proposed set of new ventilator settings.

VQ-ATTENDING then produces an English prose analysis to discuss the appropriateness of the proposed settings based on the assessment of appropriate treatment goals. The particular ventilator settings which the system critiques are:

* Fractional inspired oxygen (FiO2);

* Positive End-Expiratory Pressure (PEEP);

* Respiratory Rate (RR);

* Tidal Volume (TV);

* Mode (the ventilator mode);

* Dead space.

Figure 2.1 shows the schematic overview operation of VQ-ATTENDING.

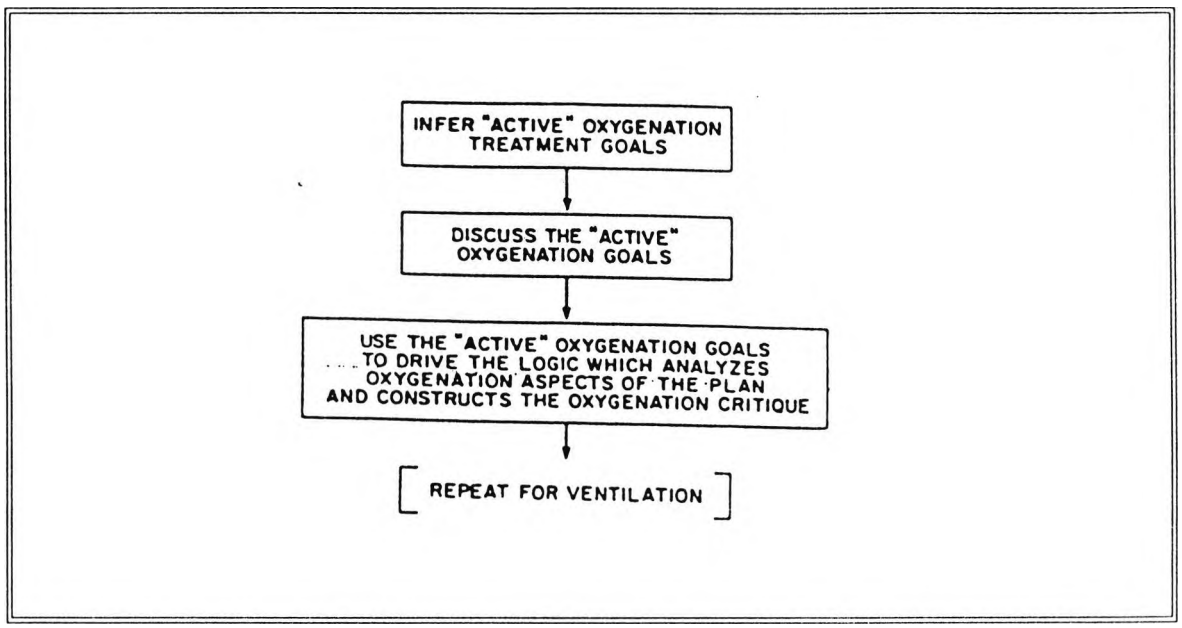
To implement a goal-directed system you should:

* define the various goals of therapy;

* specify the conditions which cause each goal;

* indicate how the different goals affect management decisions.

Figure 2.1: VQ-ATTENDING (Adapted from Miller, 1985).



In summary, VQ-ATTENDING is a goal-directed critiquing system designed to assess appropriate treatment goals and to use these goals to guide the system's critiquing analysis.

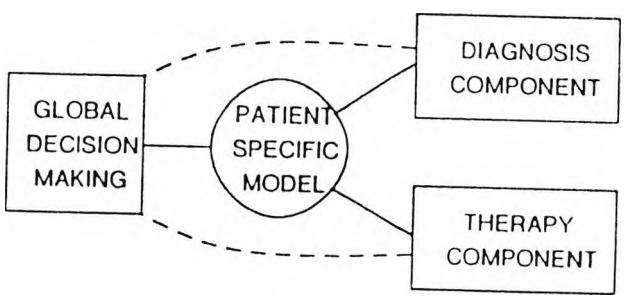
2.4.3 ABEL

The Acid-Base and Electrolyte Consultant (ABEL), (Patil et al, 1981), knowledge base includes descriptions of causal mechanisms, that capture the relation between the severity and duration of cause and effect.

According to Patil (1987), ABEL consists of four major components (Figure 2.2) the:

* Patient - Specific Model (PSM);
* Global Decision Making component;
* Diagnostic component;
* Therapy component.

Figure 2.2: The ABEL system (Adapted from Patil et al., 1982).



The ABEL is organised around knowledge of the patient and the program's hypotheses as represented by the Patient-Specific Model. The global decision-making module invokes specialists for diagnosis and for planning and execution of treatment.

PSM attempts to explain all the known facts about the patient. The PSM is used as a central data base structure with which other components of the system may reason. A critical feature of the PSM is its ability to determine interactions among multiple diseases. The global decision-making component has the responsibility of calling other programs. It calls the diagnostic and therapy programs to carry out some specific task.

PSM includes data about the patient as well as the program's hypothetical interpretations of these data in causal hierarchical networks. The operations for constructing the PSM from the program's medical knowledge and from specific data about the patient were:

* Initial formulation;
* Aggregation;
* Elaboration;
* Projection;

These operators interact with each other because the complete PSM must be self-consistent both within each level and across all its levels. In summary, ABEL explores how the causal links can help the system reason about the underlying pathophysiology of acid-base and electrolyte disorders.

2.4.4 VENTILATOR MANAGER

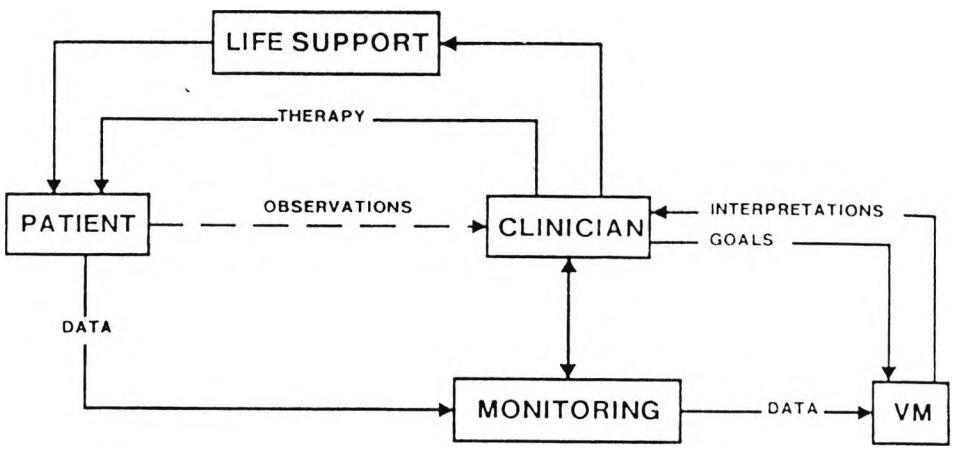
The Ventilator Manager (VM) is a prototype system designed to interpret on-line qualitative data in the Intensive Care Unit (ICU) of a hospital (see Figure 2.3) [Fagan et al., 1984]. The VM system is designed to help physicians and nurses to manage post-operative patients receiving mechanical ventilatory assistance. VM was strongly influenced by the MYCIN architecture. The difference between the two systems is that the VM system was designed to interpret measurements over time and MYCIN was based on the data available at one particular time. VM was developed between 1978 and 1980, before the current generation of ventilators were widely used.

According to Fagan (1984), the system was designed to perform five specialised tasks in the ICU:

1. detect possible errors in measurement;
2. recognise untoward events in the patient/machine system and corrective action;
3. summarise the patient's physiological status;
4. suggest adjustments to therapy based on the patient's status over time and long-term therapeutic goals, and
5. maintain a set of case-specific expectations and goals for future evaluation by the program.

Figure 2.3

The complete VM system (Adapted from Fagan et al., 1984).



VM system configuration. Physiological measurements are gathered automatically by the monitoring system and provided to the interpretation program. The summary information and therapeutic suggestions are sent back to the ICU for consideration by clinicians.

The complete system includes the patient monitoring sensors in the ICU, and the VM measurement interpretation program. The VM program run under the Stanford University Medical Experimental Computer for Artificial Intelligence (SUMEX-AIM), PDP-10 computer.

The VM uses a set of rules that are applicable at a particular point in time and have a fixed structure. The importance of a rule is constructed from the conjunction

or disjunction of a set of clauses. Each clause checks relationships about one or more of the parameters known to the program. VM consists of four types of if-then rules:

Status rules: Status rules make judgments about the patient's cardiovascular and respiratory events.

Transition rules: Transition rules in VM allow the program to notice changes in a patient's state.

Instrument rules: Instrument rules attempt to identify artifactual data.

Therapy rules: Therapy rules recommend action based on the conclusions drawn from the first three types of rules. Therapy rules can be divided in two classes:

* the long term therapy assessment, and
* the determination of response to clinical problem.

The VM program's output is in the form of periodic graphical summaries of the major conclusions of the program and short suggestions for the clinician. Summaries include:

* a description of current conclusions (eg., PATIENT HYPERVENTILATING FOR 45 MINUTES);

* a graph with time on one axis (up to six hours) and recent conclusions on the other, and

* a similar graph with time versus measurements that are beyond the expected limits.

In summary, VM is designed to aid physicians and nurses managing postoperative patients' respiratory and cardiovascular variables in real time.

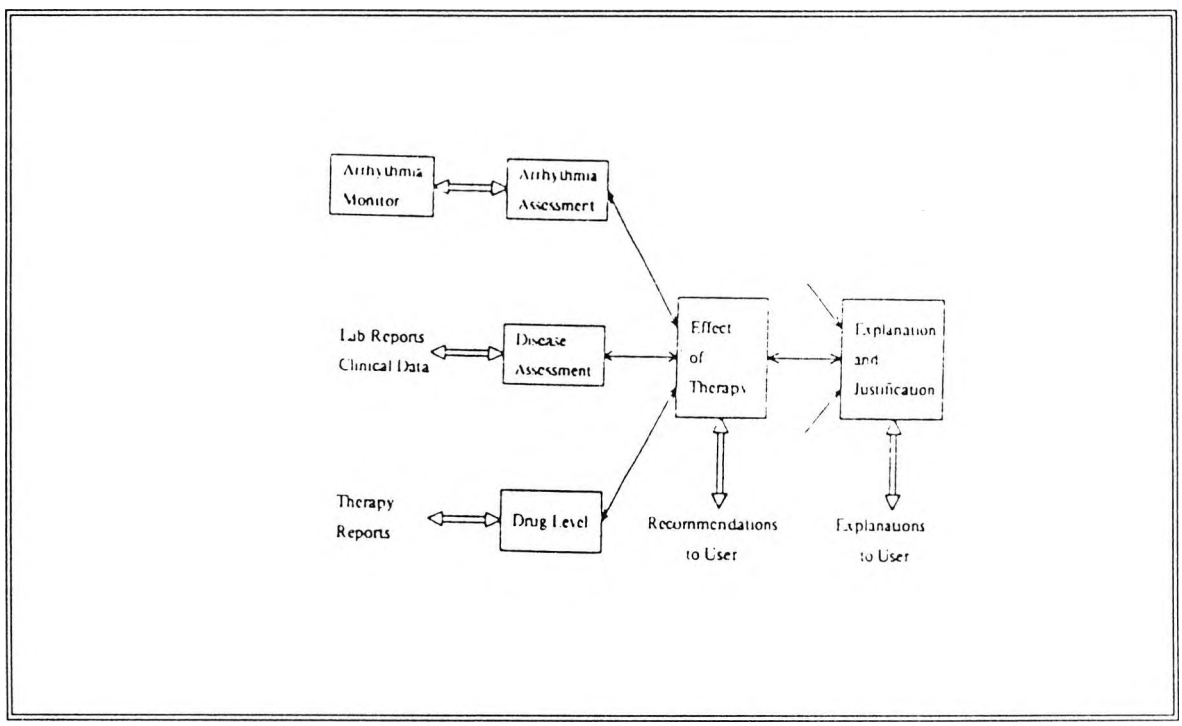
2.4.5 VENTRICULAR ARRHYTHMIA MANAGEMENT ADVISOR

The Ventricular Arrhythmia Management Advisor (VAMA) program is designed to accept information from various sources, assess it in the context of the patient, and to provide a concise summary of the state of the patient [Long et al., 1983]. This research is an extension of earlier work done in the area of cardiology with the Digitalis Therapy Advisor [Gorry et al., 1978]. The VAMA project took place in a Cardiac Care Unit (CCU) and is being carried out by MIT and Boston University.

As illustrated in Figure 2.4, VAMA requires data from more than one source to make a reasonable recommendation.

Figure 2.4

VAMA Basic Module (Adapted from Long & Russ, 1983).



According to Russ (1982), the complete management program consists of three major functional units:

Arrhythmia Assessment module: The Arrhythmia module analyses data from the EKG monitor in order to evaluate electrical disturbances and to provide an evaluation of the patient's state;

Disease State module: The Disease State module seeks to identify the underlying disease process using EKG, clinical and laboratory data;

Therapy Planning and Evaluation module: The Therapy planning is carried out on the basis of the best estimate available about the nature of the problem and its seriousness.

An interesting aspect of VAMA's design is its integration of multiple sources of knowledge and its ability to consider temporal trends. In summary, VAMA is designed with the goal to accept information from various sources, assess it in the context of patient, and to provide a concise summary of the cardiac care unit patient.

2.4.6 HARRISON's System

Harrison and Johnson (1980) built a system designed to aid the anaesthetist in planning intraoperative management. The patient's clinical details are entered into the computer suggesting recommendations in a systematic way:

* urgency of procedure;
* age of patient;

* medical problems;

* surgical requirements, and

* coexistent drug therapy.

The instructions and advice are stored in the computer under the following six headings:

* preparation;

* premedication;

* induction/intubation;

* maintenance and reversal;

* postoperative care, and

* drug interactions.

The system produces a set of recommendations which includes:

* avoid action X;

* specially recommended action X;

* use action X;

The initial program was written in FORTRAN and run under the RT-11 operating system. Dodson, Harrison and Rector (1983) built on Harrison's initial system and they developed a "medical treatment planner" for anaesthetic

management written in the PROLOG programming language. The PROLOG implementation, in addition to Harrison's rules, includes taxonomic facility and explanation reasoning. In summary, Harrison's system is a ruled-based consultation system for anaesthetic management. It is designed primarily to serve as a "reminder" to the anaesthesiologist that certain actions might need consideration, and reimplemented later to include taxonomic knowledge and explanation capability [Dodson et al., 1983].

2.4.7 Creighton On-line Multiple Medical Expert System

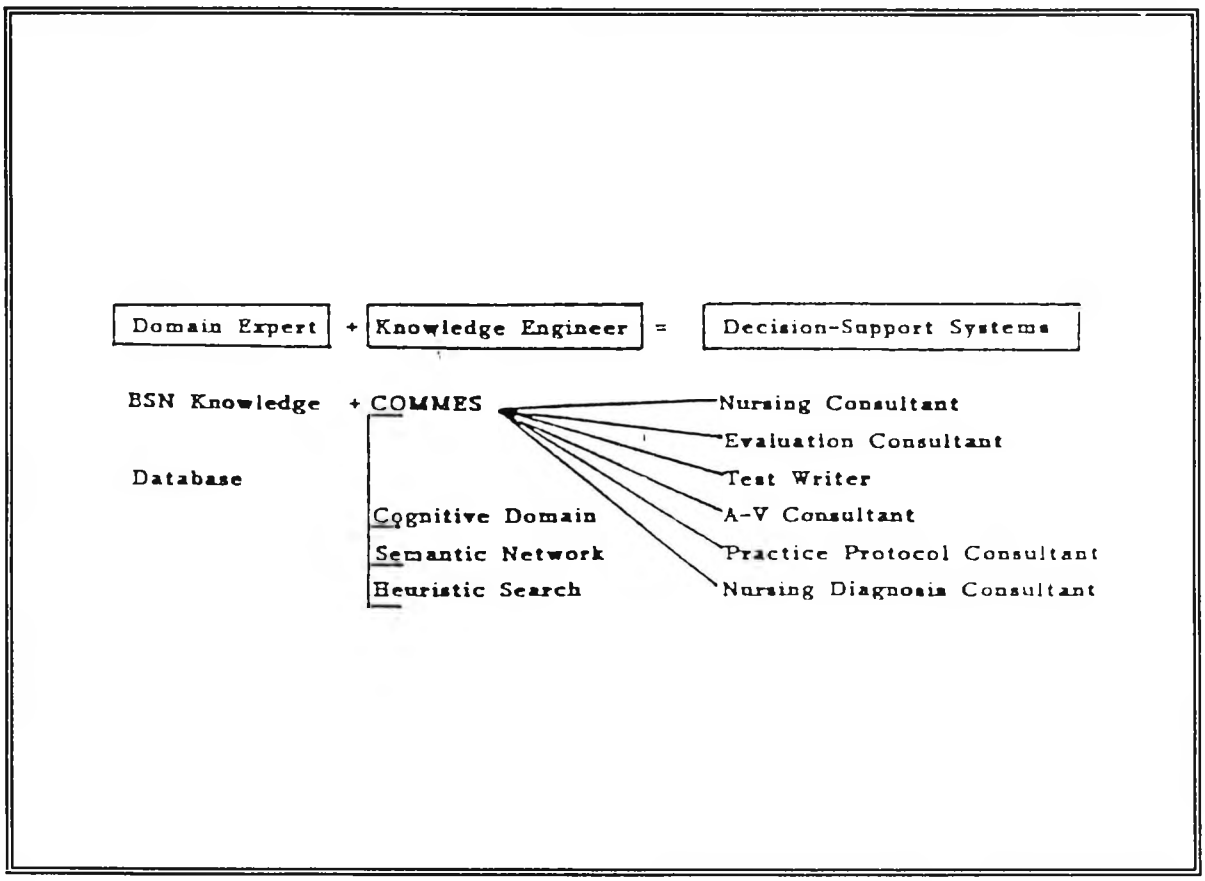
The Creighton On-line Multiple Medical Expert System (COMMES) system was based on the Creighton University's Health Sciences Center were designed and reported in 1974 by Evans (1974). The system, after being refined and tested in numerous sites under diverse situations for a number of years, was available for official external distribution in the middle of September 1983 [Evans, 1985].

COMMES is an Artificial Intelligence based system simulating a professional consultant to assist and support clinical decision making about a patient's condition. The system is built as a semantic network which includes more than 20,000 terms based on the objectives of the undergraduate baccalaureate nursing curriculum.

These terms are organised hierarchically, and heuristics are based on associative inferences. Figure 2.5 shows the components of a nursing expert system.

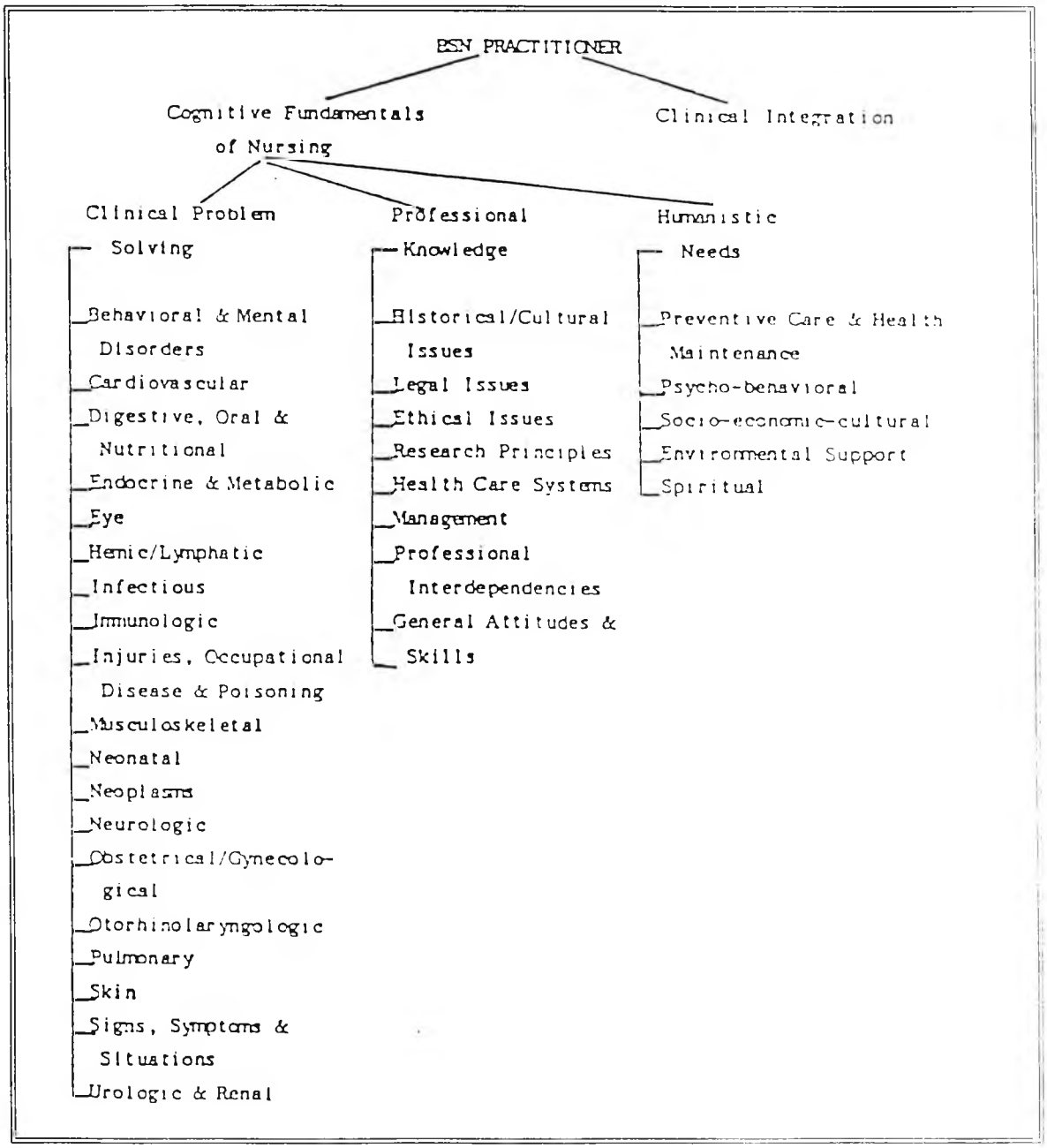
Figure 2.5

Components of Nursing Expert Systems (Adapted from Ryan, 1985).



Within clinical problem-solving, one component of the COMMES system, patient conditions are organised according to 19 medical diagnostic areas (Figure 2.6), [Ryan, 1985].

Figure 2.6: Cognitive Structure (Adapted from Ryan, 1985).



The COMMES system allowed for individualised consultations about patient problems, continuing education, and program development for in-service departments. Nursing practice protocols generated by the system were used to develop standards of care [Ryan, 1983].

2.5 Summary

The field of expert systems is one of the most active and exciting areas of applied research in Artificial Intelligence. The literature in the past decades has shown that programs can mimic a human expert. In the context of this chapter several medical models were also introduced. These models when properly applied, can be effectively incorporated into a computer to enhance its reasoning. Several prototype expert systems were based on these models. Some of these medical prototypes were reviewed and described according to their medical domain. Furthermore, their contribution to AI problems provided new insights for the development of expert systems in medicine.

Chapter Three discusses respiratory and cardiovascular physiology along with common post-anaesthetic complications.

3.0 BASIC PHYSIOLOGY

Cells need a continuous supply of oxygen to carry out the activities that are vital to their survival. Many of these activities create quantities of carbon dioxide. Since an excessive amount of carbon dioxide produces acidic conditions that are poisonous to cells, the gas must be eliminated quickly and efficiently. The two systems that both supply oxygen and eliminate carbon dioxide are the **cardiovascular** system and the **respiratory** system. The respiratory system consists of organs that exchange gases between the atmosphere and blood. These organs are the nose, pharynx, larynx, trachea, bronchi, and lungs. The cardiovascular system transports the gases in the blood between the lungs and the cells [Tortora & Anagnostakos, 1984]. Most of the following discussion on respiratory and circulatory physiology and anaesthetic agents has been summarised from the Drain and Christoph textbook [Drain & Christoph, 1987].

3.1 Respiratory Physiology

Respiration is defined as the process by which oxygen and carbon dioxide are exchanged between the outside atmosphere and the cells in the body. Life cannot be sustained without respiration, that is the consumption of oxygen and the production of carbon dioxide by cells. Ventilation brings oxygen into the blood and removes carbon dioxide. Drain and Christoph (1987) explain that care of the PACU patient

requires knowledge of the physiology and pathophysiology of the lung volumes and capacities. The lung volumes are as follows:

Tidal Volume represents the amount of air moved into and out of the lungs during a normal ventilatory excursion. Only about 70 percent of the tidal volume actually reaches the alveoli. The other 30 percent remains in air spaces of the nose, pharynx, larynx, trachea, and bronchi and is known as dead air volume (dead space). Clinically, the tidal volume can be estimated at 7ml per kg. For example, a 80 kg man will have a tidal volume of approximately 560 ml (7 X 80 = 560) [Drain & Christoph, 1987].

Expiratory Reserve Volume (ERV) is the maximum amount of air that can be expired from the resting position following a normal spontaneous expiration. It reflects muscle strength, thoracic mobility, and balance of forces that determine the resting position of the lungs and chest wall following a normal expiration [Drain & Christoph, 1987].

Residual Volume (RV) is the volume of air that remains in the lungs at the end of a maximum expiration. This lung volume represents the balance of forces of the lung elastic forces and thoracic muscle strength [Drain & Christoph, 1987].

Inspiratory Reserve Volume (IRV) is the maximal volume of air that can be inspired at the end of a normal spontaneous inspiration. It reflects a balance of the lung elastic forces, muscle strength, and thoracic mobility [Drain & Christoph, 1987].

The definition of each capacity is followed by its typical normal value in a healthy adult.

Lung capacities:

Inspiratory Capacity (IC) is the maximum volume of air that can be inspired from the resting expiratory position. The IC, the total inspiratory ability of the lungs, is the sum of the tidal volume plus inspiratory reserve volume (3,600 ml) [Drain & Christoph, 1987].

Functional Residual Capacity (FRC) represents the previously mentioned resting position. The FRC is the volume of air remaining in the lungs at the end of a normal expiration when no respiratory muscle forces are applied. The FRC is the sum of residual volume plus expiratory reserve volume (2,400 ml) [Drain & Christoph, 1987].

Vital Capacity (VC) is the amount of air that can be expired following the deepest possible inspiration. It is the sum of the tidal volume, the expiratory

reserve volume, and the inspiratory reserve volume (4,800 ml) [Drain & Christoph, 1987]. Measurement of vital capacity is particularly valuable, because it provides information regarding the ability of the patient to respond to commands, ascertains the adequacy of the respiratory drive and coordination of the chest wall and lung mechanics, and gives some indication of the severity of pre-existing lung disease [Orkin & Shapiro, 1982].

Total Lung Capacity (TLC) is simply the total amount of air in the lung at a maximal inspiration. The total lung capacity is the sum of the vital capacity and the residual volume (6,000 ml) [Drain & Christoph, 1987].

The TLC, FRC, and RV are difficult to measure clinically because these measurements include a gas volume that cannot be exhaled. Therefore, performance of these measurements requires sophisticated pulmonary function testing equipment utilising gas dilution techniques or plethysmography [Drain & Christoph, 1987].

Respiration is defined as the gas exchange between cellular levels in the body and the external environment. There are three phases of respiration [Drain & Christoph, 1987]:

ventilation, the phase of moving air in and out of the lungs;

transportation, which includes diffusion of gases in and out of the blood in both pulmonary and systematic capillaries, and the reactions of carbon dioxide and oxygen in the blood;

gas exchange, during all respiration, in which oxygen is utilised and carbon dioxide is produced as a waste product.

Blood gas transport is the important link in carrying gas to or from the cell. Oxygen is carried in the blood in two forms: in combination with haemoglobin or in simple solution. About 98 percent of the oxygen transported from the lungs to the cells is carried in combination with haemoglobin in the red blood cell. It is a reversible chemical combination. The remaining 2 percent is dissolved in the plasma and in the cytoplasm of the red blood cell. When the blood passes through the lungs, it does not normally become completely saturated with oxygen. Usually, the haemoglobin will become about 97 percent saturated.

The transport of carbon dioxide begins within each cell in the body. The carbon dioxide is mainly a by-product of the energy-supplying mechanisms of the cell. Approximately 200 ml per minute of carbon dioxide are produced within the body at rest. Carbon dioxide is 20 times more soluble in water than oxygen, therefore it traverses the fluid compartments of the body very rapidly [Drain & Christoph, 1987].

The administration of oxygen to the patient in the PACU is an important facet in the emergence phase from anaesthesia. Oxygen is given to the PACU patient

primarily because he/she has a blunted or depressed response to carbon dioxide and low lung volumes [Drain & Christoph, 1987].

3.1.1 Respiratory Complications in the PACU

Factors which may contribute to post-operative respiratory complications include: respiratory depression from pre-operative medication; anaesthetic agents; diffusion hypoxaemia; use of muscle relaxants; pain of surgical origin; dressing and bindings incidental to the surgical procedure; and the position of the patient.

The immediate post anaesthetic period is an extremely hazardous time for the patient when respiratory obstruction, aspiration of vomitus, and hypoventilation may occur. The function of the respiratory system is the delivery of oxygen to, and the elimination of carbon dioxide from the blood. Any respiratory complication will, if uncorrected, lead to inadequate oxygenation (hypoxaemia) and/or retention of CO_2 (hypercarbia), and these conditions must be readily recognisable by PACU staff [Eltringham et al., 1983].

Early recognition and treatment of complications may prevent the development of life-threatening situations. The most serious complication are considered here:

Airway Obstruction, is a potentially catastrophic complication. Respiratory problems generally are caused when the soft tissues of the mouth and pharynx interfere with the upper airway. Occasionally, obstruction may be caused by

haematoma or laryngeal oedema following trauma, or by foreign material in the pharynx (such as a dislodged tooth, mucous or saliva). Therapy includes extension of the head, insertion of an oropharyngeal or nasopharyngeal airway or positive-pressure ventilation [Cullen, 1977; Orkin & Shapiro, 1982].

Bronchospasm is the constriction of the bronchial airways due to an increase in smooth muscle tone in the airways. Factors leading to bronchospasm include irritation of the upper airway during emergence from anaesthesia, pre-operative history of smoking, bronchitis or asthma [Drain & Christoph, 1987].

Aspiration, during or following anaesthesia and surgery, though no longer common, still poses severe hazards to the unconscious patient. Aspiration may occur during pre-operative administration of narcotics, the passage of gastric tubes, gastroscopy and contrast radiography. Inhalation of stomach contents, bloody drainage, or other foreign material into the lungs is another adverse process that can occur after administration of anaesthesia. Expert clinical judgement is necessary to determine the best time to extubate such a patient [Fraulini, 1987].

Pneumothorax is a collection of air or gas within the pleural cavity [Drain & Christoph, 1987]. Pneumothorax can occur after thoracic surgery and with the use of brachial plexus and intercostal blocks. Symptoms include dyspnoea,

tachypnoea, hyper-resonance to percussion and absent breath sounds. When pneumothorax is suspected, clinical care includes calming the patient and sitting him/her upright in bed. Oxygen should be administered to relieve dyspnoea. A chest X-ray is the best way to confirm the diagnosis. [Cullen, 1982; Fraulini, 1987].

Hypoventilation is underventilation of the alveoli in the relation to the amount of carbon dioxide being produced by the body [Drain & Christoph, 1987]. Hypoventilation occurs when the patient is unable to spontaneously ventilate an adequate amount of alveolar gas to remove carbon dioxide. The result is hypercarbia and hypoxaemia if supplemental oxygen is not administered. Causes of hypoventilation in the immediate post-operative period include:

1) Insufficient respiratory drive. Central respiratory depression may be due to drugs given during anaesthesia.

2) Residual muscle paralysis. Respiratory muscle dysfunction is almost always the result of residual neuromuscular blockade [Cullen, 1982].

3) The site of incision affects the ability to take a large breath as measured by vital capacity. Nearly all patients have reduction in vital capacity, showing as much as a 60 percent reduction on the day of surgery [Fraulini, 1987].

4) Intrinsic lung disease. Intrinsic lung diseases which may lead to hypoventilation include chronic bronchitis and emphysema, bronchospastic disorders, restrictive lung disease, and disorders associated with a high wasted ventilation such as pulmonary embolism. In the immediate post-operative period, bronchospasm often occurs if the endotracheal tube causes airway irritability.

5) Increased CO_2 production. Increased CO_2 production is common in the PACU because of emergence excitement, shivering and sometimes hyperthermia [Cullen, 1982].

Hypoxaemia is defined as decreased oxygen tension in the blood. Mild hypoxaemia (PaO_2 70-90 mm Hg breathing room air) is expected for 48 hours in patients with normal, uncomplicated recovery. Moderate hypoxaemia (PaO_2 50-70 mm Hg breathing room air) is common in patients with pre-existing pulmonary disease and pulmonary complications [Fraulini, 1987]. Factors leading to hypoxaemia include a decreased inspired oxygen concentration, ventilation/perfusion abnormalities caused by regional underventilation, increased oxygen consumption caused by shivering, fever, restlessness, emergence excitement and hyperthyroidism. Hypoxaemia in the PACU is difficult to detect clinically until desaturation is extreme [Cullen, 1982].

3.2 Cardiovascular Physiology

The blood, heart, and blood vessels constitute the cardiovascular system. The red fluid that flows through all vessels except the lymph vessels is called **blood**. Blood is a viscous fluid - it is thicker and more adhesive than water. Blood is a complex liquid that performs a number of critical functions:

* it transports oxygen from the lungs to all cells of the body
* it transports carbon dioxide from the cells to the lungs
* it transports nutrients from the digestive organs to the cells
* it transports waste products from the cells to the kidneys, lungs, and sweat glands, etc [Tortora & Anagnostakos, 1984].

The heart is the centre of the cardiovascular system. It is a hollow, muscular organ that weighs about 342 grams and beats over 100,000 times a day to pump blood through over 60,000 miles of blood vessels. The blood vessels form a network of tubes that carry blood from the heart to the tissues of the body and then return it to the heart [Tortora & Anagnostakos, 1984]. The **heart** is a four-chambered mass of muscle that pulsates rhythmically, pumping blood into the circulatory system. The heart rate can range from 20 or 30 to approximately 250 beats per minute. When complete sympathetic blockade is present, the intrinsic heart rate will average 1 to 5 beats per minute. The chambers of the heart are the atria and the ventricles [Drain & Christoph, 1987].

The **atria**, which are the pathways for blood into the ventricles, are thin walled, have myocardial muscle, and are divided into the right and left atria by a partition down the middle. During each cardiac cycle, approximately 70 percent of the blood flows from the great veins through the atria into the ventricles before the atria contract. The other 30 percent is pumped into the ventricles upon contraction of the atria. The **ventricles** receive blood from the atria and then act as pumps to move blood through the circulatory system. During the first third of diastole, the atrioventricular valves open and blood rushes into the ventricles. At the end of diastole each ventricle usually contains approximately 120 ml of blood. This is the **end-diastolic volume**. During systole, each ventricle will eject 70 ml of blood, which is the **stroke volume**. The blood that remains in the ventricle at the end of systole is **end-systolic volume** and amounts to approximately 50 ml [Drain & Christoph, 1987].

Cardiac output (CO) is the amount of blood ejected from the left ventricle into the aorta by the heart each minute. Instantaneously, the output of the right and left ventricles may not be equal, and the venous return may not match the outflow of the left ventricle owing to pooling of blood in the periphery, in the pulmonary circuit, or within the heart itself. However, over any prolonged period of time the venous return and cardiac output and the outputs of both ventricles must be equal [Shander & De Angelis, 1982]. In the normal adult with a heart rate of 70, cardiac output is approximately 4900 ml. This estimate can be derived by taking the rate of 70 times the stroke volume of 70 ml. The information derived from serial

measurements of the cardiac output can be most helpful in the assessment of the general status of the cardiovascular system as well as in the determination of the appropriate amount and type of fluid therapy for the patient [Drain & Christoph, 1987].

Stroke volume, the second factor in the determination of cardiac output, refers to the volume of blood ejected by each cardiac contraction and is itself a function of three variables:

Preload, relates the energy of contraction to the initial fiber length. Factors determining preload include total blood volume, body position, venous tone, intrathoracic pressure, atrial contraction, and intrapericardial pressure.

Contractility, a measure of cardiac performance, is the second determinant of stroke volume if preload, heart rate, and afterload are held constant. Others factors affecting contractility include catecholamines, loss of muscle mass, hypoxaemia, and anaesthetic agents.

Afterload, is the final determinant of stroke volume, which is the wall stress developed by the ventricle during contraction. It is related to the shape, volume, and thickness of the ventricle as well as to the arterial blood pressure.

The **arterial blood pressure** probably is the widely used haemodynamic measurements to assess the circulatory stability of the patient. The arterial blood pressure is composed of the systolic and diastolic arterial pressures. The **systolic blood pressure** is the highest pressure that occurs within an artery during each contraction of the heart. Systolic arterial pressure is considered by some most important. Systolic pressure reflects hypertension and hypotension. It also reflects the oxygen requirement of the heart because a high pressure generated by the heart is associated with a high consumption of oxygen. The **diastolic blood pressure** is the lowest pressure that occurs within an artery during each contraction of the heart. The **mean arterial pressure** (MAP) is the average pressure that pushes blood through the systemic circulatory system [Drain & Christoph, 1987]. The formula used to approximate this pressure is MAP = diastolic pressure + 1/3 pulse pressure (systolic pressure - diastolic pressure) [Klein, 1984]. Many factors play an important role on the arterial blood pressure. Drugs can affect both the function of the heart and the peripheral vascular resistance.

3.2.1 Cardiovascular Complications in the PACU

The stress of surgery and administration of anaesthesia can produce a number of alterations in cardiovascular performance. Cardiac arrhythmias, hypotension, hypertension, bradycardia or tachycardia may be witnessed in the post-anaesthetic patient [Borchardt & Fraulini, 1987]. Decreases in blood pressure 20 to 30 percent below pre-operative levels should be considered significant. The most serious cardiovascular complications are:

Hypotension (hypo = below; tension = pressure) can be defined as a fall in systolic blood pressure to less than 90 mm Hg, or a 50 mm Hg fall in an individual whose blood pressure was elevated above normal range [McCovern & Tillen, 1980]. Before instituting any therapy, the following need to be reaffirmed: blood pressure is real and not artifactual due to an error in blood pressure measurements, the differential between one extremity and the other, and miscalibration of a transducer.

Clinical signs of hypotension include:

* Colour - pale or grey
* Skin - cold, clammy, diaphoretic
* Pulse - rapid, thready
* Respiration - rapid and shallow
* Cerebral ischaemia - disorientation, restlessness, anxiety.

Therapy for hypotension includes: fluid infusion, reversal of anaesthetic depressants, and treatment of arrhythmias and bradycardia, if present [Cullen, 1977; Cullen, 1982].

Hypertension is defined as a persistently elevated blood pressure (higher than the norm for the age of the patient). Hypertension occurs quite often in the post-operative period and is most common in PACU patients with a previous history of hypertension. Treatment is usually needed if the systolic pressure is greater than 180 mm Hg, or diastolic pressure exceeds 120 mm Hg in previously normal patients. Factors leading to hypertension include: pain; emergence excitement; distension of bladder; cardiovascular surgery; and drugs during anaesthesia. Once pain, bladder distension and respiratory complications have been treated, the blood pressure usually reverts to normal within 2 hours without the need for specific treatment. Administration of antihypertensive agents may become necessary, depending on the severity of the hypertension [Cullen, 1982; Eltringham et al., 1983].

Bradycardia (brady = slow) is defined as a heart rate of less than 60 beats per minute. Factors leading to bradycardia include: continuing action of drugs used before or during anaesthesia; pain; hypoxaemia; nausea; and heart block. Atropine or robinul is usually administered with muscle relaxant reversal agents to counteract bradycardia.

Tachycardia (tachy = fast) is a very important post-operative sign and should be fully evaluated before treatment is instituted. Factors leading to tachycardia include: pain and discomfort; anxiety; dehydration; overhydration; drugs (e.g. atropine, ephedrine, epinephrine (adrenaline); or any combinations of these factors [Drain & Christoph, 1987].

3.3 Anaesthetic Agents

In order to anticipate how a patient will react when emerging from a general anaesthesia, regional anaesthesia, conscious or deep sedation and local anaesthesia (Appendix I), the PACU nurse should have a good understanding of the pharmacological concepts. Knowledge of drug actions and interactions leads to accurate interpretation of the patient's condition and proper institution of treatment [Nagashima, 1982]. The types and dosage of drugs given as premedication can influence the recovery period. According to Frost (1982) the most common causes of delayed return post-operatively include:

* prolonged anaesthetic effect or overdose;
* drug interaction;
* respiratory insufficiency;
* intra-operative catastrophe;
* temperature abnormalities;
* fluid and electrolyte imbalance;
* allergic or a typical drug response; and
* pre-existing pathological condition.

Three factors determine how rapidly an anaesthetic agent will take a patient to surgical anaesthesia: the potency of the agent; the partial pressure at which the

agent is administered; and, the rate at which the anaesthetic agent is taken up by the blood and tissues [Drain & Christoph, 1987].

The **potency** of the anaesthetic agent refers to its ability to take the patient through all the stages of anaesthesia to respiratory and circulatory arrest without the occurrence of hypoxaemia or the use of pre-anaesthetic medication. For example, halothane is 100 percent potent as compared with nitrous oxide, which is 15 percent potent. Another way of determining potency is by the use of the minimum alveolar concentration (MAC). Potency of inhalation agents is measured using the MAC of an anaesthetic (at one atmosphere of pressure) that produces immobility in 50% of those patients or animals exposed to a noxious stimulus [Drain & Christoph, 1987].

The **partial pressure** of an inhalational anaesthetic in the brain will determine the depth of anaesthesia. The more potent the anaesthetic, the lower the partial pressure of the agent required to produce a certain depth of anaesthesia [Drain & Christoph, 1987].

The rate (**distribution**) at which the anaesthetic is taken up by the blood and tissues is governed in part by the solubility of the agent in blood. Once the potent inhalational anaesthetic is in the blood, the anaesthetic goes where the blood goes [Drain & Christoph, 1987].

3.3.1 Inhalational Agents

Inhalation anaesthesia is the administration of volatilised pharmacological agents via the respiratory tract for the purpose of producing anaesthesia. The outstanding advantage of administering drugs in this manner is that they can be retrieved by the same route as long as respiration is maintained. This, of course, presupposes that the drugs are neither metabolised nor excreted via another route by the body [Klein, 1984].

Inhalant anaesthetic substances may be divided into two groups: volatile anaesthetic agents and gaseous anaesthetic agents. **Volatile** anaesthetic agents are chemicals in the liquid state at room temperature that have a boiling point above 20 degrees Celsius. The **gaseous** anaesthetic agents are those in the gaseous state at room temperature. The following are some of the traditional inhalational anaesthetic agents: chloroform (trichloromethane); cyclopropane; diethyl ether; ethylene; fluroxene (trifluoroethyl vinyl ether, fluoromar); methoxyflurane; trichloroethylene (trilene). Some of the modern inhalation anaesthetic agents and the problems associated with these agents will be discussed in this section [Drain & Christoph, 1987]:

Halothane (Fluothane) is a saturated hydrocarbon, 100 percent potent and a very rapid acting drug. It is the first halogenated hydrocarbon to find wide clinical acceptance as an anaesthetic and is currently the most popular anaesthetic agent worldwide. It has a high fat solubility coefficient. Frequent administration of halothane may result in a "sleepy" patient due to increased

bromide levels. Post-operative hepatitis in a patient given halothane may be explained by either an allergic or a metabolic activation theory [Gorski & Wright, 1987]. Halothane is a very easily controlled agent, in that the depth of anaesthesia can be changed quickly. Induction and recovery are very rapid with this agent [Drain & Christoph, 1987].

Enflurane (Ethrane) is a halogenated ether that is enjoying significant popularity in the practice of anaesthesia. It is non-flammable, 100 percent potent, and very rapid acting. Enflurane promotes a fair amount of muscle relaxation. It has a 25-35 percent lower solubility in fatty tissue when compared to halothane. Enflurane will depress the arterial blood pressure, stroke volume, and systemic vascular resistance. Enflurane has demonstrated a low incidence of post-anaesthesia nausea and vomiting [Drain & Christoph, 1987].

Isoflurane (Forane) is a halogenated methyl ether. Isoflurane reduces the systemic arterial blood pressure and total peripheral resistance. The recovery phase is rapid owing to isoflurane's low blood-gas partition coefficient of 0.97. Isoflurane is viewed by many in the field of anaesthesia as a "close to ideal" anaesthetic inhalation agent [Drain & Christoph, 1987]. Induction and recovery from anaesthesia are somewhat shorter that with enflurane. Cardiovascular function is said to be less depressed with this agent than with

earlier halogenated hydrocarbon anaesthetics at comparable dosage levels [Klein, 1984].

Nitrous oxide is a colourless gas with a slight sweetish odour and taste that is used as an inhalation anaesthetic and analgesic. It is the only inorganic gas and as such is used to reduce dosage (and MAC) of the more potent agents. The addition of nitrous oxide to all inhalation agents significantly reduces the MAC for each agent (Table 3.1). With a blood-gas partition coefficient of 0.47, this agent has a rapid onset of action and is rapidly eliminated [Gorski & Wright, 1987]. This agent has no real side affects unless hypoxaemia is present.

TABLE 3.1: Maximum allowable concentration for inhalation anaesthetic agents is significantly reduced when nitrous oxide is added (Adapted from Frost, 1982).

Inhalational Agent	MAC (% atmosphere)	
	100% Oxygen	70% Nitrous Oxide
Halothane	0.75	0.29
Enflurane	1.15	0.50
Isoflurane	1.15	0.57

3.3.2 Intravenous Agents

Intravenous anaesthesia is the introduction of pharmacological agents into a vein to create general anaesthetic state. Intravenous anaesthesia is useful for surgical procedures of short duration of for induction purposes prior to inhalation anaesthesia. It may also supplement regional anaesthesia [Klein, 1984]. Intravenous agents, by combination with receptor sites, achieve their anaesthetic action by transmission to various sites in the brain and spinal cord. Intravenous anaesthetic agents are generally grouped by primarily pharmacological action: barbiturates (thiopental, methohexital); narcotics (meperidine, morphine, fentanyl); neuroleptics (fentanyl, droperidol, innovar); dissociative agents (ketamine); and, tranquilizers (diazepam, midazolam).

Narcotics are becoming very popular in today's anaesthetic practice. Narcotics such as morphine and fentanyl have both anaesthetic and analgesia properties, depressing the central nervous system and alleviating sensations of pain and anxiety.

Some of the narcotics will be discussed briefly in this section:

Morphine is a naturally occurring narcotic analgesic obtained from opium. It is one of the oldest known drugs, and recently has been utilised as an anaesthetic agent. The greatest advantage of morphine is the remarkable cardiovascular stability that accompanies its use. It has no major effect on

blood pressure, heart rate, or heart rhythm, even in toxic doses, when hypoxaemia is avoided. Morphine may cause nausea and vomiting, especially in ambulatory patients [Drain & Christoph, 1987].

Fentanyl (Sublimaze) is a popular synthetic narcotic, has a short duration of action and is 80 times as potent as morphine. Fentanyl, unlike most narcotics, has little or no hypotensive effects and usually does not cause nausea and vomiting. Fentanyl shares with most other narcotics a profound respiratory depressant effect, even to the point of apnea [Drain & Christoph, 1987].

3.3.3 Drugs Commonly Used in the PACU

Some of the most common drugs administered to post-operative patients in our PACU belong in the following groups: **Antibiotics** [ampicillin, gentamicin, etc.]; **Anti-emetics** [compazine (prochlorperazine), droperidol, reglan (metoclopramide), tigan, etc.]; **Antihypertensives** [arfonad (trimethaphan), hydrallazine (apresoline), inderal (propranolol), labatelol (trandate), etc.]; **Narcotics** [fentanyl (sublimaze), morphine, meperedine (demerol, pethidine), etc.]; **Pressors** [dopamine, ephedrine, epinephrine (adrenaline), etc.]; **Reversal Agents** [atropine, glycopyrrolate (robinul), naloxone (narcan), neostigmine (prostigmin), tensilon (edrophonium), etc].

Antibiotic is a compound used to fight infectious diseases. Multiple sub-classes and molecules exist. Almost without exception, the first of any series of antibiotics was discovered in nature then, through chemical manipulation, multiple congeners were created [Klein, 1984].

Ampicillin is used in infections of respiratory, gastrointestinal, and genitourinary tracts and infections of skin and soft tissues. It is used parenterally only in treatment of moderately severe to severe infections.

Anti-emetic is a pharmacological agent to prevent nausea or vomiting (emesis). The most commonly uses agents for this purpose are antihistamines or phenothiazine derivatives. Two characteristics of anti-emetics are noteworthy: (1) the anti-emetic effect is not usually the primary effect of the drug; (2) since anti-emesis is not an absolute, what appears to be adequate dose of an anti-emetic may not prevent vomiting [Klein, 1984].

Compazine (prochlorperazine) is reported to have greater anti-emetic potency and to produce less sedative, hypotensive, and atropine like effects. Used in management of psychotic disorders and to control nausea and vomiting. Possibly effective in management of excessive anxiety, tension, and agitation.

Antihypertensive drugs alter the circulatory haemostasis and strongly influence the activity of pressor amines and may alter the response to muscle relaxants and

narcotic analgesics. Antihypertensive drugs can produce systemic conditions that may result in a hypotensive crisis during anaesthesia in the immediate post-operative period [Drain & Christoph, 1987].

Arfonad(trimethaphan) blocks both sympathetic and parasympathetic ganglia. Used to produce controlled hypotension for certain surgical procedures (eg, neurological, and plastic surgery) and for treatment of hypertensive crises associated with pulmonary oedema.

Narcotics (see section 3.3.2).

Morphine relieves pain without obtunding other sensory modalities. It has no effect on blood pressure or heart rate or rhythm when patient is supine. It is used for symptomatic relief of severe pain and to relieve dyspnoea of acute left ventricular failure and pulmonary oedema and pain of myocardial infarction [Govoni & Hayes, 1982].

Pressors

Ephedrine is a naturally occurring compound known to Chinese medicine for thousands of years and introduced to Western clinical practice in the 1920s. Ephedrine is classified as a sympathomimetic drug. In anaesthetic practice it is often used as the drug of choice to counteract the pressure drop seen with epidural and spinal anaesthetics [Klein, 1984]. Also used to relieve congestion of hay fever, allergic rhinitis, sinusitis, and in treatment and prophylaxis of

mild cases of acute asthma and in patients with chronic asthma requiring continuing treatment.

Reversal Agents help to reverse the narcotic's analgesic effect. The narcotic-reversal drug in common use today is naloxone (narcan). Narcotics are easily reversed by naloxone, but inhalants cannot be reversed. If a patient received a drug to reverse the respiratory depressant effects of a narcotic, the PACU nurse must be told which narcotic-reversal drug was given, its route administration, when, in what dosage, how long its effect can be expected to last, and what evidence there is that the drug restored the patient's alveolar ventilation to adequacy [Quimby & Bailey, 1986].

Naloxone (Narcan) is a "pure" narcotic antagonist, essentially free of agonistic (morphine like) properties. It is used in treatment of narcotic overdosage and to reverse respiratory depression included by natural and synthetic narcotics [Govoni & Hayes, 1982]. Its action can be expected to last approximately 20 minutes, if given intravenously, and longer, if given sub-cutaneously [Quimby & Bailey, 1986].

3.4 Summary

In this chapter, the basic respiratory, cardiovascular physiology, and anaesthetic agents has been discussed along with the factors leading to post-anaesthetic complications. Patients who are admitted to the PACU often exhibit altered states of consciousness ranging from mild confusion or irritability to deep coma. The most common factors leading to the respiratory complications are: airway-obstruction; bronchospasm; aspiration; pneumothorax; hypoventilation; hypoxaemia. The most common factors leading to cardiovascular complications are: hypotension; hypertension; bradycardia; tachycardia. Knowledge in the fields of drug interaction, drug surveillance, and clinical pharmacology in anaesthesia and post-anaesthesia is vital to the correct management and successful outcome of the recovery period. The types and dosage of drugs given as premedication can influence the recovery period.

The next chapter discusses the purpose of a retrospective study, the environment in which it was carried out, data sources, data collection, analysis of data, and results obtained from the study.

4.0 DESCRIPTION OF THE RETROSPECTIVE STUDY

4.1 Purpose of the Retrospective Study

This chapter describes a retrospective study that was carried out in order to determine the:

1) incidence of potentially adverse blood pressure (BP) and heart rate (HR) events among PACU patients; and

2) distribution of PACU patients by type of anaesthesia, American Society of Anaesthesiologists (ASA) physical status (PS) [(system for classify patients; PS I-II (eg. healthy), PS III-IV (eg. moderately to severely disabled)], age and sex.

4.2 Environment

The Hospital of the University of Pennsylvania is a 694-bed teaching hospital affiliated with America's first medical school, the University of Pennsylvania school of Medicine, located in Philadelphia, Pennsylvania USA.

The PACU at our institution receives patients from 23 operating rooms, has 18 beds and is open 24 hours a day, seven days a week. All patients who have received general or regional anaesthesia, are transported to the PACU post-operatively. The PACU is where a patient will wait for most of the effects of his/her anaesthesia to wear off. Patients assigned to Surgical Intensive Care Unit (SICU) go directly there, from the operating room. Patients who received local anaesthesia with sedation, or who experienced an adverse reaction to medications are

admitted to the PACU. The minimum length of stay for a patient in the PACU is determined by the type of anaesthesia and operating procedure. For example, minimum stay requirements following simple laparoscopy in a healthy patient is 45 minutes, but following gastric bypass it is two hours.

4.3 Data Sources

Three data sources were used for this retrospective study: 1) the PACU nursing record (Figure 4.1); the Operating Room (OR) record (Figure 4.2); and 3) the Anaesthesia record (Figure 4.3). Operating room, Anaesthesia and PACU records of 200 consecutive patients were reviewed for the months of May and June 1988. These months were selected for several reasons, including: 1) no new patient monitoring policies were implemented in this period; 2) it avoids the beginning of a resident year (July), when new and inexperienced surgical and anaesthesia residents may bias the records regarding post-operative patient care than more experienced residents; and 3) there were no major holidays that affected the PACU schedule.

From personal communication with perioperative staff (anaesthesia, surgery, nursing) it was determined that of the data available in codifiable form the following variables were likely to be the most significant in determining the post-operative course.

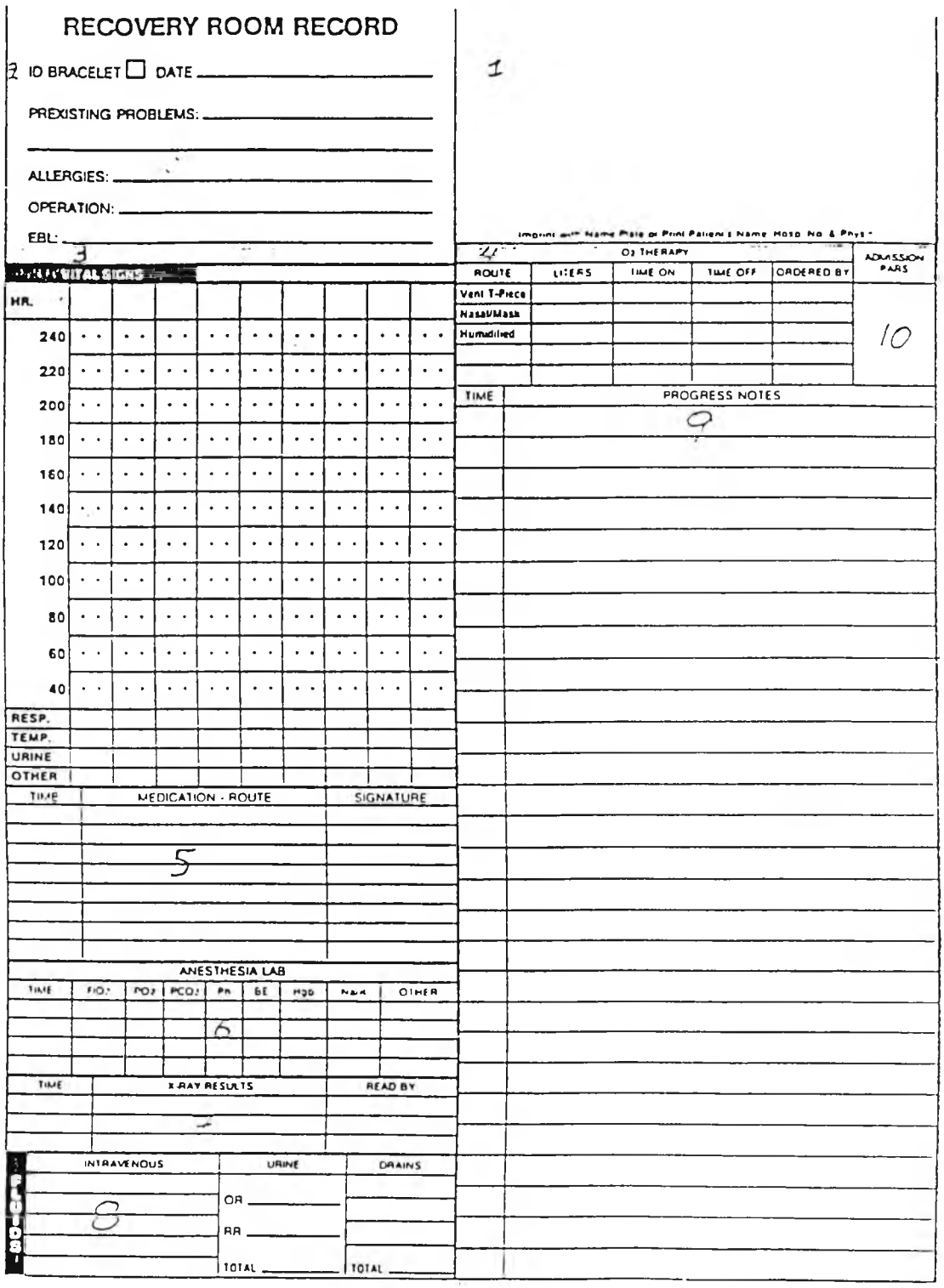
4.3.1 Post Anaesthesia Care Unit Record

Raw data collection was conducted in the PACU during the recovery period by the PACU nurse. The following raw patient variables were selected:

- Date admitted to the PACU;
- Hupid(patient identification number);
- Patient last, first name;
- Arrival to PACU PARS score (Table 4.1) [Aldrete & Kroulik, 1970];
- Discharge from PACU PARS score;
- Duration in the PACU stay (additional variable created); - Oxygen therapy;
- Transfer (Floor, SICU, MICU etc.);
- Comment (additional variable created);
- Explanation (from progress notes);
- Time of anaesthesia lab (the PACU nurse request patient results from the Blood gas lab);
- Laboratory data (FIO2, PO2, PCO2, Ph, BE, Hb, Na/K, other);
- Time taken vital signs;
- Systolic,diastolic blood pressure;
- Heart rate, respiration, oxygen saturation, temperature.

Appendix II describes the steps that nurses follow to complete the PACU record.

Figure 4.1: Post Anaesthesia Care Unit Record.



RECOVERY ROOM RECORD

2 ID BRACELET ☐ DATE _____

PREXISTING PROBLEMS: _____

ALLERGIES: _____

OPERATION: _____

EBL: _____ 3

1

Imprint with Name Plate or Print Patient's Name, Hosp. No. & Phys.

O2 THERAPY

ROUTE	LITERS	TIME ON	TIME OFF	ORDERED BY
Vent T-Piece				
Nasal/Mask				
Humidified				

4

ADMISSION PARS: 10

VITAL SIGNS

HR.									
240	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
220	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
200	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
180	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
160	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
140	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
120	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
100	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
80	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
60	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
40	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
RESP.									
TEMP.									
URINE									
OTHER									

TIME	MEDICATION - ROUTE	SIGNATURE
	5	

ANESTHESIA LAB

TIME	FIO2	PO2	PCO2	Ph	BE	Hgb	Na+	OTHER
				6				

TIME	X-RAY RESULTS	READ BY
	7	

INTRAVENOUS	URINE	DRAINS
	OR _____	
8	RR _____	
	TOTAL _____	TOTAL _____

Table 4.1: The Aldrete Post-Anaesthetic Recovery Score (PARS).

SCORE	0	1	2
Physical Signs			
Activity	no movement	moving two limbs	moving all limbs
Respiration	apnoeic	dyspnoeic, airway in place	free, deep breathing
Circulation	BP 50% or less of preop level	BP within 50-20% of preop level	BP within 20% of preop level
Consciousness	no response	responds to name	wide awake
Colour	cyanetic	dusky	normal

4.3.2 Operating Room Record

Raw data collection was conducted in the operating room during surgery primarily by the circulating nurse, and some data are entered by other operating room staff. The following raw patient variables were selected:

- Inpatient, Outpatient, Am admit, Short stay;

- Pre Op Diagnosis;

- Type of procedure;

- Surgical service;

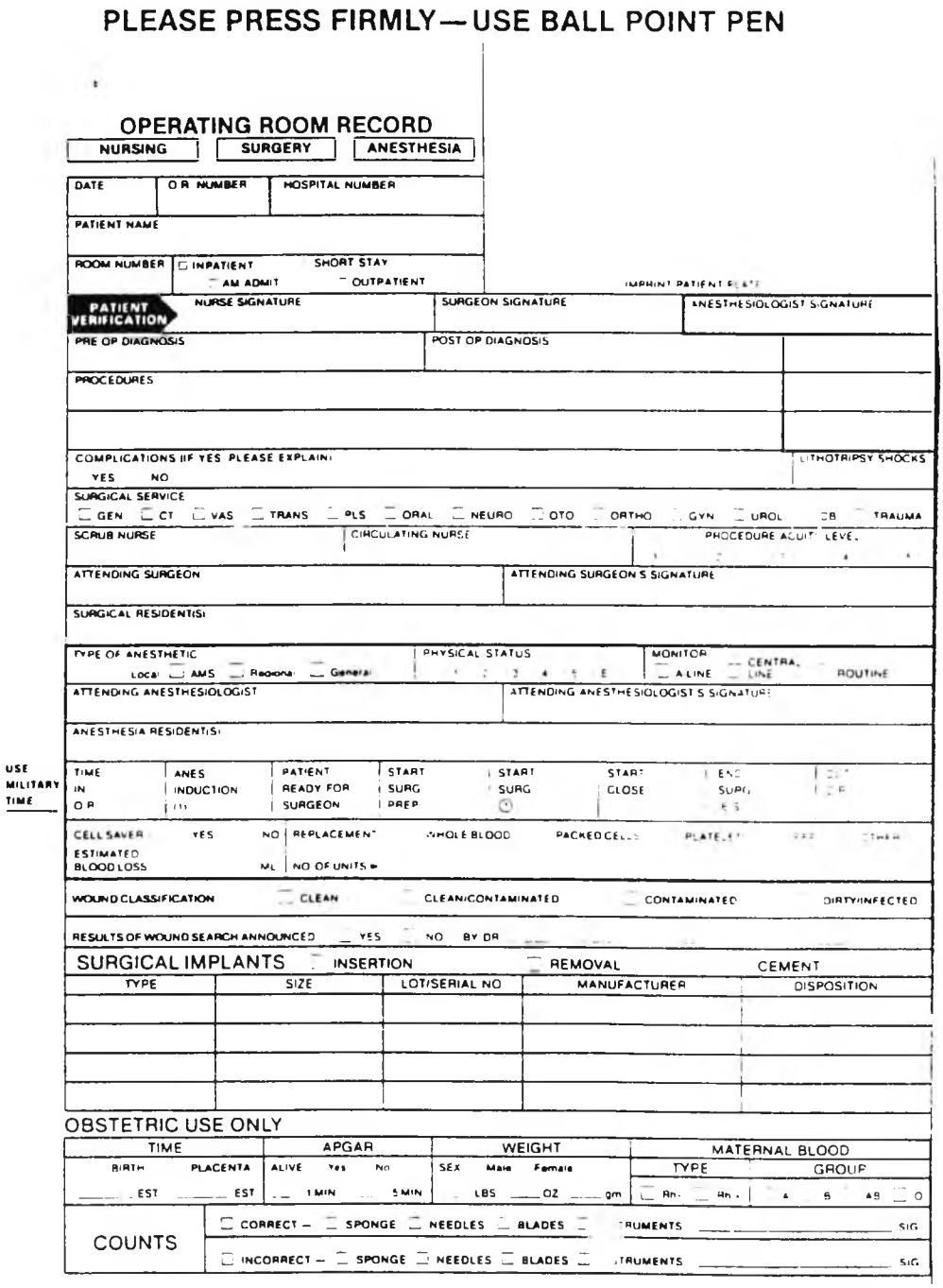
- Procedure level;

- Type of anaesthetic (local, regional, general);

- Physical status (American Society of Anaesthesiologists);

- Surgery times (time in O.R., anaesthesia induction, patient ready for surgeon, start surgery preparation, start surgery, start close, end surgery, out O.R.);

Figure 4.2: Operating Room Record.



PLEASE PRESS FIRMLY—USE BALL POINT PEN

OPERATING ROOM RECORD

NURSING | SURGERY | ANESTHESIA

DATE | O R NUMBER | HOSPITAL NUMBER

PATIENT NAME

ROOM NUMBER | ☐ INPATIENT SHORT STAY ☐ AM ADMIT ☐ OUTPATIENT | IMPRINT PATIENT PLATE

PATIENT VERIFICATION | NURSE SIGNATURE | SURGEON SIGNATURE | ANESTHESIOLOGIST SIGNATURE

PRE OP DIAGNOSIS | POST OP DIAGNOSIS

PROCEDURES

COMPLICATIONS IF YES PLEASE EXPLAIN ☐ YES ☐ NO | LITHOTRIPSY SHOCKS

SURGICAL SERVICE

☐ GEN ☐ CT ☐ VAS ☐ TRANS ☐ PLS ☐ ORAL ☐ NEURO ☐ OTO ☐ ORTHO ☐ GYN ☐ UROL ☐ OB ☐ TRAUMA

SCRUB NURSE | CIRCULATING NURSE | PROCEDURE ACUITY LEVEL 1 2 3 4 5

ATTENDING SURGEON | ATTENDING SURGEON'S SIGNATURE

SURGICAL RESIDENT(S)

TYPE OF ANESTHETIC Local ☐ MAC ☐ Regional ☐ General | PHYSICAL STATUS 1 2 3 4 5 E | MONITOR ☐ A-LINE ☐ CENTRAL LINE ☐ ROUTINE

ATTENDING ANESTHESIOLOGIST | ATTENDING ANESTHESIOLOGIST'S SIGNATURE

ANESTHESIA RESIDENT(S)

USE MILITARY TIME

TIME IN O R	ANES INDUCTION	PATIENT READY FOR SURGEON	START SURG PREP	START SURG	START CLOSE	END SURG	OUT O R

CELL SAVER ☐ YES ☐ NO | REPLACEMENT WHOLE BLOOD PACKED CELLS PLATELETS FFP OTHER

ESTIMATED BLOOD LOSS ML | NO OF UNITS ▸

WOUND CLASSIFICATION ☐ CLEAN ☐ CLEAN/CONTAMINATED ☐ CONTAMINATED ☐ DIRTY/INFECTED

RESULTS OF WOUND SEARCH ANNOUNCED ☐ YES ☐ NO BY DR

SURGICAL IMPLANTS ☐ INSERTION ☐ REMOVAL CEMENT

TYPE	SIZE	LOT/SERIAL NO	MANUFACTURER	DISPOSITION

OBSTETRIC USE ONLY

TIME	APGAR	WEIGHT	MATERNAL BLOOD
BIRTH PLACENTA	ALIVE Yes No	SEX Male Female	TYPE GROUP
____ EST ____ EST	__ 1 MIN __ 5 MIN	__ LBS ____ OZ ____ gm	☐ Rh+ ☐ Rh- A B AB ☐ O

COUNTS

☐ CORRECT – ☐ SPONGE ☐ NEEDLES ☐ BLADES ☐ INSTRUMENTS ____ SIG

☐ INCORRECT – ☐ SPONGE ☐ NEEDLES ☐ BLADES ☐ INSTRUMENTS ____ SIG

4.3.3 Anaesthesia Record

Raw data collection is conducted in the OR by the anaesthesiologist during surgery. The following raw patient variables were selected.

- Sex, age, weight, height;

- Preoperative level of systolic blood pressure;

- Preoperative level of diastolic blood pressure;

- Preoperative level of heart rate;

- First systolic blood pressure;

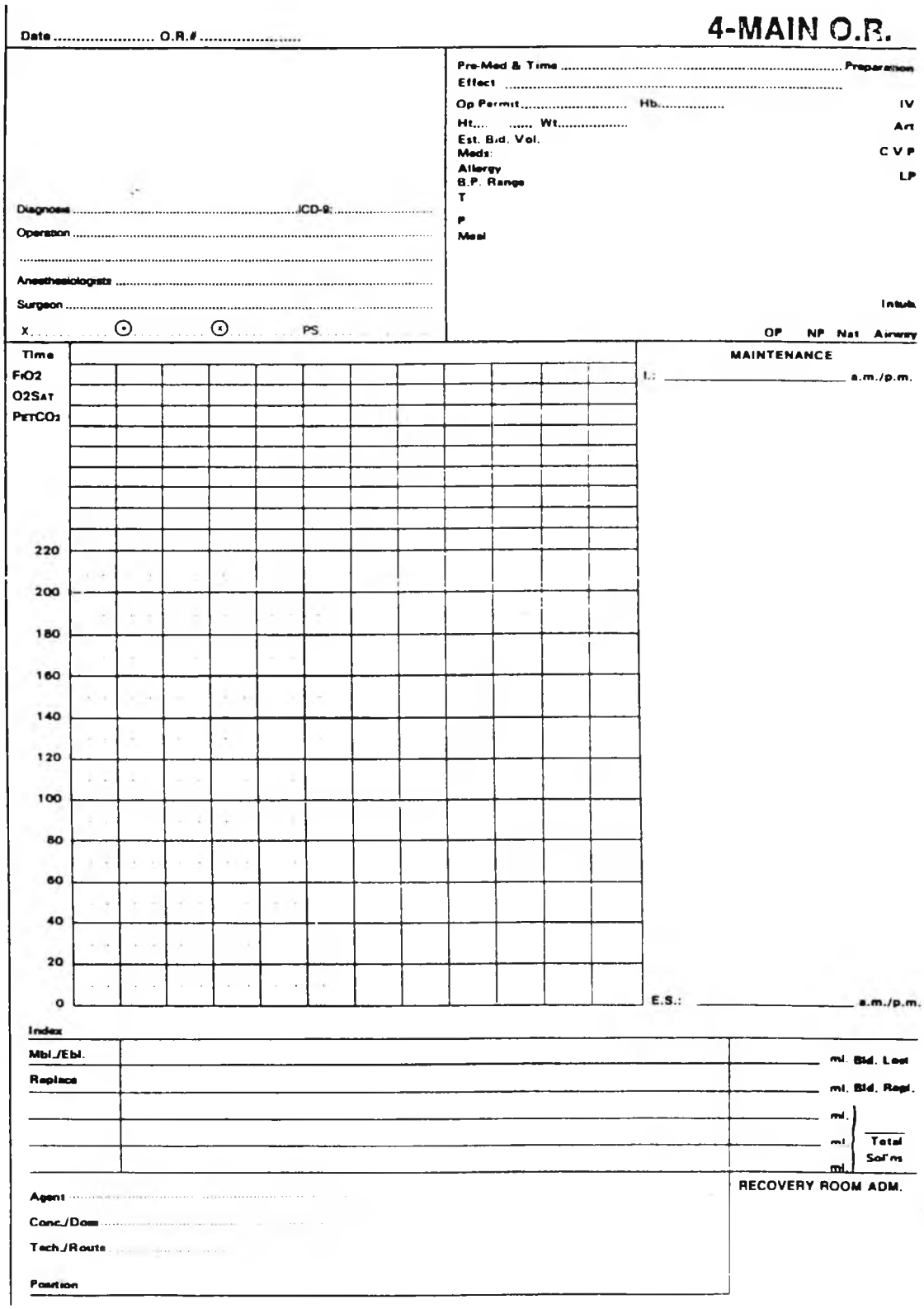
- First diastolic blood pressure;

- First heart rate;

- Intubation(y/n);

- Extubation(y/n);

Figure 4.3: Anaesthesia Record.



4.4 Data Collection

The Hospital Operating Room Network (HORNET) of the Hospital of the University of Pennsylvania (HUP) maintains operating room management data, analyses information, generates and stores patient data [Garfinkel et al., 1987].

A computer database was designed and implemented using KNOWLEDGEMAN/KMAN (Micro Data Base Systems, Lafayette, IN) to record and retrieve information about the PACU patients. KMAN runs under the ULTRIX 1.2 operating system on a Digital Equipment Corporation VAX-8200 super-minicomputer. The database is based on the Structure Query Language (SQL) implementation of relational algebra. Features of this implementation include; interactive use of commands as part of a procedure and extensive mathematical and string functions. KMAN was customised and a PACU management system created with special attention to several factors: data entry; data verification; data retrieval; maintenance; and backup. Data were entered via a menu-driven system on screen forms with direct transcription and stored in individual patient files for later analysis. Importing data with this system was accomplished in a logical, intuitive, manner. The patient data were automatically extracted from the computer file and manipulated. The SQL language allowed analyses from multiple tables.

Table 4.2 illustrates the structure of the data base and Table 4.3 the terminal entry screens.

Table 4.2: Structure of the Database.

```
/* RECOVERY ROOM TABLES */
define recovery with "recovery.itb";\
field opdate num;\
field hupid str 7 using "ddddddu";\
field lastnme str 12 using "%12u";\
field firstnme str 12 using "%7u";\
field inpars num using "dd";\
field outpars num using "dd";\
field inrr str 5 using "dd:dd";\
field outrr str 5 using "dd:dd";\
field durinrr num using "dd.dd";\
field o2ther str 1 using "u";\
field transf str 1 using "u";\
field comment str 1 using "u";\
field explanat str 40 using "%40u";\
enddef

define anaeslab with "anaeslab.itb";\
field opdate num;\
field hupid str 7 using "ddddddu";\
field point num using "dd";\
field atime str 5 using "dd:dd";\
field fio2 num using "ddd";\
field po2 num using "dd.d";\
field pco2 num using "ddd";\
field ph num using "d.dd";\
field be num using "ddd.d";\
field hgb num using "dd.d";\
field na num using "ddd";\
field k num using "d.d";\
field other str 8 using "uuuuuuuu";\
enddef

define vitsigns with "vitsigns.itb";\
field opdate num;\
field hupid str 7 using "ddddddu";\
field point num using "dd";\
field vtime str 5 using "dd:dd";\
field sbp num using "ddd";\
field dbp num using "ddd";\
field pulse num using "ddd";\
```

```
field resp num using "dd";\
field sat num using "ddd";\
field temp str 4 using "uuuu";\
enddef


/* ANAESTHESIA RECORD TABLES */
define anaesrec with "anaesrec.itb";\
field opdate num;\
field hupid str 7 using "ddddddu";\
field sex str 1 using "u";\
field age num using "ddd";\
field weight num using "ddd";\
field height str 6 using "d'dd"";\
field virheigt num =
tonum(height)+tonum(substr(height,3,2))/12;\
field presbp num using "ddd";\
field predbp num using "ddd";\
field prepulse num using "ddd";\
field firsbp num using "ddd";\
field firdbp num using "ddd";\
field firpulse num using "ddd";\
field intubat str 1 using "u";\
field extubat str 1 using "u";\
enddef
finish all


/*INDEXES */
use local recovery
index "recovery.ind" for recovery by opdate hupid
finish recovery

use local anaeslab
index "anaeslab.ind" for anaeslab by opdate hupid point
finish anaeslab

use local vitsigns
index "vitsigns.ind" for vitsigns by opdate hupid point
finish vitsigns

use local anaesrec
index "anaesrec.ind" for anaesrec by opdate hupid
finish anaesrec
```

For carrying out some of the data analysis and statistical reports additional data base tables created, including:

- range of values (highest, lowest) for the haemodynamic and oxygen saturation parameters;

- body mass index calculation.

```
/* TABLE HIGH - LOW */
define hilow;\
field opdate num;\
field hupid str 7 using "uuuuuuu";\
field hisbp num using "%3d";\
field lowsbp num using "%3d";\
field hidbp num using "%3d";\
field lowdbp num using "%3d";\
field hihr num using "%3d";\
field lowhr num using "%3d";\
field hisat num using "%3d";\
field lowsat num using "%3d";\
field hiresp num using "ddd";\
field lowresp num using "ddd";\
field hitemp num using "ddd.d";\
field lowtemp num using "ddd.d";\
enddef

/* BODY MASS INDEX TABLE */
define bmindex \
read "l" write "l";\
field opdate num;\
field hupid str 7 using "ddddddu";\
field ornumber num using "d";\
field age num using "ddd";\
field height num using "d.dd";\
field weight num using "ddd.dd";\
field bmi num using "dd.dd";\
field bs str 6 using "%6u";\
field procedur str 60 using "%60u";\
enddef
finish bmindex

/* index the hilow tables */
index hilow by opdate hupid
finish hilow
```

Table 4.3: PACU Data Entry Screens.

SCREEN 1

*** HOSPITAL OF THE UNIVERSITY OF PENNSYLVANIA ***
PACU STUDY

Do you like to **A**dd a record, **E**dit a record,
Delete a record or just **Q**uit the program: **A**

Date: Hupid:
Patient's Last Name: First Name:

In PARS Out PARS In R.R. Out R.R. Duration in R.R.
(score) (time hh:mm)

O2 Therapy(**V**ent T-Piece, **N**asal, **H**umidified):
Transferred to ICU(**Y**/**N**): Comment(**Y**/**N**):

Explanation:

ANAESTHESIA LAB
Time FIO2 pO2 pCO2 pH BE Na K Other

VITAL SIGNS
Time SBP DBP Pulse Resp. Saturation Temperature

SCREEN 2

*** HOSPITAL OF THE UNIVERSITY OF PENNSYLVANIA ***
PACU STUDY

Do you like to **A**dd a record, **E**dit a record,
Delete a record or just **Q**uit the program: **A**

Date: Hupid:
Patient's Last Name: First Name:

Sex(**M**/**F**): Age: Height: Weight:

Pre-Operative Vital Signs First Vital Signs

SBP: DBP: Pulse: SBP: DBP: Pulse:

Intubation(**Y**/**N**): Extubation in O.R.(**Y**/**N**):

4.5 Methods for Data Analysis

Three types of statistical analyses processes were used in this study, Descriptive analysis, Student's t-tests analysis and Chi-square analysis. To avoid sampling bias statistical analysis was restricted to the data set obtained 30 minutes into the recovery period. The boundaries were:

- hypertension (Systolic Blood Pressure >= 180);
- hypotension (Systolic Blood Pressure <= 80);
- tachycardia (Heart Rate >=110); and
- bradycardia (Heart Rate <= 60).

4.5.1 Descriptive Analysis

To describe, summarise and organise the PACU patients data, descriptive analysis was conducted on the following variables:

- sex;
- age;
- weight;
- type of surgical procedure;
- type of anaesthesia;
- duration of surgery;

- ASA physical status;
- duration of PACU stay;
- PARS score;
- systolic blood pressure (low, high);
- diastolic blood pressure (low, high);
- heart rate (low, high);
- oxygen saturation (low, high);
- respiration (low, high);

4.5.2 Students T-tests Analysis

T-tests were used to determine whether differences in BP and HR changes were significantly higher for males *versus* females, physical status I-II *versus* PS III-IV, general anaesthesia *versus* regional anaesthesia, and older (≥55 years) *versus* younger (<55 years) patients. T-tests analysis were conducted on the following variables:

- blood pressure;
- heart rate;
- type of anaesthesia;

- physical status;
- sex;
- age;

4.5.3 Chi Square Analysis

Chi-square analysis was used to determine the differences in the incidence of haemodynamic changes among the PACU patients. For example, the incidence of hypertension and tachycardia was compared for males *versus* females, physical status I-II *versus* PS III-IV, general anaesthesia *versus* regional anaesthesia, and older (≥55 years) *versus* younger (<55 years) patients. Chi-square analyses were conducted on the following variables:

- blood pressure
- heart rate
- type of anaesthesia
- physical status
- sex
- age

Heart rate (HR) and blood pressure (BP) were measured at standard intervals (10 minutes).

4.6 Data Analysis and Results

The initial phase of this analysis was the establishment of the demographics of the 200 PACU patients. These patients received all forms of anaesthesia and had a variety of surgical operative procedures. The study population was 53.5% female (107/200). The characteristics of the population were [mean, ± standard deviation, (range)]: age, 47.3 ± 19.1 years (15-87); weight, 74.7 ± 18.3 kg (43-159); duration of surgery, 125 ± 96.3 minutes (10-815); duration of PACU stay, 91.1 ± 54.7 minutes (18-373).

Of the 200 patients, 147 (73.5%) received PARS score of 9 or higher at the start of the post-anaesthetic period. There were no PARS scores less than 6. There were 35 General surgery patients, 8 Cardiovascular, 6 Vascular, 9 Transplant, 16 Plastic, 4 Oral, 17 Neurosurgery, 14 Otorhinolaryngology, 40 Orthopaedics, 28 Gynaecology, and 18 Urology patients. The nature of the surgery was not determined for 10 patients. The overall incidence of hypertension was 8%, hypotension 4%, tachycardia 4%, and bradycardia 5%. Both mean systolic blood pressure and the incidence of hypertension were significantly greater ($p<.05$) for males *versus* females, physical status III-IV *versus* PS I-II and older (>55 years) *versus* younger (<55 years) patients. There were no significant differences by type of anaesthesia. Because of the low incidence, no comparisons were carried out for hypotension, tachycardia, or bradycardia. Almost 1/5 of PACU patients had at least 1 of the adverse conditions.

From the retrospective study it was concluded that age > 55 years, male gender and ASA physical status greater than II are associated with an increased incidence of hypertension in the post anaesthetic period.

4.7 Summary of findings

In order to link the findings from the descriptive, t-test and chi square analysis, Table 4.4 was developed.

Table 4.4: Comparison of Findings.

COMPARISON OF FINDINGS FOR SELECTED VARIABLES BY METHOD OF ANALYSIS
SYSTOLIC BLOOD PRESSURE AND THE INCIDENCE OF HYPERTENSION

Variable	Descriptive	T-test's	Chi-square
sex	53.5% female and 46.5% male	significant p=.005	significant .0134 p = .0272 *higher for males
age	mean years 47.374 std. dev. 19.163 variance 367.230 minimum 15 years maximum 87 years	significant p=.001 *higher for older (≥55 years)	significant .0042 p = .0117 higher for older (≥55 years)
type of anaesthesia	66.5% General 1% Regional	not significant	not significant
physical status(PS)	16.5% PS I,II 18.5% PS III,IV	significant p=.013 *higher for PS III,IV	significant .0046 p = .0132 *higher for PS III,IV

While the incidence of adverse events was low the serious nature warrants intensive efforts to maximise the efficacy of monitoring. Because of the frequency of artifact it was not possible to include accurate data for oxygen saturation in our analysis. In the retrospective study we focused on one data set only. However, the power of the statistical analysis would be improved if more data could be included.

Chapter Five discusses some of the technological developments in clinical monitoring, along with a brief background of computer-assisted monitoring. A discussion is presented of the advantages and disadvantages of invasive, non-invasive techniques, alarms and physiological monitoring in the PACU.

5.0 CLINICAL MONITORING

5.1 Introduction

The pace of technological innovation underwent a vast change following World War II. Technological development and the hard sciences underwent a great expansion because of the military needs of World War II. In the years that followed, many of the scientists and engineers who had participated in the war effort turned to more peaceful pursuits; applications of their work to biology and medicine had a particular appeal [Eden, 1984]. Health care depends more and more on technology to meet its large variety of needs. It uses technology to gather information necessary for appropriate diagnosis; to process this information and present it in comprehensible forms; to treat disorders effectively when diagnosed; to monitor treatment and evaluate its efficacy; and, last to prevent disease. The stethoscope and phonocardiogram are examples of the first technological solution to an existing medical problem. They offered an improvement in auscultation of the heart, replacing direct auscultation, which required putting the physician's ear to the patient's chest [Anbar, 1984].

Through the ages it has been the task of the physician to watch and observe the patient with the specific purpose (=monitoring) of making diagnosis and/or performing a therapeutic action [Meijler, 1987]. The word "monitor" is derived from the Latin verb "monere - to warn", and in particular to warn of danger. Wilber and Derrick (1965) define that "**a monitor** is an instrument that measures (as vital signs

during surgery) or gives warning. They define "**to monitor** is to watch, observe, or check, especially for a special purpose". Hope and Morrison (1986) define "monitor" as to "remind or give warning; maintain regular surveillance over". Gorski and Fraulini (1987) define monitor as "an instrument used to measure, display and record (continuously or intermittently) certain physiological variables such as pulse, blood pressure, and respiration". Crockett (1970) proposes that the object of monitoring is "to ascertain, and in some cases to record, changes in the condition of the patient and to give warning of approaching or established danger". Calkins (1981) proposes that active monitoring demands "an active process of data collection analysis, and decision making". Monitoring is not merely the process of measurement or collection of data; it involves the analysis and interpretation of the data which have been collected [Hope & Morrison, 1986]. Therefore, patients are monitored to detect adverse side-effects produced by drugs or clinical actions.

According to Quimby & Bailey (1986), the first step in monitoring is to state clearly the question to be answered and why it is important to the patient's welfare. The second step is to select in the best way the factors in question. The final step is to collect and amass the data, and finally having amassed the data, the clinical personnel must then organise, correlate, and weigh them to draw inferences and to arrive at conclusions on which to base his/her management of the patient [Quimby & Bailey, 1986].

5.2 Historical Background of Computer-Assisted Monitoring

Dramatic improvements in technology have provided a wide variety of very powerful mini and microcomputers which have opened the doors to far more extensive computer usage throughout the health service. Computational speed has increased 200 times in 25 years and energy consumption and computer size have decreased by a factor of 10,000 [Gardner, 1985]. During the late 1960s pharmaceutical firms were using computers to enhance research, design and calculations of pharmaceutical data. Later came laboratory automation. Laboratories began using computers to automate procedures and to store additional data. During the early 1970s, CT scanners became established in the United States. The CT scanner is an X-ray machine which takes X-rays from several angles; the computer then interprets the images and produces a three-dimensional image. During the '70s, magnetic resonance imaging (MRI) became available. This procedure utilises an electromagnetic laser. The Smart Laser has the capability of targeting tissue and is used to open coronary arteries. With the use of the Smart Laser, the physician can differentiate between plaque and viable tissue with increased precision and accuracy [Stringer, 1989]. In the last few years new computer hardware and software have been offered on the market almost daily. Several computer systems have been introduced into specialised units caring for the critical ill patient, and in recent years computers to assist medical decision making have gained wider acceptance. The major advantage of computer-based systems is their ability to acquire and store large amounts of data which can then be processed for presentation in the clearest manner, thus assisting in overall patient management

[Diprose & Evans, 1985]. The use of microcomputers in bedside monitors has revolutionised the acquisition, display and processing of physiological signals. In the early phases computers were used to acquire physiological data such as blood pressure and cardiac output. Monitoring of the critically ill patient with the assistance of the computer has been explored intensively for more than two decades.

The following summarises some of the first reported systems that utilised a digital computer to acquire physiological data from the authors' original papers.

Weil, Shubin and Rand (1966) were among the first to report the utilisation of a digital computer in Intensive Care. An important development for which the Shock Research Unit (Department of Medicine, University of Southern California, School of Medicine) shares responsibility, is the use of a combination of sensing devices coordinated by a digital computer to develop an integrated picture of a patient's physiological condition on a time-related basis. On January 1, 1965 an IBM (model 1710) digital computer became operational for use at the bedside of critically ill patients. The system was used both to bolster efficient monitoring of the physiological condition of the patients and to serve as an aid in interpreting the acquired data. To make the data available to ward personnel, a plotter and output typewriter were also included in this system. They reported (1966) that using this computer in over 200 cases demonstrated its acceptance and value in a clinical setting [Weil et al., 1966). Since that time, there has been an expansion of interest in automated measuring and computer systems.

After the solution of problems related to the collection of single items of physiological information, more was demanded of the computer. Investigators began to make multiple physiological measurements and organise them using computers. In particular they directed their efforts towards specific types of system, such as: clinical decision making (Wilber et al., 1965; Gardner et al., 1982); closed loop control (Sheppard et al., 1974; Ferrari et al., 1977); intelligent alarms (Raison et al., 1968; Shubin et al., 1971; Lewis et al., 1972); record keeping (Forthman & Niejadlik 1983; Paulus et al., 1985).

Wilber and Derrick (1965) used a physiological communication network consisting of an automatic transducer system and a digital computer to accumulate and present accurate physiological data to the surgical team for immediate use in clinical decision-making. The computer patient monitoring system became operational at the University of Texas M.D. Anderson hospital and Tumor Institute. The computer patient monitoring system worked as follows:

Computer hardware - on command from the transducer electronics terminal, the computer accepted patient data in analog form. These data were converted to digital form by the analog-digital converter and stored in the computer memory.

Monitoring program - using the stored data accumulated from the first ten cycles of the transducer-electronics system, calculations were performed to obtain upper and lower limits for each physiological variable. Data accumulated from each cycle of the transducer system were compared with these limits, and any violation was printed out and punched into cards. The authors' primary goal from that article was to

demonstrate that computers could help the anaesthesiologist to accurately record and compute physiological variables and thereby lead to better understanding of clinical anaesthetic behaviour [Wilber & Derrick, 1965].

Ferrari et al. (1977) at the Cardiovascular Unit of Charlotte Memorial Hospital and Medical Center, developed a Computer-Based Intensive Care system. The system became operational in 1974 using a Roche Medical Electronics, Series 5000. The primarily goal of the system was the management of patients following open heart operations. Their original goal was:

* direct monitoring
* digital input of laboratory results, and
* permanent records.

They expanded the computer system to:

* decrease the amount of charting that is required of nurses, and
* develop a medical logic program that can make therapeutic decisions based on the various patient inputs.

They reported that the reliability of the system after the first two to three months of initial difficulties had been excellent.

Comparing the data of 400 patients who consecutively underwent open heart surgery just before the installation of the computer system with an identical number of patients operated on a year later, they found a significant reduction in the length of their hospital stay from the day of surgery to their discharge from the hospital [15.2 0.7 to 13.8 0.6, ($p < 0.05$) respectively]. They also observed a 10% reduction in significant post-operative complications resulting primarily from respiratory problems [Ferrari et al., 1977].

Shubin et al. (1971) developed an alarm system in which the goal was to call attention to changes in the values of frequently monitored variables. The alarm system was also used to screen data, so that values reflecting a steady state condition could be suppressed when the patient file was reviewed. Their system utilised an XDS Sigma 5 computer with a core memory size of 24K, 32-bit words and standard XDS peripherals, including digital I/O, A/D converter, D/A converter, a three million byte fixed head disc drive, two seven-track tape drives, a line printer, a card reader and five keyboard displays. Application programs were written in FORTRAN IV using subroutine calls to handle the analog, video terminal display, and other special I/O. These programs were stored as absolute load modules in the program library on the disc [Shubin et al., 1971].

Forthman and Niejadlik (1983) reported that the Anaesthesia Service and the Computer Service at the Miami Heart Institute, Miami Beach, Florida, began in 1976 to explore the possibility of utilising a computer to collect data and to generate an

accurate and legible anaesthetic record. An operational system was put into use in the Operating Room of the Miami Heart Institute in the Spring of 1980. At the conclusion of the procedure, a comprehensive operative report was generated, which included the following:

* personal data
* pre-operative data
* selected laboratory data
* cardiac catheterisation reports
* listing of medications, and
* pre-anaesthetic drugs.

A summary sheet was developed, which included a summary of haemodynamic and cardiac events, a complete listing of anaesthetic agents. They estimated that 60% of the time involved in producing a handwritten record spent in recording physiological data, thus, considerable relief from this routine activity is achieved [Forthman & Niejadlik, 1983].

However, the clinically successful projects have been so few that it must be questioned whether the objectives have been realistic and the problems adequately defined. When viewed in the broader context of patient care, monitoring is only a part of the overall task [Sheppard & Kouchoukos, 1976].

J.J Osborn (1982) indicated that the way to reach the stage of having a coherent patient monitoring system was to break down the general problems and

have the subcomponents working first. He proposed that the first component should be **truly monitoring**. Alarms are its output, and their purpose is to attract the attention of the staff. Its major deficiency is false alarms. The second major division he called **statistical monitoring**. This plots the patient's own unique data in a multidimensional grid, created from analysis of a large data bank on critically ill patients. Its tools are linear regression, covariance analysis, and multivariate cluster analysis. Statistical monitoring has exciting possibilities and has real predictive value. The third major division he called **integrative monitoring**. It is concerned with the automatic summation of multiple bits of data into packages which mean something. Its tools are mathematical modeling and rule-based logic. Its output consists of statements about the function of specific organs which might be called diagnostic statements.

5.3 Physiological Monitoring

In the last several decades a major contribution has been made by the introduction of new monitoring equipment and techniques. Today's medical personnel have access to better equipment to improve patient care (Table 5.1). The use of central microprocessing units has become common place in the manufacture of electrocardiogram (ECG), blood pressure, and other devices that monitor patient parameters. All of the estimated 75,000 adult, paediatric, and neonatal intensive-

care beds operating in the United states are equipped with some type of physiological monitor. The simplest units display the ECG and heart rate, and have simple high/low-rate alarms. The most sophisticated monitors can also: analyse ECG arrhythmias, monitor intravascular pressures and respiratory status, and measure arterial and mixed venous oxygen saturation [Gardner, 1986]. The benefit of monitoring system is measured in terms of the information gained.

Table 5.1

Spectrum of Monitoring Devices (Adapted from Blitt, 1982).

	Left ventricular pressure	
	Left atrial pressure	
	Pulmonary artery pressure	
	Intraventricular catheters	
	Central aortic pressures	
	CVP	
	Radial artery pressures	
I	Indwelling urinary catheter	**N**
N	TM, Rectal, Oesophageal temperature	**O**
V	Oesophageal stethoscope	**N**
A	Spectrophotometric gas measurement	**I**
S	Nuclear cardiology	**N**
I	Peripheral nerve stimulator	**V**
V	Transcutaneous O2 and CO2	**A**
E	Three dimensional CT	**S**
	Finger pulse transducer	**I**
	Systolic time intervals	**V**
	Doppler apparatus (and similar equipment)	**E**
	Cuff BP	
	ECG	
	EEG (compressed spectral array)	
	RPP	
	Echocardiogram	
	Precordial stethoscope	

Invasive: monitor that penetrates the skin, mucosal membrane, or enters some body cavity.

Non-invasive: monitor that does not penetrate body orifice but may require a transducer.

Crul and Payne (1970) proposed that patient monitoring systems serve three main functions:

1) they protect the patient by ensuring that variations in a physiological variable beyond an acceptable range are immediately apparent to the attendant clinician.
2) they indicate the pattern of response to treatment so that it can be modified as required.
3) they provide data from which advances in therapeutics may be developed.

Gravenstein and Paulus (1987) grade invasiveness as follows:

Non-invasive: The monitor is applied to the skin, as exemplified by electrocardiograph electrodes or blood pressure cuffs.
Minimally invasive: Requires breaking the skin, but only for local application of catheters such as intravenous catheters placed in the back of the hand or the crook of the elbow, or abrasion of the skin, for instance, for placement of cutaneous oxygen electrodes.
Penetrating: Requires insertion of a probe into a bodily orifice such as the mouth, bladder, or anus, as is done for the placement of oesophageal stethoscopes, temperature probes, catheters and the like.

Invasive: Requires the cannulation of an artery or central vein.

Highly invasive: Cannulation of a ventricle of the brain or heart, as is done with intracranial pressure monitoring or pulmonary artery catheters.

Monitoring activities should be ranked on a different categories, for instance, from most to least often used. Ranking by importance would be of interest because we all would like to monitor the essential variables, the ones that make a different, and to forget the others. Greenberg and Peskin (1983) proposed three different levels of monitoring: basic, advanced, and sophisticated.

Basic Monitoring: The set of surveillance data required daily on all patients to define degree of stability or detect deviation constitutes basic monitoring. Surveillance is a continuous process. For those patients who reside only 24 to 48 hours in the SICU as an extension of the post-operative PACU, this is the usual level. Elderly or otherwise high-risk patients (e.g., cardiac or renal failure) also benefit from this monitoring on an elective basis.

Advanced Monitoring: This level of monitoring is indicated for patients with significantly greater deviations or greater potential for deviation as a result of their pre-existing diseases, trauma, or stress. Monitoring at this level may simply require more frequent observation, not necessarily inclusion of new variables. This level of monitoring of necessity becomes more invasive. It

always includes a central venous pressure line and an arterial catheter for monitoring pressures as well as easily acquiring blood samples for multiple blood gas determinations. The majority of patients in the SICU require this level of monitoring for a period of time.

Sophisticated Monitoring: Sophisticated monitoring is reserved for patients with major traumatic or surgical stress and true multisystem disease, either acute or pre-existing. These patients constitute a "high-risk" group and generally will not tolerate major deviations in physiology, as they are already functioning at maximal homeostatic compensation. This group of patients must have as completely uneventful and error-free a post-injury course as possible in order to recover. Thus, monitoring must be both more aggressive and more frequent [Greenburg & Peskin, 1983].

Bendixen and Duberman (1986) divided monitoring into four categories:

Minimal Monitoring is applicable to healthy patients undergoing simple procedures. Measurement of blood pressure, pulse rate, respiratory rate, body temperature, and monitoring of the electrocardioscope are the most common methods.

Major Monitoring is dictated by the physical status of the patient, the complexity of the procedure or both. Major monitoring includes minimal monitoring plus the use of invasive catheters to obtain readings of physiological parameters not otherwise available.

Special Monitoring is to measure specific parameters affected by a medical condition or procedure. Special monitoring includes the use of specialised equipment (invasive or non-invasive).

Fail-Safe Monitoring is the use of devices to inform the clinician (anaesthetist) that a potentially critical deterioration of physiological parameters has occurred or that a situation such a mechanical event exists which, if uncorrected, will lead to such a deterioration. Fail-safe monitoring should be used at all times in conjunction with minimal, major, and special monitoring [Bendixen & Duberman, 1986].

5.3.1 Invasive Monitoring

Invasive monitoring has dominated, if not replaced the traditional vital signs to evaluate circulatory function and to make clinical decisions for fluids and pharmacological support of the circulation. Although highly effective when used prophylactically, invasive monitoring systems are expensive, time consuming and not user-friendly [Shoemaker et al., 1988]. Arterial pressure monitoring has been controversial at least since 1903 and continues to centre around the use of direct blood pressure measurement. The greatest criticism of direct arterial pressure monitoring is that there no agreement among clinicians as to what they really want (systolic, diastolic, mean pressure, pressure trends). Invasive arterial pressure monitoring is far from risk-free. The hazards of invasive arterial pressure monitoring are summarised by Bedford (1985) as:

* vascular compromise
* disconnection
* accidental injection
* infection, and
* damage to nearby nerves.

Non-invasive techniques are preferred, as the invasive approach is always a source of potential harm from injury and infection. However, invasive techniques usually are needed for specific accurate monitoring [Orkin & Shapiro, 1982].

5.3.2 Non-Invasive Monitoring

Non-invasive techniques are preferred because they are readily performed, require no time consuming preparation of sterile equipment, calibration, placement of needles or catheters, cause no complications, and are often inexpensive. The non-invasive approach is essential for routine monitoring because the invasive devices hurt, their placement is time consuming, they are costly, and their use has unacceptable risks in many instances. Ease of operation and continuous automated measurement are desirable characteristics of non-invasive monitors. Philip and Raemer (1985) presented the following degrees of non-invasiveness:

Absolutely non-invasive: Observation(e.g. chest motion, pupil size).

Very non-invasive: Airway gas sampling or energy transmission (e.g. ECG).

Moderately non-invasive: Percutaneous superficial (e.g. intravenous).

Moderately invasive: Percutaneous deep (e.g. systemic artery, pulmonary artery).

Very invasive: Organ invasion (e.g. ICP).

Absolutely invasive: Destructive (e.g. biopsy, autopsy).

Three examples of the most common non-invasive monitors are reviewed in this section the: Non-invasive Blood Pressure; Pulse oximeter; and, Electrocardiogram.

Non-invasive Blood Pressure (NIBP): NIBP devices can be classified by the type of signal sensed or detected during the determination of blood pressure [Ramsey, 1980]. According to Maier (1983), there are two basic methods of non-invasive blood pressure monitoring. Pressure can be measured either manually or with the use of one of a number of electromechanical devices. Each of these two methods has three different techniques which can be employed. These are the techniques of auscultation, oscillometry, and blood flow detection.

The **auscultatory** method of non-invasive blood pressure monitoring is certainly the most commonly used one today, and consists of determining the onset (systolic pressure) and muffling (diastolic pressure) of Korotkoff sounds.

The **oscillometry** method of non-invasive blood pressure monitoring uses a method of sensing variations in the pressure of a blood pressure cuff. Use of this technique was widespread in the early twentieth century, and still a major indirect method for older patients in whom Korotkoff sounds are not readily heard.

The **indirect automatic blood pressure** monitor utilises the oscillometric principle and a microprocessor [Maier, 1985].

By building some level of intelligence into devices, their operation can appear quite simple to the operator, yet can be very sophisticated and complex. The DINAMAP manufactured by Critikon Inc., is an example of an indirect blood pressure monitor, that utilises the oscillometric principle and a microprocessor. The NIBP monitor (Dinamap 1846SX), measures systolic, diastolic and mean blood pressures (in mm Hg) and the pulse rate (beats per minute) at intervals ranging from 1 to 16 minutes. The NIBP works as follows: the operator merely pushes a button to begin a determination, waits, and reads the results (systolic, diastolic, mean pressure, pulse rate). However, the monitor is performing a complex sequence of tasks and making decisions about the quality of data. Without the microcomputer, this would not be possible. Before the late 1960s, non-invasive blood pressure monitoring equipment was entirely manual.

All methods of non-invasive blood pressure measurement require at least the following fundamental building blocks [Ramsey, 1980]:

* an inflatable cuff,
* a means of inflating the cuff,
* a means of deflating the cuff,
* a pressure sensor and indicator,

* a signal sensor or detector, and

* a determination strategy and algorithm.

Pulse oximeter: Pulse oximetry has its origins in the work of Nicolai, who, in 1931, applied the Beer-Lambert Law to the transmission of light through the hand to study the dynamics of tissue oxygenation. He demonstrated that occlusion of the circulation produced an exponential fall in oxyhaemoglobin and rise in deoxyhaemoglobin [Cohen, 1987]. Non-invasive methods for determining the saturation of haemoglobin have been available for many years. However only recently have clinically popular pulse oximeters become widely accepted. The principle of pulse oximetry is based on the fact that reduced haemoglobin absorbs different wavelengths of light that does oxyhaemoglobin [Gravenstein & Paulus, 1987]. Pulse oximetry is a sensitive, reliable, non-invasive measure of oxygen saturation, capable of diagnosing and providing an early warning of desaturation prior to the development of the signs and symptoms of hypoxaemia, regardless of the experience of the observer [Cote et al., 1988]. The pulse oximeter works as follows: the operator applies the device, turns it on and a readout of pulse rate and arterial oxygen saturation appears. The device is continuously modulating the intensity of two wavelengths of infrared light, measuring its transmission through the extremity to which is applied (usually a fingertip), and performing a series of simultaneous computations to convert the raw data into meaningful information [Waterson & Calkins, 1986]. Many clinical studies with the pulse oximeter have shown that hypoxaemia and poor circulation are relatively

common. Thus, hypoxaemia was diagnosed quickly and easily by pulse oximetry in patients during one-lung anaesthesia, during postanaesthesia transport, in the PACU, with pulmonary disease in the intensive care unit, and during dental procedures under sedation. The device also proved useful in detecting local ischaemia - or evidence of good perfusion - during the reimplantation of severed fingers [Gravenstein & Paulus, 1987].

Electrocardiogram (ECG, EKG): This is the recording, by means of electrodes or leads, of the electric activity of the heart. Conventionally, three electrode lead systems are used in which standard positions for electrode placement exist. These are known as (1) three limb leads, in which lead I connects right and left arm; lead II, right arm and left leg; and lead III, left arm and left leg; (2) three augmented unipolar limb leads, aVR (right arm), aVL (left arm), aVF (left leg); and (3) six precordial leads, which connect different areas on the anterior chest to a limb and are known as leads V1-V6 according to the specific placement along the intercostal spaces. Each of these leads shows the electric activity of the heart on the side nearest the respective limb. The American Heart Association recommends a frequency band width of 0.5-100 Hz for diagnostic ECG recording. A much narrower bandwidth of 1-50 Hz is adequate for monitoring purposes [Klein, 1984]. Einthoven, in 1903 invented the string electrocardiogram, a device capable of recording current generated by the heart. The ECG is now used as a routine monitor during anaesthesia, surgery, and postanaesthesia period. Cannard, Dripps, et al. (1960)

showed the value of the ECG in diagnosing rhythm disturbances during anaesthesia. Each portion of the cardiac cycle produces a different electrical impulse. Three clearly recognisable waves accompany each cardiac cycle. The first is called the **P wave**, and indicates atrial depolarisation. The second wave, called the **QRS wave**, represents ventricular depolarisation, that is, the spread of the electrical impulse through the ventricles. The third recognisable deflection is a domeshaped **T wave**, and indicates ventricular repolarisation [Tortora & Anagnostakos, 1984]. In the first decade of the American manned space flight effort, the electrocardiogram was a consistent source of biomedical information received during the course of a space flight [Charles & Bungo, 1986]. Some uses of the ECG are:

Intra-operative

* to monitor a cardiac arrest
* to diagnose ischaemic changes
* to identify arrhythmias
* to check for electrolyte changes
* to observe pacemaker function.

Post-operatively

* to identify arrhythmias
* myocardial infarction.

The ECG also serves as an important diagnostic device in cases where no cardiac activity can be detected by auscultation (precordial or oesophageal stethoscope), where no pulse or blood pressure can be obtained [Kaplan, 1980].

5.3.3 Alarms

Clinicians are becoming increasingly reliant upon machines to assist in diagnosis and treatment. The last two decades has seen an increasing trend toward incorporating alarms into medical devices. Many of these devices (patient monitoring and life support) now include alarms as standard features. Alarms are designed to signal some or all of the following [Hyman & Drinker, 1983]:

* adverse changes (if a patient measured variable (heart rate, arterial pressure) triggered by a vital sign outside of the preselected range of values),
* operator error, including attention lapse, and
* failure or malfunction of the device.

The purpose of the alarm is to attract the attention of the staff, and the alarm signal is usually either a sound, a light, or both. Alarm outputs usually include both audible and visible displays, and may allow the user the option of disabling either or both. Alarms were introduced by companies whose engineers thought that clinicians would appreciate an automatic alarm that could be set as desirable [Gravenstein &

Paulus, 1987]. Although admirable in concept, in practice alarms have limited value. Early monitors were often set off by artifacts rather than by true patients' complications. Modern monitors now incorporate many features that limit, but do not eliminate, false alarms due to artifact. The following are possible reasons for a false alarm sounding: alarm variables set inappropriate by the clinician; alarm activated by an inappropriate device; alarm malfunction; alarm setting by designer inappropriate for the clinical circumstances [McIntyre, 1985].

False alarms present a number of special challenges to the equipment designer. Some of the challenges are the selection of the variables that will be provided with alarm outputs, the design of the alarm displays and setting controls, the provision of alarm test procedures, and the preparation of labelling and instructional materials. Furthermore, alarms can improve the safety and efficacy of equipment, if the designer provide an optimally useful, uncomplicated, and cost-effective device that also affords protection against foreseeable hazards. Throughout the design process, the designer must be alert to possible adverse effects of the alarm on user performance, including both overdependence (an alarm can fail) and diminished vigilance [Hyman & Drinker, 1983].

5.4 Physiological Monitoring in the PACU

In the United States and Canada the PACU were considered essential by the 1960s, but it is only with the present generation of British hospitals that a PACU adjacent to the operating theatres has been regarded as a necessity [Farman,1979]. Before the 1960s it was routine to immediately return post-operative patients to their rooms. Little monitoring and observation was carried out except for an occasional measurement of pulse and blood pressure and less frequently, ventilatory rate. A judgement handed in a North American Provincial Supreme Court decision in 1969 aptly describes the currently recognised position of the PACU:

> The function of this room is to provide highly specialise of care, frequent and careful observation of patients who are under the influence of anaesthesia. They remain in this room until they have regained consciousness and their bodies return to their normal functions. Respiratory arrest is not an uncommon occurrence in the PAR room (PACU) and therefore the personnel in this room must be watchful and alert at all times in order to protect the patient in this labile and vulnerable stage. The nurses in this room are there for the purpose of promptly recognising any respiratory problem, cardiovascular problem or haemorrhaging. They are expected to take corrective action and/or to summon help promptly. The patient is more prone to crises after the

> operation than while in the operating room where the respiration is being controlled. From this point of view it is my opinion that this is the most important room in a hospital and one in which the patient requires the greatest attention because it is fraught with the greatest potential dangers to the patient. As the dangers or risks are ever-present there should be no relaxing of vigilance if one is to comply with the standard of care required in this room. Close scrutiny and ever-present watchfulness is required in this room and the patient is entitled to expect the same [Fisher, 1970].

The patient entering the PACU has just undergone an acute, reversible, and potentially lethal intoxication for the purpose of being operated on without pain [Quimby & Bailey, 1986]. The duration and severity of post-anaesthetic risk are dependent on the patient's original condition, nature of the surgical procedure, length of the procedure, drugs used, blood and other vital fluid loss and individual patient responses. Patients are at considerably increased risk for adverse circulatory and respiratory events. Some of these can be quite dramatic and life threatening, such as total airway obstruction with attendant hypoxaemia or severe hypotension. Because of this transition period and the frequent inability of the patient to communicate with those caring for him, it is utmost importance that physiological monitoring be performed [Calkins, 1981]. In fact, any organ system whose malfunction may become malignant or signify the progression toward a rapidly

developing course of change should be monitored [Orkin & Shapiro, 1982]. Monitoring in the PACU is directed primarily to the detection of abnormalities related to either the emergence from anaesthesia or the surgical procedure [Greenburg & Peskin, 1983]. The role of monitoring in the PACU is to provide the PACU nurse with accurate and reliable information about the state of the patient, on which clinical decisions can be based [Waterson & Calkins, 1986]. Respiration, cardiac rate and rhythm, blood pressure, and body temperature are now routinely monitored post-operatively, since abnormalities in these functions portend important dysfunction.

It is the responsibility of the PACU nurses to help the patient regain consciousness, re-establish his normal physiological balance and to initiate the appropriate therapeutic action. Thus, this has demanded more attention to the monitoring and management of the PACU patients. The ease of operation and continuous nature of non-invasive monitors make them particularly useful in the PACU. Non-invasive monitors are preferred because they are easy to use, are associated with almost no complications, incorporate audible alarms and free the nurse's hands for other duties. The following non-invasive monitors are routinely used in our PACU:

Automatic oscillometric blood pressure monitor (NIBP); used to identify hypotension, hypertension and disturbances in heart rate.

Pulse oximeter; used to detect a decrease in oxygen saturation and disturbances in heart rate.

Electrocardiogram (ECG); used to diagnose change in heart rate, arrythmias and to provide indication of cardiac muscle hypoxia.

In the PACU, subjective observations and important objective physiological data must be obtained, analysed, and assimilated into the patient care decision making process [Calkins, 1981].

5.5 Summary

Health care depends more and more on technology to gather information necessary for appropriate diagnosis and patient management. Through the ages it has been the task of the physician to watch and observe the patient with the specific purpose (=monitoring) of making diagnosis and/or performing therapeutic action [Meijler, 1987]. The word "monitor" derived from the Latin verb "monere - to warn" and in particular to warn of danger. The last two decades major contribution has been made by the introduction of new monitoring equipment and techniques. There are two monitoring methods: **invasive** (monitor that penetrates the skin, mucosal membrane, or enters some body cavity); **non-invasive** (monitor that does not penetrate or puncture tissues but may require a transducer). Non-invasive techniques are preferred because they are easy to use, require no time consuming preparation of sterile equipment, are associated with almost no complications, and

free the clinician's hands for other duties [Orkin & Shapiro, 1982; Gorski & Fraulini, 1987]. Monitoring of the critically ill with the assistance of the computer has been explored intensively for more than two decades. In 1966, Weil et al. were among the first to report for the first time, the utilisation of a digital computer in the intensive care environment. Physiological monitoring must be performed in the PACU because of the transition period and the frequently inability of the patient to communicate with those caring for him/her [Calkins, 1981].

To become familiar with available hardware and provide further insight into adverse events in our patient population, a prospective study (ARRES) was devised. The specific aims of this prospective study of the PACU patients were to determine the incidence of potentially adverse blood pressure, heart rate and hypoxic events, their predictors, demographic characteristics as well as assessment of ARRES performance. The automated data collection system was used to determine the occurrence of several adverse events frequently revealed by these monitors.

The next chapter discusses the purpose of the prospective study, the methods used for data analysis (on-line data collection system; hardware; software), and results obtained from the study.

6.0 ARRES: DESCRIPTION OF THE PROSPECTIVE STUDY

6.1 Introduction

Most of medical decisions, such as arriving at a diagnosis or estimating a prognosis, require the simultaneous consideration of multiple factors, each with a different degree of importance to the decision. For instance, in deciding whether a patient with chest pain has myocardial infarction, factors that may influence the decision, include age, sex, past medical history, and location of the pain. Similarly, in predicting the prognosis of a patient with an acute myocardial infarction, it is necessary to consider the age of the patient, the presence or absence of heart failure, the location of the infarct, and the previous state of health. Multivariate analysis is a technique that identifies variables that are important in making a decisions and assigns a weight to each variable, based on its influence relative to other "important" variables. This information can be used to develop a mathematical model for making a diagnosis or prognosis [Young et al., 1984]. Multivariate analysis presents a powerful tool for combining all the objective data obtained at a particular moment in the patient's course [Afifi et al., 1971].

Discriminant analysis is one multivariate technique; it is used to classify the dependent variable into two discrete groups. For example, one may use discriminant analysis to predict an outcome that has only two values, such as hypoxia versus normoxia, or survival versus death [Young et al., 1984]. The best known example of this technique is the linear discriminant function. According to McNeil and Hanley

(1981), this sophisticated approach uses a statistical regression technique to derive a single predictive score for each patient. The discriminant function contains a set of weights by which each variable is multiplied before all are added together into a single discriminant score. The variables with large weights are the most important ones for predictive purposes. The development of a predictive system requires collection of data about a number of patients - that is, a data base that contains relevant clinical and laboratory features and the correct diagnosis or outcome for each patient [McNeil & Hanley, 1981].

In summary, multivariate techniques offer great promise for improved medical decision making [McNeil & Hanley, 1981], and have the potential to help the clinician decide when to use diagnostic and therapeutic technology [Young et al., 1984].

6.2 Review of Previous Work

Some examples in which multivariate techniques have been used to predict patient outcomes or aid medical decision making are presented below.

Afifi et al., (1971) used a discriminant function to predict patient survival after drug overdose. Stepwise discriminant analysis was used to determine the best combination of variables for predicting survival. The authors developed two objective indices:

The momentary prognostic index, which estimated the patient's probability of survival on the basis of a single set of measurements.

The accumulative prognostic index, which takes into account previous sets of measurements.

The authors reported formulae derived from the analysis, that permitted calculation with a desk-top calculator of the accumulative prognostic index, and its immediate application by the clinician [Afifi et al., 1971].

Dolgin et al. (1981) used a discriminant function to identify gallstones dissolvable with chenodeoxycholic acid, based on their appearance on an oral cholecystogram. Using stepwise discriminant analysis, they separated patients with cholesterol stones from those with pigment stones. They reported that the sensitivity

of the discriminant function was 95%, the specificity 82%, the efficiency 91%, the positive predictive value 93%, and the negative predictive value 88%. They also demonstrated that the discriminant function is more useful when expressed in terms of probabilities. The authors suggested that using discriminant analysis can improve the prediction of gallstone composition and the subsequent selection of medical or surgical therapy [Dolgin et al., 1981].

Brand et al. (1982) used a discriminant function to predict whether patients with injured extremities needed x-rays. The investigator's protocol was derived from a prospective collected clinical data base and subsequently tested on another series of patients to demonstrate its safety and effectiveness. The authors reported that the protocol reduced by 5%, x-ray usage for upper extremities and by 16%, x-ray usage for lower extremities. It was also claimed to diminish the likelihood of conviction in a malpractice suit against a physician who uses the protocol. They suggested that by eliminating superfluous x-ray procedures, the protocol for patient selection could save between $79 million and $139 million in charges for radiography nationwide without compromising quality of care [Brand et al., 1982].

Lee et al. (1986) used multivariate analysis to compare the accuracy of a data-based statistical model and several expert clinicians in predicting patient outcomes for a chronic disease. The purpose of their study was to compare the relative accuracy of a modern experience-based multivariable statistical model and senior

cardiologists in predicting the long term likelihood of (1) death and (2) death or nonfatal myocardial infarction in patients with chronic coronary artery disease. They reported that for patients who survived, the distributions of model survival probabilities at one and three years were more accurate than the corresponding distributions of doctor predictions. Contrasting patients who died with those who survived, the doctors' predictions had less separation (more overlap) than the model predictions. Their model correctly rank-ordered pairs of patients with respect to three-year survival 80% of the time, whereas the doctors' ranking was correct 74% of the time. When model and doctor predictions were jointly considered, there was a significantly stronger relationship of model predictions. The authors suggested that a multivariable statistical model developed from a large clinical data base could make prognostic predictions that were more accurate than those made by experts [Lee et al., 1986].

6.3 Purpose of the Prospective Study

In the preliminary retrospective study (chapter 4) it was found that the overall incidence of hypertension was 8 percent, hypotension 4 percent, tachycardia 4 percent, and bradycardia 5 percent among PACU patients. Both mean systolic blood pressure and the incidence of hypertension were significantly higher for males versus females, sick (physical status III-IV) versus healthy (physical status I-II), and older (>55 years) versus (< 55 years) patients. Because of the high incidence of artifact, it was not possible to examine data for oxygen saturation in the preliminary analysis. Also, the retrospective study focused on one data set only. However, the power of the statistical analysis would be improved if more data could be included. To gain familiarity with the available hardware and provide further insight into adverse events in the patient population under study a prospective study (ARRES) was devised. The ARRES system was developed at the Hospital of the University of Pennsylvania with the assistance of an intersciplinary group of senior clinicians, nurses, statisticians and computer scientists.

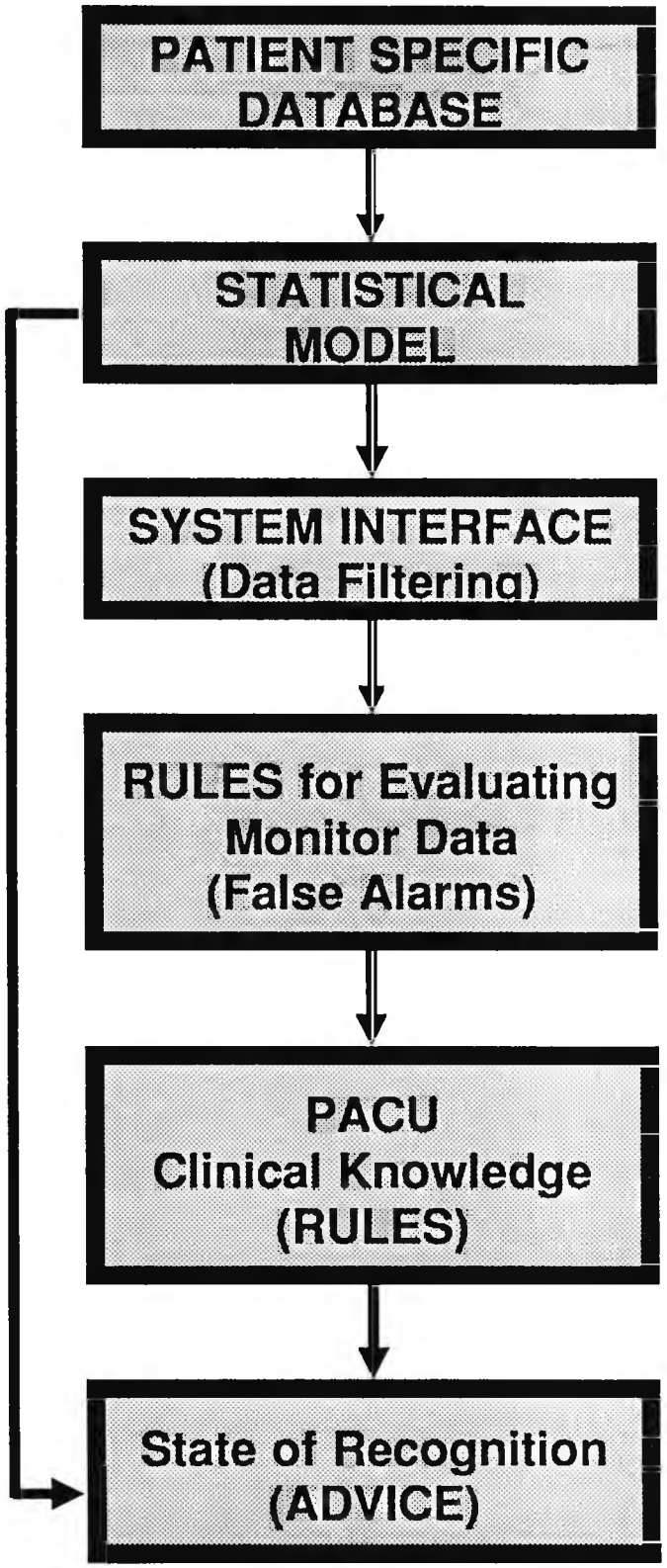
J.J Osborn (1982) indicated the way to reach a stage of a coherent patient care system by its use, that is to break down the general problems and once it has been decided what to measure, work on the sub-components first. This is the path that has been followed in the design of the ARRES system, breaking it down into single modules, and trying to make them work.

The ARRES modules include (Figure 6.1):

* patient database
* statistical model
* interface to monitoring devices
* rules for evaluating the monitor data (expert system)
* clinical knowledge, and
* advice

The purpose of the prospective study was to determine the incidence of potentially adverse blood pressure, heart rate and hypoxic events, their distribution, demographic characteristics and evaluation of the validation rules, as well as demonstration of the ARRES performance.

Figure 6.1: Modules of the ARRES System.



6.4 Data Sources

Four data sources were used for this prospective study: 1) the Operating Room record (Appendix III); 2) the Anaesthesia record (Appendix IV); 3) the PACU record (Appendix V); and 4) an on-line automated computer system.

The OR record was used as the data source for the surgical procedure, type of anaesthesia (Local, Ams, Regional, General), procedure acuity (1 - 5), ASA physical status (1 - 5), surgical procedure emergency, time of specific events (e.g., time in OR - anaesthesia induction - start surgery - end surgery - out of OR), length of surgery, and estimated blood loss (EBL).

The Anaesthesia record was used to provide information about each patient's sex, age, weight, height, intraoperative vital signs (oxygen saturation, blood pressure and heart rate) ranges, presence of invasive monitoring (arterial line, central), intraoperative urine output, volume of fluid infused in the OR and use of intraoperative narcotics.

The PACU record provided the time of admission to the PACU, discharge time, airway support (none - oral - nasal - endotracheal), oxygen support (nasal, mask, humidified, ventilator, T-piece) level of consciousness (alert, agitated, unresponsive, lethargic, confused), post-operative urine output, volume of fluid infused in the PACU, and use of post-operative medications.

The On-line automated computer system was used to collect the post-operative time, blood pressure, heart rate and oxygen saturation measurements. The patient monitoring data are being used to develop decision rules for evaluating the monitoring data (acceptability of data).

6.5 Automated Data Collection

According to Osborn (1982), three steps must be followed to bring the important numbers to our attention and remind us of what they mean: 1) to clean up the data (minimise false alarms and artifact); 2) to make predictions using the filtered data on discrete models, and; finally to simplify further by extracting the key measurements and their meaning.

The first task for the ARRES project was the setting-up of a data bank and the evaluation of available means for the storage, retrieval and processing of PACU patient information. A computer file was established for each patient admitted to the PACU. Pertinent demographic and medical information were entered in each patient's file in the relational data base. The second task was to interface the ARRES system with the non-invasive PACU monitors. Upon arrival to the PACU, each patient was attached to a standard set of non-invasive monitors. An automated data collection system was developed to record data continuously from the non-invasive blood pressure, pulse oximeter and electrocardiogram monitors. During the third phase, knowledge based rules for validating the monitoring (minimise false alarms and artifact) data were developed. Finally by using all data available the PACU model was developed.

6.5.1 Data Collection Problems

Among the many problems that arise with automation are: the time necessary to learn how to use, interpret, and troubleshoot the system; the confusion that can result with inexperienced personnel, not being able to sort through the enormous amount of data that are generated; and how to apply this information to the clinical status of the patient [Davenport, 1987].

The development of the ARRES system started with comprehensive task analysis of decisions, activities and requirements of the PACU nurses. Before introduction of the ARRES data collection system to the PACU it had been thoroughly tested in the Day Surgery Unit on healthy patients. During the first month a group of clinical engineer, systems engineer and computer scientist were available to troubleshoot the ARRES system. When the ARRES system was moved into the PACU some new problems emerged. The first and one of the most obvious problems was placing the personal computer and associated peripherals so as not to interfere with routine nursing duties. To avoid congestion cables were passed from monitors through the ceiling to an empty room adjacent to the monitored PACU bed and connected the physiological monitors to the microcomputer through an internal serial communications adapter. Many monitoring devices supply an RS-232 port to allow interfacing with personal computers. Difficulties with the RS-232 protocol arise from generally poor manufacturer support, non-standard nature of protocols and manuals that are incomplete and confusing. Historically, monitors have not been

equipped with appropriate communication interfaces, and the present systems are not greatly improved. The functions and the electrical characteristics are specified but most RS-232 connections use only 4 to 6 signals, and the handshake protocol varies with the individual vendor [Waterson & Calkins, 1986]. Therefore, the cables had to be customised in order to connect the monitoring devices to the communication ports (Table 6.1).

Table 6.1: Computer to Device (RS-232) Cable Connections

Pin	Name	Computer Dinamap	Computer ECG	Computer Nellcor-200
1	Shield	1 ------ 1	1 --- 1	
2	TXD	2 ------ 3	2 --- 3	2 --------- 2
3	RXD	3 ------ 2	3 --- 2	3 --------- 3
4	RTS	4 ------ 5		4 --------- 6
5	CTS	5 ------ 4	5 --- 20	5 --------- 7
6	DSR			6 --------- 4
7	GND	7 ------ 7	7 --- 7	7 --------- 5
20	DTR		20 --- 5	20 --------- 8

During the first month the ARRES system suffered more than 6 failures. The problems were solved with minor hardware or software changes. Software problems or "bugs" appeared frequently in the original version, less so in later versions. For example when the program tried to read a character that was not present, it caused the program to "hang". The solution for this problem was to check and make sure that the character was in the buffer before reading it, and to limit the time in the loop waiting for data to 15 seconds. Hardware failures of individual physiological

monitors caused monitored data not to appear in the central database. In the first month our ECG failed about 5 times causing the ECG communication port to crash. A hardware problem in its serial communication subsystem was identified and corrected so that this event would nor recur. In addition crashes sometimes occurred because the power cord came loose at the connector on the back of the personal computer. To minimise these problems the system was checked twice a day during the first month and once a day in following months. After the first month of operation, the frequency of ARRES failures decreased markedly. Notes were placed on the ARRES system instructing the nurses how to reach me by telephone or pager, when failures occurred. If failures occurred on certain monitors and a quick solution, it was not at hand a clinical engineer brought in alternative monitors. The ARRES system was used successfully over a six month period during which data from 157 patients were collected.

We hope that elaboration of our experiences designing, building and using the ARRES system, will assist others from avoiding similar mistakes.

6.5.2 Hardware Selection

ARRES utilises a microcomputer (IBM/PC/XT) with an internal 20 Mbyte hard disk and customised software (Figure 6.2). All available hardware and software utilised by the ARRES system was provided by the HORNET group in our hospital. The ARRES system interfaces with three automated PACU physiological monitoring devices (Figure 6.3):

Figure 6.2: ARRES Hardware.

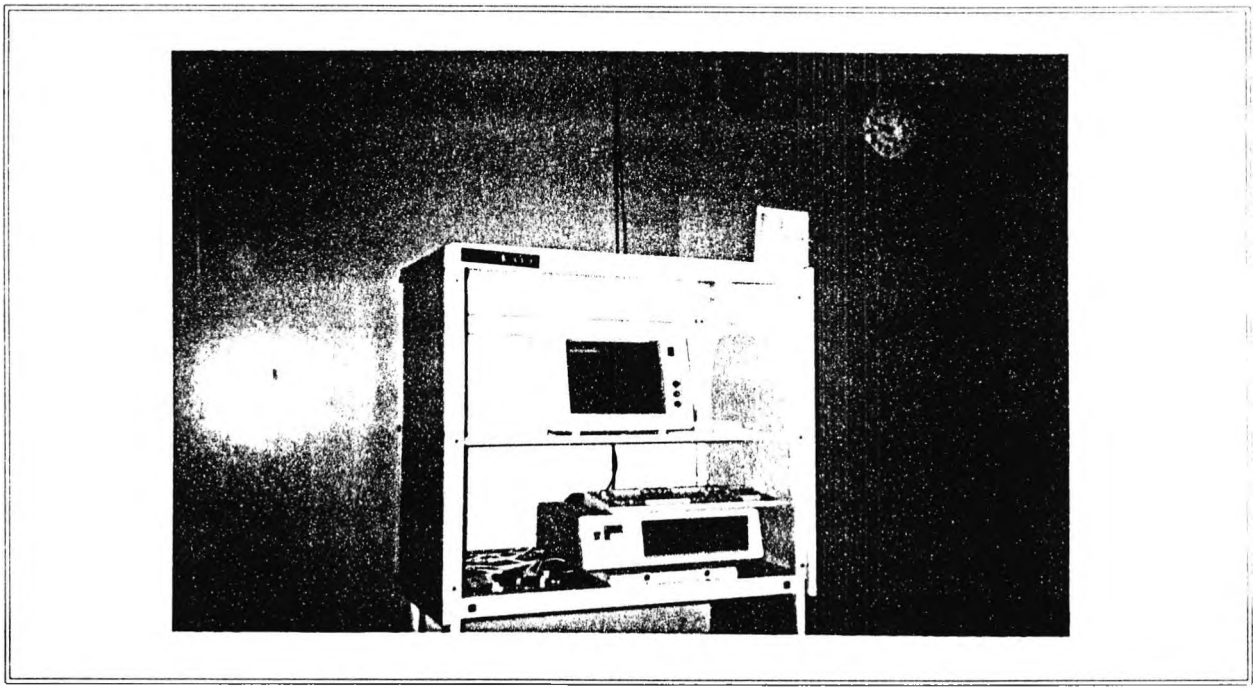
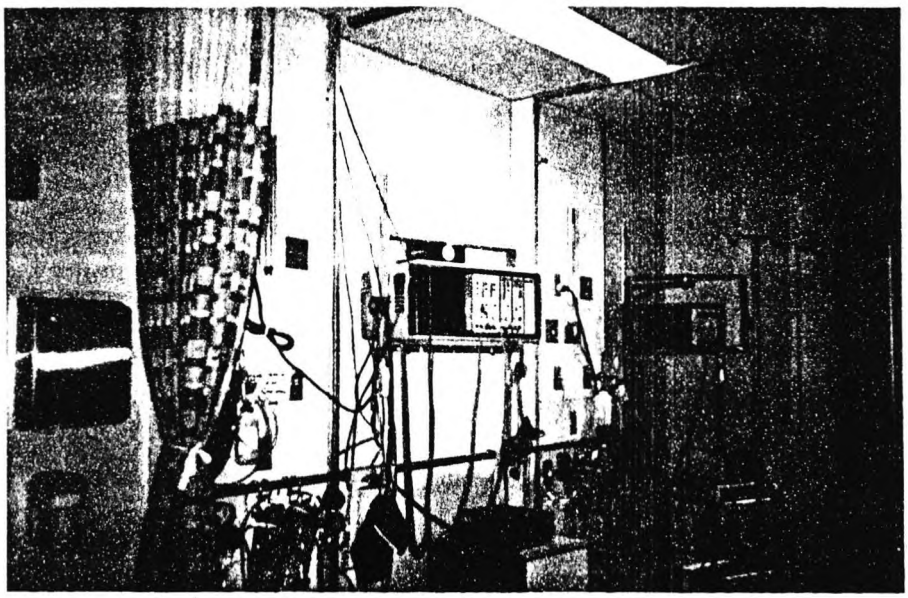


Figure 6.3: ARRES Physiological Monitoring Devices.



* A Non-Invasive Blood Pressure (Dinamap 1846SX, Critikon Inc.) was used to measure mean arterial, systolic and diastolic blood pressure [in mm Hg], and pulse [beats per minute] (Figure 6.4).
* An ECG (Hewlett Packard 78534C) was used to collect heart rate data (Figure 6.5).
* A Pulse oximeter (N-200, Nellcor Inc.) was used to measure heart rate and oxygen saturation (Figure 6.5).

Figure 6.4: ARRES Non-Invasive Blood Pressure Monitor.

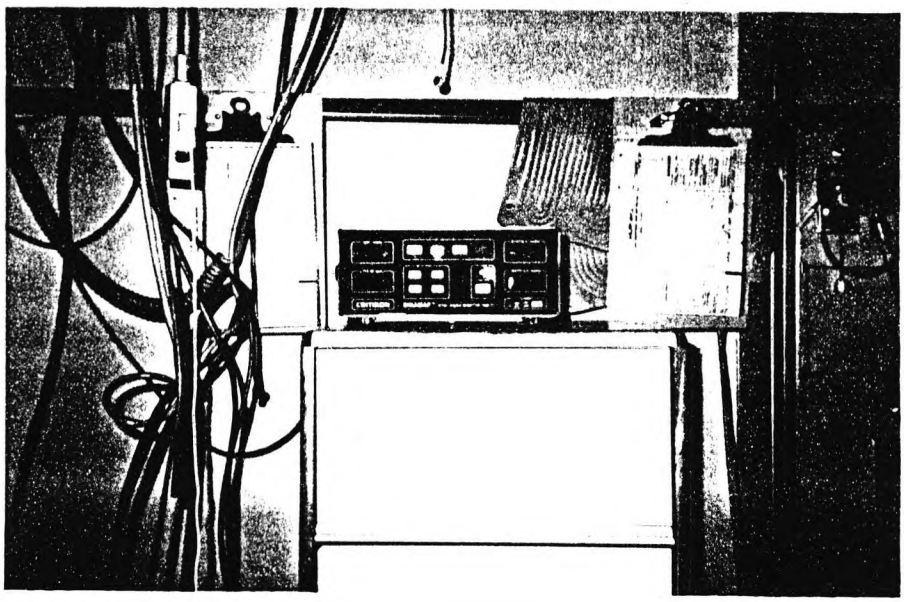
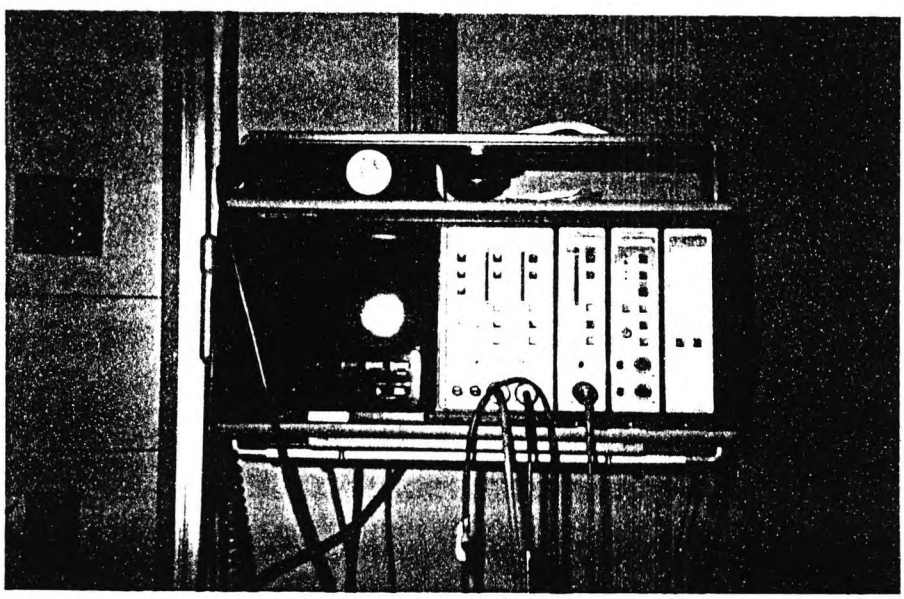


Figure 6.5: ARRES - Pulse Oximeter & Electrocardiogram Monitors.



These devices connect to a microcomputer through an internal serial communications adapter (DigiBoard COM/8). The adapter provides eight DB-25P, RS-232C standard DCE ports using programmable interface elements and independent status and control registers. A software driver COMS.SYS (version 2.3), permits access to the board by emulating eight serial DOS compatible ports (COM3 - COM10). Each port has specific (Table 6.2) RS-232 interface parameters (e.g., partial RS-232 or full RS-232C), baud rate (600 baud to 9600 baud), parity (even, odd, or none), stop bits (one or none), and data bits (seven or eight).

Table 6.2: ARRES - Serial Hardware Interface.

Device	RS-232	DCE/DTE	Baud	Parity	Data	Stop
pulse oximeter	RS-232C	DCE	1200	none	8	1
non-invasive blood pressure	RS-232 (pins 1-7)	DTE	600	none	8	1
ECG	RS-232C	DTE	9600	none	8	1

6.5.3 Software Selection

Hope and Morrison (1986) explain that the variable measurements must be prepared, or conditioned, in some manner, usually with the use of amplifiers, filters or conversion to a digital format [Hope & Morrison, 1986]. This was the path that has been followed and to implement this function in the ARRES system, a program written in Lattice C was used (Version 3.3), along with the Greenleaf Library (Version 2.21). This combination provided a high-speed, programmable interface (Appendix VI). Upon initiating the program, communications parameters and request strings were set (Table 6.3). The ARRES system uses five request strings: three individual character strings for the pulse oximeter (pulse, pulse amplitude, and oxygen saturation), one character string for the NIBP (all available data), and one binary request string for the ECG (all available data). ARRES also uses an initial string for the ECG to determine status information.

Table 6.3: ARRES - Software Interface.

Device	Type of Protocol	Parameter Request/ Reply	Total Delay
pulse oximeter	conversation (per request)	individual	< 2.0 s
NIBP	conversation (per request)	all	< 1.5 s
ECG	conversation (per request)	all	< 1.0 s

Two measurement intervals were defined, one system limited and the other device limited. The pulse oximeter and ECG continuosusly measure a patient's status. Thus, the measurement interval was limited by the response time of the system. It was determined by summing the response times for the individual monitors (Response time[PO] + Response time[NIBP] + Response time[ECG] <= Measurement interval). In the ARRES system, the defined measurement interval is 15 seconds. The NIBP takes measurements intermittently. Therefore, its interval was limited by the time between measurements, usually 3 to 10 minutes. When new NIPB data were not available, the places where new data would appear in the value array were replaced by nulls.

Data collection were started at eight a.m. each day. The ARRES system opened four files, three raw data files labelled with the date and the device name (e.g. 0219PO.989), and a partially processed, combined data file (e.g. 0310RR.989). For

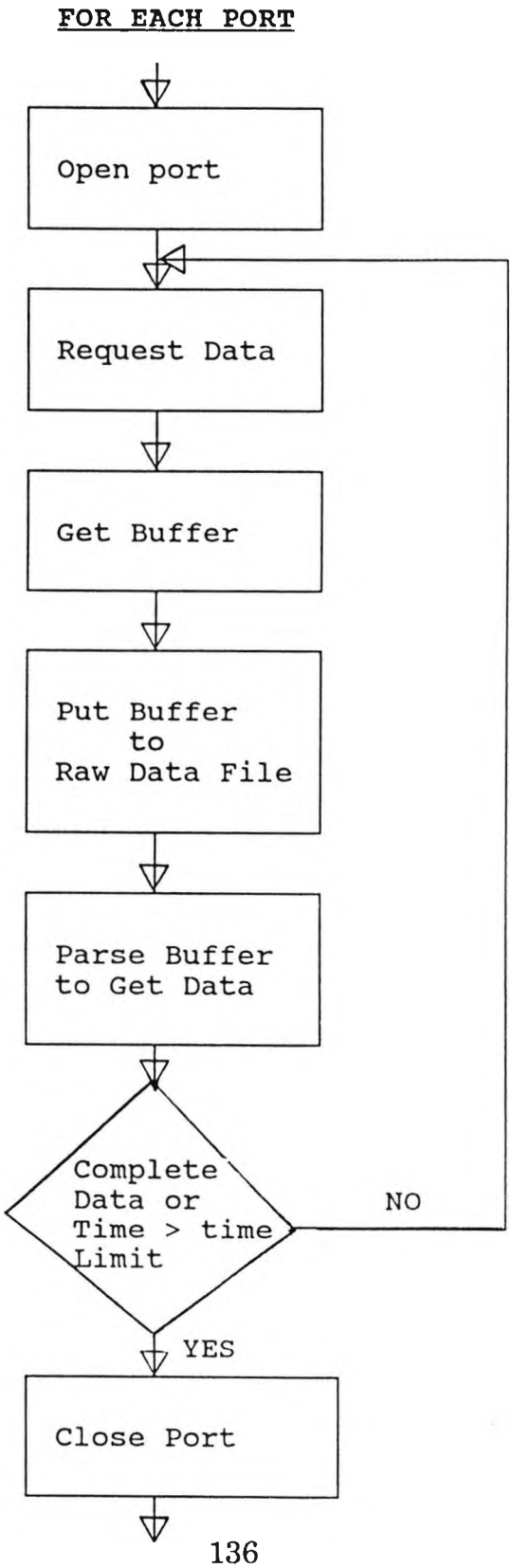
each device, the program opens its port, passes the 'initial' string to the port, and then closes the port (Figure 6.6). Software specified the port address, the transmit and receive buffer length (256 bytes), the mode (two-way, ASCII), Data-Terminal-Ready (DTR) (off), and Request-To-Send (RTS) (off). Characters were received from an open port until the response time limit of the device expires, the maximum data length were reached, or an end-of-string character were received. The buffer contents were then written to the device's raw data files. If the data string from the buffer matches the device's format specification, it was passed to a value array. After the process was completed for each port (device) and the time of day was appended to the value array, the array was written to the combined data file and reset (Appendix VII). At eight p.m., the program closes the four data files. The program features an escape routine to allow for user access to the data files. The software was used successfully over a five month period during which data from 157 patients were collected.

Once a pathway had been established for transfer of data from the monitors to the computer via the interface, the next task was to ensure that the signals received reflect changes in patient parameters rather than (e.g. from limb movement during a pulse rate measurement) artifacts [Roessler et al., 1986]. During this phase, the data were passed to a rule based system written in PROLOG, designed to get rid of false alarms and artifactual data. Data were sequentially tested, first for non-validity, after being tested for validity. The routine incorporated 36 rules (22 for

validity rules and 14 for non-validity). When data for the same parameter were available from multiple devices, rules based on redundancy of values were implemented. When they were not, the rate of change of the values was tested against the maximum probable rate of change. Another PROLOG module calculated the post-operative vital signs [systolic blood pressure, heart rate and oxygen saturation (minimum, maximum, average)] ranges for each patient and passed them to an output file [Appendix VIII]. Computer validated data were spot checked manually by experienced clinicians to confirm the efficacy of the rule based system. Data are checked, filtered and described in the working format before transmission to the data base.

The final step in the data management was to match the set of monitored data to the patient demographic and clinical data. To manage the data files, a computer database using KMAN was designed and implemented. The database is based on the Structure Query Language (SQL) implementation of relational algebra. The database was customised and a PACU data management system created. Appendix IX illustrates the structure of the data base and Appendix X the data entry screens.

Figure 6.6: Flow Diagram for Each Port.



6.6 Methods for Data Analysis

The objective of data analysis is to organise the findings to relate them to the purposes of the study. One hundred fifty seven consecutive PACU patients were studied. Sex, age, weight (WTPOUND), height, type of anaesthesia (TYPEANES), ASA physical status (PSTATUS), surgical urgency (EMERG), procedure acuity (ACUITY), length of surgery (TOTALOR), intra-operative vital sign (oxygen saturation, blood pressure and heart rate) ranges (AMSATMIN, ANSBPMAX, ANSBPMIN, ANHRMAX, ANHRMIN) estimated blood loss (EBLOR), intra-operative urine output (URINEOR), volume of fluid infused in the OR (FLUIDSOR), presence of invasive monitoring (ARTLINE, CENTRAL), and use of intra-operative narcotics (NARCANES) were extracted for each patient from the operating room and anaesthesia records. In addition, level of consciousness (LOC), oxygen support (OXYGENS) and airway support (AIRSUP) were assessed and scored by nursing personnel when each patient arrived in the PACU.

Upon arrival at the PACU, each patient was attached to a standard set of non-invasive monitors. A NIBP unit (Dinamap 1846SX, by Critikon Inc.) was used to measure mean arterial, systolic and diastolic blood pressure (in mm Hg), and pulse (beats per minute). A physiological monitor (Hewlett Packard 78534C) was used to collect ECG heart rate data. A pulse oximeter (N-200, Nellcor Inc.) was used to measure heart rate and oxygen saturation. Nurses recorded data from these monitors in the PACU record. On-line data were collected using the automated system.

A survey of 13 senior anaesthesiologists was used to determine the boundaries of five adverse physiological events for both the intra-operative and post-operative periods (Table 6.4). The average values were very similar to the default alarm settings provided by the equipment manufacturers.

Table 6.4: Alarm settings for adverse physiological events.

Complication	RED (audible alarm)	N	Range
HYPOXIC (O2Sat)	< 89	11	(70-94)
HYPERTEN (BP/sys)	> 180	9	(160-250)
HYPOTEN (BP/sys)	< 80	9	(70-90)
TACHY (HR)	> 110	9	(100-160)
BRADY (HR)	< 60	10	(40-70)

HYPERTEN = Hypertension
HYPOTEN = Hypotension
TACHY = Tachycardia
BRADY = Bradycardia

The events were **hypoxia** (oxygen saturation < 89), **hypertension** (systolic blood pressure > 180), **hypotension** (systolic blood pressure < 80), **tachycardia** (heart rate > 110), and **bradycardia** (heart rate < 60). In addition, requirement for PACU care longer than 150 minutes was defined as a problem, "**long PACU stay**" (LPACUST).

A four-part analysis process was used in this study: (1) Descriptive analysis, (2) Student T-tests analysis, (3) Chi-square analysis, and (4) Discriminant analysis. Each of these methods is outlined in the following discussion.

6.6.1 Descriptive Analysis

Descriptive analysis was used to summarise and organise the PACU patients according to sex, age, weight, height, duration of surgery and duration of PACU stay. Descriptive analysis was conducted on the following variables:

- sex
- age
- weight
- height
- duration of surgery
- duration of PACU stay

6.6.2 Student T-tests Analysis

Student's T-tests were used to evaluate differences in mean oxygen saturation, blood pressure and heart rate between males and females, physical status I-II (healthy) and physical status III-IV (sick) groups, general anaesthesia and regional anaesthesia patients, and patients $\geq$ 55 years old versus $<$ 55 years old patients.

Student T-tests were completed for the following variables:

- sex
- age
- physical status
- type of anaesthesia

6.6.3 Chi-Square Analysis

Chi-square analysis was used to evaluate the differences in the incidence of adverse physiological events between males *versus* females, physical status I-II *versus* physical status III-IV groups, general anaesthesia *versus* regional anaesthesia patients, and patients ≥ 55 years old *versus* < 55 years old patients. Chi-square was completed for the following variables:

- sex
- age
- physical status
- type of anaesthesia

6.6.4 Discriminant Analysis

Stepwise discriminant analysis was used to determine whether any of the objective data available when the patient was admitted to the PACU were significant

predictors of the occurrence in the PACU of any of the defined adverse physiological events of a long PACU stay, or if any of these occurrences were noted, a PACU problem (PACUPROB). To facilitate analysis an additional nominal variable "sick" was created to replace the multidimensional non-parametric descriptor, physical status, where "sick" (PS_SICK) was defined as physical status ≥ 3. Similarly, procedure acuity (MINSURG) was replaced by "major surgery", defined as acuity ≥ 2. Other nominal descriptors included general anaesthesia (GENANES), presence of an intra-arterial catheter (ARTLINE), use of central venous or PA catheter (CVP), presence of mechanical airway support with endotracheal tube, nasal or airway (AIRWAY), presence of ventilatory support via mask, ventilator, or T-Piece (BAGGED), and whether the patient was alert (ALERT) on admission to PACU.

The following variables were included in the discriminant analysis: SEX; AGE; WTPOUND; HEIGHT; MINSURG; GENANES; PS_SICK; EMERG; TOTALOR; EBLOR; ARTLINE; CVP; SEDANES; NARCANES; URINEOR FLUIDSOR; AIRWAY; BAGGED; ALERT; ANSBPMAX; ANSBPMIN; ANHRMAX; ANHRMIN; ANSATMIN.

The **dependent** variables were binary (1 or 0) depending on whether the outcome occurred (eg., the patient was hypertensive) or not.

Statistical analysis was performed with "Statistical Package for the Social Sciences" (SPSS) programs [Norusis, 1986] (Appendix XI).

6.7 Data Analysis and Results

The study population of 157 patients contained 95 females and 62 males. The characteristics of the population were [mean, ± standard deviation, (range)]: age, 48.0 ± 19.3 years (14-86); weight, 70.8 ± 17.3 kg (45-132); height, 1.67 ± 0.09 m (1.49 - 1.98); duration of surgery, 160.4 ± 74.9 minutes (30-411); duration of PACU stay, 77.3 ± 48.5 minutes (8-360) [Table 6.5].

Table 6.5: Anthropomorphic Data (N=157)

	Mean ± S.D.	Minimum	Maximum
Age	48.0 ± 19.3	14	86
Weight (kg)	70.8 ± 17.3	45	132
Height (m)	1.67 ± 0.09	1.49	1.98
Duration of Surgery	160.4 ± 74.9	30	411
Duration of PACU stay	77.3 ± 48.5	8	360

Ranges and average values in the PACU for maximum and minimum blood pressure and heart rate, minimum value for saturation, and length of PACU stay are presented in Table 6.6. The average maximum systolic blood pressure was 233.0 ± 26.9 mm Hg and the minimum 99.0 ± 26.9. The average maximum systolic blood pressure was significantly higher for males than females (154.9 ± 26.0 *versus* 143.8 ± 26.8), and for patients who received general anaesthesia than for patients who received other types of anaesthesia (154.3 ± 27.5 *versus* 138.9 ± 24.1). The average minimum systolic blood pressure was also significantly greater for patients receiving general anaesthesia (122.3 ± 23.5 *versus* 112.6 ± 17.0). The average maximum heart

rate was significantly higher for patients receiving general anaesthesia than for patients who received other types of anaesthesia (101.2 ± 19.6 *versus* 91.7 ± 23.2). The average maximum heart rate was also significantly greater for patients under 55 years of age than for patients over 55 years of age (103.3 ± 22.4 *versus* 90.1 ± 17.0). The average minimum oxygen saturation was significantly higher for patients receiving general anaesthesia versus another types of anaesthesia (91.3 ± 6.0 *versus* 89.1 ± 6.2). The average of minimum oxygen saturation was also significantly greater for patients under 55 years of age than for patients over 55 years of age (91.4 ± 5.6 *versus* 89.2 ± 6.4).

Table 6.6: Vital Signs Ranges in the PACU

	Male	Female
Maximum SBP	154.9 ± 26.0	143.8 ± 26.8*
Minimum SBP	121.5 ± 23.5	116.8 ± 21.1
Maximum HR	98.2 ± 21.7	98.0 ± 21.3
Minimum HR	65.6 ± 15.8	66.0 ± 12.7
Minimum SAT	90.8 ± 4.5	90.4 ± 6.9
Time in PACU	74.8 ± 49.9	78.8 ± 47.6
	General Anaesthesia	**Other types of Anaesthesia**
Maximum SBP	154.3 ± 27.5	138.9 ± 24.1*
Minimum SBP	122.3 ± 23.5	112.6 ± 17.0*
Maximum HR	101.0 ± 19.6	91.7 ± 23.2*
Minimum HR	67.7 ± 13.5	62.9 ± 14.4
Minimum SAT	91.3 ± 6.0	89.1 ± 6.2*
Time in PACU	77.2 32.9	74.5 ± 57.0
	Old (≥ 55 years)	**Young (< 55 years)**
Maximum SBP	151.2 ± 28.7	146.6 ± 25.6
Minimum SBP	120.3 ± 21.9	117.9 ± 22.3
Maximum HR	90.1 ± 17.0	103.3 ± 22.4*
Minimum HR	63.8 ± 14.1	67.2 ± 13.9
Minimum SAT	89.2 ± 6.4	91.4 ± 5.6*
Time in PACU	83.4 ± 52.9	73.9 ± 45.0

* $p < 0.05$ by Student T-test | Mean ± Standard Deviation

SBP = Systolic Blood Pressure

HR = Heart Rate

SAT = Oxygen Saturation

Incidence of the defined adverse physiological events in the PACU paralleled the findings for average maximum and minimum values (Table 6.7). Hypertension occurred in 19 patients and hypotension in 12. Hypertension was seen in 17 of 90 patients who received general anaesthesia but in only 2 of 54 patients who received other anaesthesia ($p<.05$). Tachycardia was observed in 39 patients and bradycardia in 2 patients. The incidence of tachycardia was over 50% in patients under 55 years of age, but occurred in only 7 of 61 patients 55 or older. Similarly, the incidence of tachycardia was nearly 50% when general anaesthesia has been used but occurred in only 6 of 54 patients who received other anaesthesia ($p<.05$). Hypoxia occurred at some time during the PACU stay in over one third of patients (55 of 157). Hypoxia occurred less frequently in patients who received general anaesthesia, but the difference was not statistically significant. PACU stay of over 150 minutes was required for 17 patients and was nearly three times as likely for patients over 55 years as for patients 55 years of age ($p<.05$). Our data indicated that hypotension and bradycardia were more likely to occur in the OR, and hypoxia more likely to occur in the PACU (Table 6.8).

Table 6.7

Incidence of Adverse Events by Demographic Characteristics.

	Male	Female	General	Other	Sick	Not Sick	Old	Young
HYPER	11/62	8/95	17/90	2/54*	8/43	10/110	8/61	11/95
HYPO	5/62	7/95	6/90	4/54	3/43	9/110	4/61	8/95
TACHY	17/62	22/95	27/90	6/54*	12/43	26/110	7/61	32/95*
BRADY	1/62	1/95	2/90	0/54	1/43	1/110	0/61	2/95
HYPOXIC	17/62	38/95	25/90	24/54	18/43	36/110	26/61	29/95
LONG PACU STAY	4/62	13/95	6/90	9/54	5/43	11/110	11/61	6/95*

* p < 0.05 by Chi Square

Table 6.8

Number of Patients who Experienced an Adverse Event (N=157).

Adverse Event	OR	PACU	Ratio OR : PACU
Hypoxia	0	55	0.0: 1
Hypertension	21	19	1.1: 1
Hypotension	45	12	3.8: 1
Tachycardia	32	39	0.8: 1
Bradycardia	46	2	23.0: 1

OR = Operating Room
PACU = Post Anaesthesia Care Unit

Discriminant functions were evaluated using the:

* discriminant function,
* standardised canonical discriminant function coefficient,
* Wilk's Lambda value (stepwise procedure), and
* discriminant function scores for predicted groups.

Stepwise discriminant analysis was limited to the **five best predictors** for each problem. Results of the discriminant analyses for predicting the adverse events are shown in Table 6.9.

Hypoxia was best predicted by estimated blood loss (EBLOR), volume of fluid infused in the operating room (FLUIDSOR), SEX, length of surgery (TOTALOR), and whether the patient was alert on admission to PACU (ALERT). Discriminant analysis correctly classified 66.88 percent of patients with hypoxia, meaning that group membership could be predicted with 67 percent accuracy on the basis of scores obtained for selected variables.

Hypertension was best predicted by maximum intra-operative systolic blood pressure (ANSBPMAX), general anaesthesia (GENANES), presence of mechanical airway support (AIRWAY), intra-operative minimum oxygen saturation (ANSATMIN), and intra-operative maximum heart rate (ANHRMAX). The function correctly

classified 90.45 percent of patients for hypertension.

Hypotension was predicted by use of central venous or PA catheter (CVP), intra-operative systolic blood pressure minimum (ANSBPMIN), estimated blood loss (EBLOR), volume of fluid infused in the operating room (FLUIDSOR), and whether or not general anaesthesia was administered (GENERAL). It was able to correctly classify 92.99 percent of patients for hypotension.

Tachycardia was best predicted by maximum intra-operative heart rate (ANHRMAX), surgical urgency (EMERG), length of surgery (TOTALOR), use of intra-operative sedatives (SEDANES), and whether the patient was alert on admission to PACU (ALERT). Eighty percent of patients were correctly classified for tachycardia.

Bradycardia was best predicted by presence of mechanical airway support (AIRWAY), intra-operative maximum heart rate (ANHRMAX), presence of ventilatory support (BAGGED), and intra-operative minimum heart rate (ANHRMIN). The function correctly classified 96.82 percent of patients for bradycardia.

Long PACU stay was best predicted by use of central venous catheter (CVP), intra-operative maximum systolic blood pressure (ANSBPMAX), SEX, intra-operative minimum oxygen saturation (ANSATMIN), and estimated blood loss (EBLOR). The function correctly classified 91.08 percent of patients for PACU care longer than 150 minutes.

PACU problems was predicted by maximum intra-operative heart rate (ANHRMAX), volume of fluid infused in the OR (FLUIDSOR), use of intra-operative narcotics (NARCANES), estimated blood loss (EBLOR), and presence of ventilatory support (BAGGED). It was able to correctly classify 64.97 percent of patients for any of the above problems.

Discriminant function. The discriminant functions are displayed in Table 6.10. It reports one function which accounts for 100 percent of the variance between groups.

Table 6.9

Best Combinations of Variables to Predict the Adverse Events

Adverse event	Discriminators	Sig.	Eigenvalue	Percent classified correctly
Hypoxia	EBLOR	.0178	0.1322	66.88
	FLUIDSOR	.0067		
	SEX	.0028		
	TOTALOR	.0020		
	ALERT	.0020		
Hyper-tension	ANSBPMAX	.0000	0.3252	90.45
	GENANES	.0000		
	AIRWAY	.0000		
	ANSATMIN	.0000		
	ANHRMAX	.0000		
Hypotension	CVP	.0001	0.1857	92.99
	ANSBPMIN	.0001		
	EBLOR	.0001		
	FLUIDSOR	.0001		
	GENANES	.0001		
Tachycardia	ANHRMAX	.0000	0.3837	80.25
	EMERG	.0000		
	TOTALOR	.0000		
	SEDANES	.0000		
	ALERT	.0000		
Bradycardia	AIRWAY	.0015	0.1689	96.82
	ANHRMAX	.0001		
	BAGGED	.0001		
	ANHRMIN	.0001		
Long PACU stay	CVP	.0015	0.1301	91.08
	ANSBPMAX	.0012		
	SEX	.0014		
	ANSATMIN	.0015		
	EBLOR	.0022		
PACU Problems	ANHRMAX	.0076	0.1566	64.97
	FLUIDSOR	.0031		
	NARCANES	.0016		
	EBLOR	.0010		
	BAGGED	.0005		

Table 6.10: Canonical Discriminant Functions.

Hypoxia					
Function	Eigenvalue	Percent of Variance	Canonical Correlation	Wilk's Lambda	Chi Square
1	.1322	100.00	.3417	.88	18.93
5 degrees of freedom, significant at .0020					

Hypertension					
Function	Eigenvalue	Percent of Variance	Canonical Correlation	Wilk's Lambda	Chi Square
1	.3252	100.00	.4953	.75	42.93
5 degrees of freedom, significant at .0000					

Hypotension					
Function	Eigenvalue	Percent of Variance	Canonical Correlation	Wilk's Lambda	Chi Square
1	.1857	100.00	.3958	.84	25.98
5 degrees of freedom, significant at .0001					

Tachycardia					
Function	Eigenvalue	Percent of Variance	Canonical Correlation	Wilk's Lambda	Chi Square
1	.3837	100.00	.5266	.72	49.52
5 degrees of freedom, significant at .0000					

Bradycardia					
Function	Eigenvalue	Percent of Variance	Canonical Correlation	Wilk's Lambda	Chi Square
1	.1689	100.00	.3801	.85	23.87
5 degrees of freedom, significant at .0001					

Long PACU Stay					
Function	Eigenvalue	Percent of Variance	Canonical Correlation	Wilk's Lambda	Chi Square
1	.1301	100.00	.3393	.88	18.65
5 degrees of freedom, significant at .0022					

PACU Problems					
Function	Eigenvalue	Percent of Variance	Canonical Correlation	Wilk's Lambda	Chi Square
1	.1566	100.00	.3680	.86	22.19
5 degrees of freedom, significant at .0005					

Standardised Canonical Discriminant Function. Each variable is displayed (Table 6.11) by descending order of power based on the standardised canonical discriminant function. This procedure provides a coefficient for the discriminant function in descending order of power. The higher the coefficient, the more the variable contributes to the difference between groups.

Wilk's Lambda. The stepwise procedure was used to compute the Wilk's Lambda for each variable. These findings are displayed in Table 6.12. A tolerance level of .001 was selected to determine whether to include a variable in the stepwise procedure. The tolerance level determines which variables are most discriminating when there is no clear basis for ordering variables. The variables listed in Table 6.13 were identified as the best predictors for the adverse events.

Table 6.11

STANDARDISED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

Adverse event	Discriminators	Function 1
Hypoxia	FLUIDSOR	-.90
	EBLOR	.88
	TOTALOR	.55
	SEX	.52
	ALERT	.34
Hypertension	ANSBPMAX	.76
	AIRWAY	.37
	ANSATMIN	-.32
	GENANES	-.27
	ANHRMAX	-.22
Hypotension	CVP	.77
	EBLOR	-.49
	ANSBPMIN	-.38
	FLUIDSOR	.36
	GENANES	.28
Tachycardia	ANHRMAX	.62
	EMERG	.49
	TOTALOR	.48
	SEDANES	-.39
	ALERT	.38
Bradycardia	AIRWAY	.69
	ANHRMAX	-.52
	BAGGED	.35
	ANHRMIN	-.33
Long PACU stay	CVP	.72
	SEX	-.38
	ANSBPMAX	.38
	ANSATMIN	-.36
	EBLOR	.27
PACU problems	FLUIDSOR	.69
	ANHRMAX	.55
	EBLOR	-.54
	NARCANES	.45
	BAGGED	.44

Table 6.12

WILK'S LAMBDA FOR VARIABLES INCLUDED IN THE STEPWISE PROCEDURE

Adverse Event	Discriminators	Wilk's Lambda	Significance Level
Hypoxia	EBLOR	.964	.0178
	FLUIDSOR	.937	.0067
	SEX	.912	.0028
	TOTALOR	.895	.0020
	ALERT	.883	.0020
Hypertension	ANSBPMAX	.812	.0000
	GENANES	.796	.0000
	AIRWAY	.779	.0000
	ANSATMIN	.763	.0000
	ANHRMAX	.754	.0000
Hypotension	CVP	.903	.0001
	ANSBPMIN	.882	.0001
	EBLOR	.867	.0001
	FLUIDSOR	.853	.0001
	GENANES	.843	.0001
Tachycardia	ANHRMAX	.835	.0000
	EMERG	.812	.0000
	TOTALOR	.779	.0000
	SEDANES	.752	.0000
	ALERT	.722	.0000
Bradycardia	AIRWAY	.937	.0015
	ANHRMAX	.879	.0001
	BAGGED	.866	.0001
	ANHRMIN	.855	.0001
Long PACU stay	CVP	.937	.0015
	ANSBPMAX	.916	.0012
	SEX	.903	.0014
	ANSATMIN	.891	.0015
	EBLOR	.884	.0022
PACU problems	ANHRMAX	.954	.0076
	FLUIDSOR	.927	.0031
	NARCANES	.904	.0016
	EBLOR	.885	.0010
	BAGGED	.864	.0005

Predicted Group Membership: In order to ascertain how efficient the discriminant function was in predicting group membership, cases in each group were classified according to their discriminant scores by predicted groups. These results are displayed in Table 6.13. Discriminant analysis was able to correctly classify at least 90% of patients for hypertension, hypotension and long PACU stay. It correctly classified about 60% of the other problems.

Table 6.13: Efficiency of Discriminant Analysis.

Adverse Event	Percent classified correctly Not Present	Present	Overall	Eigen-value
Tachycardia	94.9 (112/118)	35.9 (14/39)	80.25 (126/ 57)	0.3837
Hypertension	97.8 (135/138)	36.8 (7/19)	90.45 (142/157)	0.3252
Hypotension	99.3 (144/145)	16.7 (2/12)	92.99 (146/157)	0.1857
Bradycardia	97.4 (151/155)	50.0 (1/ 2)	96.82 (152/157)	0.1689
Hypoxia	90.2 (92/102)	23.6 (13/55)	66.88 (105/157)	0.1322
Long PACU stay	99.3 (139/140)	23.5 (4/17)	91.08 (143/157)	0.1301
PACU problems	34.4 (21/ 61)	84.4 (81/96)	64.97 (102/ 57)	0.1566

6.8 Summary of Findings

The routine use of pulse oximeters, non-invasive blood pressure monitors and electrocardiogram monitors has considerably improved patient care in the post anaesthesia period. Using an automated data collection system, the occurrence of five adverse physiological events (hypoxia, hypertension, hypotension, tachycardia, bradycardia) frequently revealed by these monitors were investigated. In addition, the requirement for PACU care for longer than 150 minutes was defined as a problem. It was found that the incidence of hypoxia was 35%, hypertension 12%, hypotension 8%, tachycardia 25% and bradycardia 1% and long PACU stay 11%. More than half of PACU patients experienced at least 1 of the adverse physiological events (Table 6.8). Stepwise discriminant analysis was able to correctly predict at least 90% of patients for hypertension, hypotension and long PACU stay. It correctly classified about 60% of the other problems (Table 6.13). Use of automated data collection increased the yield of adverse physiological events to 50%, up from 20% in the retrospective study in which data were collected manually. The ARRES system (Figure 6.1) minimised artifact, validated data for epidemiological studies, and was able to identify variables that predict adverse events through application of appropriate statistical and artificial intelligence techniques.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary of the Previous Chapters

Technological advancement in physiological monitoring of critically ill patients has moved rapidly during the past two decades. The tremendous growth of medical information from new tests, procedural innovation, and advanced monitoring techniques has increased the volume of data clinicians must record and interpret. As the amount of data has increased, PACU personnel may become overwhelmed by the quantity of data arriving from multiple sources. While computer-assisted decision making systems have been utilised in other critical care areas for data acquisition and processing, they have not previously been applied on-line in the PACU.

The ARRES project was undertaken in an attempt to help fill this gap. ARRES is an on-line PACU clinical management system designed to minimise artifact, demonstrate the feasibility of collecting and processing data, and identify variables that predict adverse events through appropriate statistical and artificial intelligence techniques.

An initial retrospective study was designed to determine the: 1) incidence of potentially adverse blood pressure and heart rate events among PACU patients; and 2) distribution of PACU patients by type of anaesthesia, physical status, age and sex. Operating, anaesthesia and PACU records of 200 consecutive patients were collected

manually for review. A survey of 13 senior anaesthesiologists was used to determine the threshold values for hypertension, hypotension tachycardia, bradycardia, and hypoxia.

Results indicated that the overall incidence of hypertension was 8 percent, hypotension 4 percent, tachycardia 4 percent, and bradycardia 5 percent. Mean systolic blood pressure and the incidence of hypertension were significantly greater for males *versus* females, sick (physical status III-IV) *versus* healthy (physical status I-II), and older (>55 years) *versus* younger (<55 years) patients. There were no significant differences by type of anaesthesia. Because of the frequency of artifact, it was not possible to include accurate data regarding oxygen saturation.

Based on the findings from the retrospective study, a follow up prospective study was developed (ARRES). The purpose of this component was to determine the incidence of potentially adverse blood pressure, heart rate and hypoxic events, demographic characteristics of patients experiencing these events, to evaluate validation rules and to demonstrate the capabilities of the ARRES system. The ARRES modules include the patient database, interface to monitoring devices, rules for evaluating the monitor data, clinical knowledge, and a statistical model. First, the data-bank was developed to evaluate available means for storage, retrieval and processing of PACU patient information. Secondly, the ARRES system interface to the three selected physiological monitoring devices was implemented. The software was used successfully over a six month period during which data from 157 patients

were collected. Thirdly, data validation routines were developed and used to minimise false alarms and artifact. All data were tested for validity using a rule-based system written in PROLOG. Finally, multivariate statistical analysis was used to identify the factors that are most important in predicting post-operative adverse events, and to evaluate the ARRES system.

Results indicate that the overall incidence of hypoxia was 35 percent, hypertension 12 percent, hypotension 8 percent, tachycardia 25 percent, and bradycardia 1 percent. Stepwise discriminant analysis classified at least 90 percent of patients correctly for hypertension and hypotension. It correctly classified about 60 percent of patients with the other problems. Use of ARRES, the automated data collection system, increased the yield of identification of adverse physiological events to 50%, up from 20% in the retrospective study in which data were collected manually.

7.2 Conclusions from the Study

The findings of this study indicate the following conclusions in response to the goals of this project. The first objective for this study was to minimise artifact in our database. This has been accomplished through the use of data validation routines written in PROLOG. Secondly, data were collected continuously without disrupting the normal PACU routine, thus demonstrating the efficacy of ARRES in collecting and processing on-line data for epidemiological studies. Multivariate statistical and artificial intelligence techniques were also used to identify factors that predict adverse events.

This project demonstrated the feasibility of collecting and processing data free of artifact and ambiguity, with an unattended computer system of moderate cost. Data-recording and analysis capacity afford us the opportunity to evaluate and identify the incidence of adverse events, and to determine whether particular physiological parameters and demographic factors are good predictors of adverse events in the PACU. In fact, the approach that was taken matches the approach suggested by Osborn (1982) and Hope & Morrison (1986). J.J Osborn indicated that the way of reaching a stage of having a coherent patient care system was to break down the general problems and have the sub-components working first [Osborn, 1982]. This is the path that has been followed in the design of the ARRES system, beginning with single modules and trying to make them work.

Future applications of the findings of this study may include:

* structuring decisions and solving problems using the data;

* providing data to assist rational decision-making about capital expenditure for monitors that improve quality of care and address risk management concerns in the PACU population;

* refining monitoring practice and aiding in the management of limited PACU resources;

* providing objective data for medicolegal protection.

* improving our understanding of patient care in the PACU;

* directing the responses of nurses to adverse PACU events;

* improving the efficiency of medical staff and nurses in the PACU. For the nurse the system decreases the workload by automatically collecting valid data from existing monitoring practice. For the patient it improves the quality of health care and may permit a shorter length of PACU stay;

7.3 Recommendations for Future Research

Future developments are to integrate and organise the patient's records to improve their presentation is the contest of decision making. The future system should automatically acquire as many physiological data as possible without user interaction. The ARRES system has gone a considerable way towards achieving effective automated PACU physiological monitoring. However, at no point was this system envisaged as a complete computerised PACU patient monitoring system. The system does not address the recording of fluid balance, quantification of drug administration, pupillary size and reactivity, sweating, skin colour, blood loss, etc. The well-designed system of the future for the PACU should be a totally integrated system that incorporates on-line operating room data which are fed directly to an on-line PACU system. It should also be based on sound ergonomic principles, and (human factors) to interact with human operators in the safest and most productive manner, taking into account known human capabilities and limitations [Duberman et al., 1984; Waterson et al., 1986]. It must be realised that human errors can never be completely avoided. Nor can the need for professional interaction and oversight ever be completely eliminated. As technology improves it is possible to monitor more data, but patient care will improve only if medical care providers remember that the new technologies are but tools.

7.4 Limitations of the Study

The limitations of the study include the following: The system was developed in a teaching hospital with no ambulatory surgery patients. Paediatric patients were not included in the study group. A second limitation was that the ARRES system deals with a central set of PACU management considerations. There are other considerations that ARRES ignores. These include on-line recording of drug administration, fluid balance, skin colour, blood loss, etc.

7.5 Contributions to Systems Science and Medicine

A system can be thought of as a combination of components that interact with each other. For example, a patient admitted to the PACU after receiving general anaesthesia represents a complex system accompanied by a variety of environmental, pharmacological and intraoperative circumstances . The PACU nurse along with the anaesthesiologist and surgeon is consider part of the system involved with the patient's care. The interface is defined as the area of contact between sub-components. Adoption of the systems approach provides insight into how system components interact dynamically. The ARRES system demonstrated in systems science the feasibility of integrating diverse monitoring equipment. Furthermore, the ARRES system was able to accurately and reliably facilitate the acquisition, storage and retrieval of multiple vital parameters, allowing simplified data management. Finally, the ARRES system was able to archive data, free of artifact

and ambiguity thus permitting retrospective identification of adverse events.

The ARRES system can be incorporated into the medical patient care system to provide the supervising clinician with information which can be integrated into the overall decision making process. It also permits standards of practice to be established, followed and monitored, thereby improving quality of care and reducing risk management concerns in the PACU population.

7.5 Summary

In summary, the ARRES system minimised artifact, demonstrated the feasibility of collecting and processing validated data for epidemiological studies, and was able to identify variables that predict adverse events. Although the prototype system was operated off-line, its simplicity and reliability should allow its implementation on-line. It is hypothesised that its on-line implementation would facilitate rapid clinical decision making. The ARRES system should be easily transported to other critical areas (ICU, SICU, etc.) were it could be used to conduct valuable epidemiological studies in their respective environments. The software addresses many of the problems common to automated record and smart alarm systems. These problems are identification of artifact and selection of the "correct" value when ambiguous results are returned from different devices capable of measuring the same variable. The techniques we used to solve these problems could readily be applied to commercial monitors and record keepers. They could also augment the front end of a smart alarm system.

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APPENDIX I

Types of Anaesthesia

Anaesthesia is an important part of the surgical operation, not only to relieve pain, but to make the operation safer. Anaestesia is a state of freedom from pain. Anaesthesia may involve the whole body or only a portion of it. The anaesthesiologist monitors and helps sustain body functions which are constantly altered by surgery and anaesthesia (American Society of Anaesthesiologists).

General anaesthesia: A physiological altered state classically containing four progressive components: (1) analgesia, (2) amnesia, (3) muscle relaxation, and (4) unconsciousness [Klein, 1984]. This may be produced by an injection into the vein through the intravenous or by inhaling a gas or vapour.

Spinal/Epidural anaesthesia: A type of regional anaesthesia induced by the injection of a local anaesthetic agent into the epidural (extradural) space, thus blocking the spinal nerve trunks [Klein, 1984]. The patient will remain conscious and have a medication injected into his spinal canal that will "numb" those nerves that are in the region of his/her operation.

Local anaesthesia: An agent which produces a transient and reversible loss of sensation in a circumscribed portion of the body [Klein, 1984]. This is used for minor surgical procedures involving a small area of the body. The surgeon injects the site of the incision with a drug that will block the sensation and thus it may feel "numb" the area so that discomfort should be felt.

APPENDIX II

Description of The Post Anaesthesia Care Unit Record

Steps followed by the nurse to complete the Post Anaesthesia Care Unit record (see Figure 4.1).

1. The PACU nurse has to record the hospital patient ID number, patient last/first name, and address.

2. ID BRACELET: Every patient arriving in the PACU must have an identification bracelet on his/her wrist. The PACU nurse is responsible to check for the patient identification bracelet.

DATE: Patient's operation date.

PRE-EXISTING PROBLEMS: Are taken from the Anaesthesia Record.

ALLERGIES: Are taken from the Anaesthesia Record.

OPERATION: Is taken from the Anaesthesia Record.

Estimated Blood Loss (EBL): Is taken from the Anaesthesia Record. All patients sustaining blood loss greater than 800cc during a surgical procedure they remain in the PACU for observation, a minimum of 90 minutes.

3. VITAL SIGNS: The purpose is to monitor, maintain and/or improve respiratory and circulatory function.

v = Systolic

^ = Diastolic

x = Mean

. = Pulse

o = Respiration

Nurses in the PACU take patients vital signs every 10 minutes from the time he/she arrives in the PACU until discharge to the floor nurse. All patients receiving anaesthesia have blood pressure, pulse, and respiration taken and recorded on the PACU record every 10 minutes unless otherwise indicated. All patients entering the PACU have their temperature taken and recorded to the PACU record.

4. OXYGEN THERAPY: All patients recovering from anaesthesia receive oxygen therapy unless otherwise indicated by the physician. Usually the nurses apply nasal prongs to patients in the recovery at 3-4 liters per minute unless otherwise indicated. Patients recovering from bronchoscopy, diagnostic laryngoscopy and all other patients whose otopharynx have been compromised, receive high humidity oxygen by facemask or face tent.

5. MEDICATION-ROUTE: All medications administered to the patient in the PACU are recorded. PACU nurse may administer only those drugs on authorised list for direct IV push (ie. Atropine, Morphine sulphate, Calcium chloride, Neostigmine etc.). A patient remains in the PACU a minimum of one hour after administration of an IV narcotic antagonist. The reason they stay a minimum of one hour is to monitor the patient for signs of respiratory depression and somnolence. If after one hour the patient's respiratory rate is greater or equal (>=16) than 16, and the patient meets all other discharge criteria, may be discharged to his/her room.

6. ANAESTHESIA LAB: The PACU nurse request the patient's results from the Blood Gas Lab. The Anaesthesia Lab sends the results to the PACU approximately in 10 minutes (about 5% of HUP patients in the PACU need a anaesthesia lab test).

7. POST-OPERATIVE X-RAYS: All patients requiring post- operative chest and hip x-rays are to remain in the PACU until a post-operative diagnosis is made by the radiologist.

8. FLUIDS: Most patients returning from the operating suite receive intravenous fluids. Urinary output is closely monitored in the recovery phase. The nurse take note immediately of the surgical site and check the dressing

for drainage. She/he also must be aware of whether or not the drain is in place and how much drainage is expected. Nurses check all drainage tubes to ensure patency and observe the amount, colour, and odour of any drainage.

9. PROGRESS NOTES: The PACU nurse checks the vital signs every 10 minutes and then writes an immediate post-operative note (progress notes).

10. ADMISSION PARS: The Post-anaesthetic Recovery Score (PARS) evaluates fine physical parameters and gives a number score much like the Apgar Score. It is utilised to make a quick assessment of the patient's condition following surgery and anaesthesia (see Table 1). The score taken upon arrival of the patient in the PACU and documented by the nurse. A second score is performed upon discharge with adequate written documentation. The decision to discharge a patient from the PACU is made by an anaesthesiologist. A written discharge note, date, and time are documented in the PACU record. The nurse writes a comprehensive discharge summary based on discharged criteria.

Criteria for discharge:

a. protects airway

b. clear secretions

c. haemodynamically stable - Vital signs stable

d. appropriate mental status - awake, alert, oriented to person etc.

Physical signs:

a. Activity (score 0-2)

b. Respiration (score 0-2)

c. Circulation (score 0-2)

d. Consciousness (score 0-2)

e. Colour (score 0-2)

For example: Circulation - use changes of arterial blood pressure from pre-anaesthetic level. If patient's Blood pressure (BP) is 50% less of pre-operative level then PARS score for circulation = 0

if patient's BP within 50-20% of preoperative level then

PARS score for circulation = 1

if patient's BP with 20% of preop level then

PARS score for circulation = 2

Similar procedure is followed for all physical signs. In order for the patient to be discharged he/she must have a total PARS score of 9 or 10.

APPENDIX III

Operating Room Record

OPERATING ROOM RECORD

NURSING | SURGERY | ANESTHESIA

DATE	O.R. NUMBER	HOSPITAL NUMBER
PATIENT NAME		
ROOM NUMBER	☐ INPATIENT ☐ SHORT STAY ☐ AM ADMIT ☐ OUTPATIENT	IMPRINT PATIENT PLATE

PATIENT VERIFICATION — NURSE SIGNATURE | SURGEON SIGNATURE | ANESTHESIOLOGIST SIGNATURE

PRE OP DIAGNOSIS | POST OP DIAGNOSIS

PROCEDURES

COMPLICATIONS (IF YES, PLEASE EXPLAIN) ☐ YES ☐ NO | LITHOTRIPSY SHOCKS

SURGICAL SERVICE
☐ GEN ☐ CT ☐ VAS ☐ TRANS ☐ PLS ☐ ORAL ☐ NEURO ☐ OTO ☐ ORTHO ☐ GYN ☐ UROL ☐ OB ☐ TRAUMA

SCRUB NURSE | CIRCULATING NURSE | PROCEDURE ACUITY LEVEL 1 2 3 4 5

ATTENDING SURGEON | ATTENDING SURGEON'S SIGNATURE

SURGICAL RESIDENT(S)

TYPE OF ANESTHETIC ☐ Local ☐ AMS ☐ Regional ☐ General | PHYSICAL STATUS 1 2 3 4 5 E | MONITOR ☐ A-LINE ☐ CENTRAL LINE ☐ ROUTINE

ATTENDING ANESTHESIOLOGIST | ATTENDING ANESTHESIOLOGIST'S SIGNATURE

ANESTHESIA RESIDENT(S)

USE MILITARY TIME

TIME IN O R	ANES INDUCTION (1)	PATIENT READY FOR SURGEON	START SURG PREP	START SURG ①	START CLOSE	END SURG (E.S.)	OUT O R

CELL SAVER ☐ YES ☐ NO | REPLACEMENT ☐ WHOLE BLOOD ☐ PACKED CELLS ☐ PLATELETS ☐ FFP ☐ OTHER—

ESTIMATED BLOOD LOSS _____ ML | NO. OF UNITS ▸

WOUND CLASSIFICATION ☐ CLEAN ☐ CLEAN/CONTAMINATED ☐ CONTAMINATED ☐ DIRTY/INFECTED

RESULTS OF WOUND SEARCH ANNOUNCED ☐ YES ☐ NO BY: DR. _____

SURGICAL IMPLANTS ☐ INSERTION ☐ REMOVAL ☐ CEMENT

TYPE	SIZE	LOT/SERIAL NO.	MANUFACTURER	DISPOSITION

OBSTETRIC USE ONLY

TIME		APGAR		WEIGHT		MATERNAL BLOOD	
BIRTH	PLACENTA	ALIVE: ☐ Yes ☐ No		SEX: ☐ Male ☐ Female		TYPE	GROUP
_____ EST	_____ EST.	____ 1 MIN.	____ 5 MIN.	____ LBS. ____ OZ	____ gm	☐ Rh- ☐ Rh+	☐ A ☐ B ☐ AB ☐ O

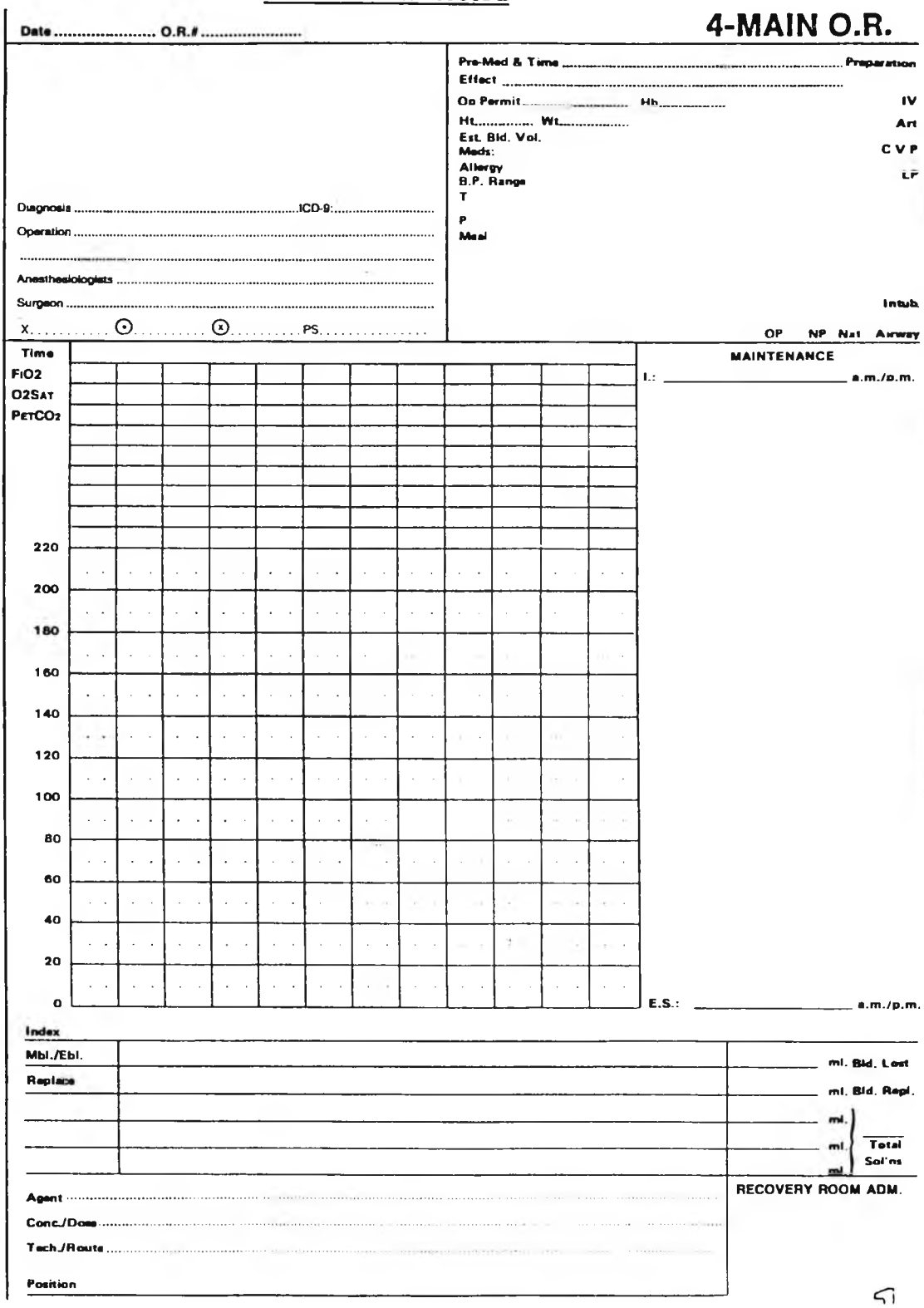
COUNTS

☐ CORRECT — ☐ SPONGE ☐ NEEDLES ☐ BLADES ☐ INSTRUMENTS _____ SIG.

☐ INCORRECT — ☐ SPONGE ☐ NEEDLES ☐ BLADES ☐ INSTRUMENTS _____ SIG.

APPENDIX IV

Anaesthesia Record



086435 10/88

Imprint with Name Plate or Print Patient's Name, Hosp No & Physn

HUP HOSPITAL OF THE UNIVERSITY OF PENNSYLVANIA

POST ANESTHESIA CARE UNIT RECORD

Allergies: _____

ARTERIAL BLOOD GASES

TIME	FIO_2	PO_2	PCO_2	Ph	BE	HCO_3	Hgb	Na	K	Ca++	GLU

MEDICATION

DRUGS	DOSE-RT	TIME	RN

DATE _____ ADMIT TIME _____ AM PM

ADMISSION SUMMARY

ID BRACELET ☐
Pre existing Problems

Airway ☐ None ☐ Oral ☐ Nasal
Support ☐ Endotracheal

Resp Quality _____

Br Sounds R ☐ Clear _____
L ☐ Clear _____

Nasal _____ Mask _____ % Humidified _____ %
☐ Ventilator ☐ T-piece _____ %

ECG ☐ NSR ☐ _____

Surgical dsg site ☐ Dry _____
☐ _____

LOC ☐ Alert ☐ Agitated ☐ Unresponsive
☐ Lethargic ☐ Confused

Neuro ☐ Moves all extremities
☐ See PACU Progress Notes

Skin Condition _____

LINES/CATHETERS/TUBES
Peripheral ☐ UE ☐ L ☐ R ☐ IV Site
☐ LE ☐ L ☐ R Check ☐

Central _____

Arterial ☐ L ____ ☐ R ____

☐ Epidural _____

☐ Salem ☐ NG ☐ Foley ☐ Jejunostomy
☐ Urinary with Irrigation ☐ Ureteral Stent

Drains _____

JP _____

Hemovac _____

Other _____

Orders Checked By _____

OPERATION _____ EBL

TIME																				
FIO_2																				
O_2 SAT																				
240																				
220																				
• PULSE																				
200																				
180																				
160																				
✓ SYS																				
140																				
120																				
100																				
˚ DIA																				
80																				
60																				
RESP																				
TEMP																				
URINE																				
OTHER																				

DISCHARGE SUMMARY

Resp quality _____
☐ Room air ☐ Nasal ____ ☐ Mask ____ %
☐ Humidified ____ %

ECG ☐ NSR ☐ _____

Surgical dsg ☐ dry
☐ _____

LOC ☐ Alert ☐ Unresponsive
☐ Lethargic ☐ Confused

Neuro ☐ Moves all extremities
☐ See PACU Progress Notes

Skin Condition _____

LINES/CATHETERS/TUBES
☐ As on admission
☐ _____

DESCRIBE CHANGES

Discharge time _____ AM PM

Discharge RN _____

Discharged to _____

I V F L U I D S

O R AND PACU	URINE	DRAINS
	OR _____	
	PACU _____	
	TOTAL _____	TOTAL _____

LABORATORY - X RAY

PROCEDURE	TIME	RESULTS	READ BY
ECG			
CXR			
XR			
OTHER			

APPENDIX VI

ARRES main module written in Lattice C (version 3.3)

```
/*
 *
 *  arres.c     code    main
 *
 *  automated PACU monitoring system (recovery room)
 *
 */
#include    "stdio.h"
#include    "dos.h"
#include    "string.h"
#include    "asiports.h"
#include    "gf.h"

#define     MSL         120
#define     SSL         14
#define     STARTPORT   2
#define     ENDPORT     4

FILE    *tfp[ENDPORT+1], *farres, *fout;

int     port[]      = { 0, 0, COM3, COM4,   COM5    };
int     maxdata[]   = { 0, 0, 78,   10,     30      };
float   waittime[]  = { 0, 0, 1.5,  1.0,    1.5     };

struct PORT_PARAMETERS
{
    unsigned int    a8250, mask;
    int     baud, par, stopbt, wordln;
}   params[] =
    {
        0,      0,  0,      0,      0,  0,
        0,      0,  0,      0,      0,  0,
        0x100,  0,  1200,   P_NONE, 1,  8,
        0x108,  1,  9600,   P_NONE, 1,  8,
        0x110,  2,  600,    P_NONE, 1,  8
    };

extern int      cltoa(), doinit(), domin(), dosec(), putvalues(), secinc();
extern float    secdiff();
```

```
main()
{
   unsigned char   clock[9], minclock[9], secclock[9];

   char    filename[ENDPORT+1][SSL+4], arresname[SSL],
           request[ENDPORT+1][SSL], initial[ENDPORT+1][SSL],
           stop[ENDPORT+1][SSL],
           syear[7], smonth[7], sday[7], shr[7], smin[7], ssec[7],
           ornum;
   int     im, key, jm,
           hr,
           quit_req, exit_req,
           buff[MSL], prior[MSL];
   float   values[40],
           mintime, sectime;

   fout    = fopen( "arres.out", "a" );

   ornum   = 'B';

   mintime = 60.0;
   sectime = 15.0;

/*
 *
 *  Pulse Oximeter (PO)
 *
 */
   strcpy( initial[2], "S.R.P." );        /* Sat, Rate, Pa        */
   strcpy( request[2], "S.R.P." );        /* Sat, Rate, Pa        */

/*
 *
 *  ECG (EC)
 *
 */
   initial[3][0] = 27;
   initial[3][1] = 3;
   initial[3][2] = 0;                     /* mode 0 - status      */
   initial[3][3] = 33;
   initial[3][4] = 0;

   request[3][0] = 27;
   request[3][1] = 3;
```

```
   request[3][2] = 2;                    /* mode 2 - data        */
   request[3][3] = 33;
   request[3][4] = 0;


/*
 *
 *  Non-Invasive Blood Pressure Monitor (NI)
 *
 */
   strcpy( request[4], "bea" );


   exit_req = 0;
   while( exit_req==0 )
   {
      printf( "\nWaiting for 9:00 am  ....\n" );

      getclk( clock );
      hr  = clock[4];
      while( ( hr<9 ) || ( hr>19 ) )
      {
         getclk( clock );
         hr  = clock[4];

         if( kbhit() )
         {
            key = getch();
            if( key=='^' )
               break;
         }
      }

/*
 *
 *  Set the file names using the date and ornumber.
 *
 */
      cltoa( syear, smonth, sday, shr, smin, ssec, clock );
      sprintf( arresname, "rr\\%s%sRR.9%s", smonth, sday, syear );
      farres = fopen( arresname, "a" );
      for( im=STARTPORT; im<ENDPORT+1; im++ )
         sprintf( filename[im], "raw\\%s%sdv.9%s", smonth, sday, syear );
      fprintf( fout, "%s/%s/%s.\n", smonth, sday, syear );
```

```
/*
 *
 *  Pulse Oximeter file (port[2])
 *
 */
        filename[2][8] = 'P';
        filename[2][9] = 'O';
        tfp[2] = fopen( filename[2], "a" );
        if( tfp[2]==NULL )
        {
            printf( "\nfopen: Can't Create %s.\n", filename[2] );
            exit( 0 );
        }

/*
 *
 *  ECG file (port[3])
 *
 */
        filename[3][8] = 'E';
        filename[3][9] = 'C';
        tfp[3] = fopen( filename[3], "a" );
        if( tfp[3]==NULL )
        {
            printf( "\nfopen: Can't Create %s.\n", filename[3] );
            exit( 0 );
        }



/*
 *      NIBP file (port[4])
 */
        filename[4][8] = 'N';
        filename[4][9] = 'I';
        tfp[4] = fopen( filename[4], "a" );
        if( tfp[4]==NULL )
        {
            printf( "\nfopen: Can't Create %s.\n",filename[4]);
            exit( 0 );
        }
        doinit( buff, initial );
```

```
for( im=0; im<29; im++ )
   values[im] = -1.0;
prior[0] = '\0';

getclk( clock );
while( clock[6]!=0 )
   getclk( clock );
clock[7] = 0;

cltoa( syear, smonth, sday, shr, smin, ssec, clock );
printf( "%s:%s:%s\n", shr, smin, ssec );

secinc( minclock, clock, mintime );
cltoa( syear, smonth, sday, shr, smin, ssec, minclock );
printf( "%s:%s:%s\n", shr, smin, ssec );

secinc( secclock, clock, sectime );
cltoa( syear, smonth, sday, shr, smin, ssec, secclock );
printf( "%s:%s:%s\n", shr, smin, ssec );
quit_req = 0;
while( hr<20 && quit_req==0 )
{
   getclk( clock );
   hr = clock[4];
   clock[7] = 0;

   if( secdiff( minclock, clock )<=0.0 )
   {
      cltoa( syear, smonth, sday, shr, smin, ssec, clock );
      for( im=STARTPORT; im<ENDPORT+1; im++ )
      {
         fprintf( tfp[im], "\n\n%s/%s/%s", smonth, sday, syear );
         fprintf( tfp[im], " - %s:%s:%s\n\n", shr, smin, ssec );

      }
      domin( buff, values, request, prior );
      secinc( minclock, minclock, mintime );
   }
   if( secdiff( secclock, clock )<=0.0 )
   {
      dosec( buff, values, request, stop, prior );
      putvalues( values, secclock );
      for( im=0; im<29; im++ )
         values[im] = -1.0;
```

```
            secinc( secclock, secclock, sectime );
        }

        if( kbhit() )
        {
            key = getch();
            if( key=='^' )
                quit_req = pass();
        }

/*
 *
 * While before 8:00 p.m. and quit is not requested.
 *
 */
    }
    printf( "\n                ... Quiting at %s:%s.\n", shr, smin );
    fprintf( fout, "%s:%s.\n", shr, smin );
    for( im=STARTPORT; im<ENDPORT+1; im++ )
    {
        asiquit( port[im] );
        fclose( tfp[im] );
    }
    fclose( farres );
    fclose( fout );

    for( jm=0; jm<=30000; jm++ )
    {



/*
 *
 * Keyboard interrupt
 *
 */
        if( kbhit() )
        {
            key = getch();
            if( key=='^' )
                exit_req = pass();
        }
        if( exit_req==1 )
```

```
                break;
        }
/*
 *  While exit is not requested.
 *
 */
    }
    exit( 0 );
}
```

APPENDIX VII

Sample of (ARRES) Automated Monitoring Data Collection

% 0310RR.989

	NIBP				Pulse oximeter		ECG	
Time	SBP	DBP	HR	MAP	SAT	HR	PA	HR
09:40:00	0	0	0	0	93	105	12	0
09:40:15	x	x	x	x	90	106	80	0
09:40:30	x	x	x	x	93	107	24	5
09:40:45	x	x	x	x	96	103	29	102
09:41:00	173	106	102	154	96	104	22	105
09:41:15	x	x	x	x	96	103	23	104
09:41:30	x	x	x	x	96	99	32	98
09:41:45	x	x	x	x	95	98	34	98
09:42:00	x	x	x	x	94	101	20	107
09:42:15	x	x	x	x	94	105	67	106
09:42:30	x	x	x	x	94	104	81	102
09:42:45	x	x	x	x	93	101	75	99
09:43:00	x	x	x	x	93	97	100	97
09:43:15	x	x	x	x	92	102	49	102
09:43:30	x	x	x	x	94	99	80	99
09:43:45	x	x	x	x	93	102	37	107
09:44:00	x	x	x	x	94	108	50	108
09:44:15	x	x	x	x	95	105	82	105
09:44:30	x	x	x	x	0	0	0	106
09:44:45	x	x	x	x	96	104	90	106
09:45:00	x	x	x	x	96	100	93	93
09:45:15	x	x	x	x	95	97	100	96
09:45:30	x	x	x	x	95	99	98	98
09:45:45	x	x	x	x	95	98	83	98
09:46:00	186	107	100	147	95	100	59	99
09:46:15	x	x	x	x	95	97	100	98
09:46:30	x	x	x	x	94	96	100	95
09:46:45	x	x	x	x	94	96	100	95
09:47:00	x	x	x	x	95	97	55	97
09:47:15	x	x	x	x	95	98	33	97
09:47:30	x	x	x	x	93	97	25	97
09:47:45	x	x	x	x	90	99	2	104
09:48:00	x	x	x	x	91	106	35	108
09:48:15	x	x	x	x	94	106	25	105
09:48:30	x	x	x	x	95	101	25	100

09:48:45	x	x	x	x	96	98	34	96
09:49:00	x	x	x	x	0	0	0	96
09:49:15	x	x	x	x	94	95	68	96
09:49:30	x	x	x	x	94	95	100	95
09:49:45	x	x	x	x	94	95	100	95
09:50:00	x	x	x	x	94	97	78	97
09:50:15	x	x	x	x	94	96	100	95
09:50:30	x	x	x	x	93	94	100	93
09:50:45	x	x	x	x	93	95	100	95
09:51:00	x	x	x	x	93	95	100	95
09:51:15	x	x	x	x	93	95	100	95
09:51:30	x	x	x	x	93	95	100	95

APPENDIX VIII

PROLOG Module for Vital Signs Ranges (minimum, maximum, average)

```
% accumulate MIN, MAX, & AVG  % call right after classifying
accumulateMMA(v(_),VAR,VALUE):-
        recorded(accumulateMMAd,(VAR,NUM,MIN,MAX,AVG),REF),!,
        NUMp1 is NUM+1,
        NEW_AVG is (NUM*AVG+VALUE)/NUMp1,
        ifthenelse(VALUE < MIN,NEW_MIN=VALUE,NEW_MIN=MIN),
        ifthenelse(VALUE > MAX,NEW_MAX=VALUE,NEW_MAX=MAX),
        replace(REF,(VAR,NUMp1,NEW_MIN,NEW_MAX,NEW_AVG)).
accumulateMMA(v(_),VAR,VALUE):-!,
        recorda(accumulateMMAd,(VAR,1,VALUE,VALUE,VALUE),_).
accumulateMMA(_,_,_).

writeMMA(H):-
        recorded(accumulateMMAd,(VAR,NUM,MIN,MAX,AVG),_),
        write(H,VAR),put(H,9),
        write(H,num:NUM),put(H,9),
        write(H,min:MIN),put(H,9),
        write(H,max:MAX),put(H,9),
        write(H,avg:AVG),put(H,9),nl(H),
        fail.
writeMMA(H):-nl(H).
```

Sample Output File

```
% 0421cas1.mma

bpsys num : 13          min : 155   max : 206   avg : 174.92307692
bpdia num : 13          min : 71    max : 112   avg : 96.46153846
o2sat num : 319         min : 88    max : 99    avg : 95.7460815
hr        num : 688     min : 75    max : 108   avg : 87.15261628
```

APPENDIX IX

Structure of the PACU Database

```
/* Noninvasive Monitoring Data */

define vsigns with "vsigns.itb";\
field rdate str 8 using "dd/dd/dd";\
field jdate num=tojul(rdate);\
field rcase# num using "d";\
field admptime str 8 using "dd:dd:dd";\
field sysbp num using "ddd";\
field diabp num using "ddd";\
field hrnibp num using "ddd";\
field map num using "ddd";\
field oxsat num using "ddd";\
field hrpo num using "ddd";\
field pa num using "ddd";\
field hrecg num using "ddd";\
enddef

/* Operating Room record */

define prstudy with "prstudy.itb";\
field rdate str 8 using "dd/dd/dd";\
field rcase# num using "d";\
field admptime str 8 using "dd:dd:dd";\
field disptime str 8 using "dd:dd:dd";\
field patname str 25 using "%25u";\
field hupid str 9 using "uuuuuuuuu";\
field or# str 3 using "ddd";\
field sex num using "d";\
field age num using "ddd";\
field pweight num using "ddd";\
field pheight num using "ddd";\
field surgserv num using "ddd";\
field pacuity num using "ddd";\
field tanes num using "ddd";\
field pstatus num using "ddd";\
field psemerg num using "d";\
field inor str 5 using "dd:dd";\
field anind str 5 using "dd:dd";\
field prfs str 5 using "dd:dd";\
field stsp str 5 using "dd:dd";\
```

```
field stsurg str 5 using "dd:dd";\
field stclos str 5 using "dd:dd";\
field endsurg str 5 using "dd:dd";\
field outor str 5 using "dd:dd";\
field lsaver num using "d";\
field eblor num using "dddd";\


/* Anaesthesia record */

field stanes str 5 using "dd:dd";\
field stsurgan str 5 using "dd:dd";\
field arpacu str 5 using "dd:dd";\
field aline num using "d";\
field central num using "d";\
field sedanes num using "d";\
field narcanes str 4 using "dddd";\
field antichol str 4 using "dddd";\
field hisbp num using "ddd";\
field lowsbp num using "ddd";\
field hihr num using "ddd";\
field lowhr num using "ddd";\
field hisat num using "ddd";\
field lowsat num using "ddd";\
field totfl num using "dddd";\
field totbl num using "dddd";\

/* PACU Record */

field discto num using "ddd";\
field urineor num using "dddd";\
field urinpacu num using "dddd";\
field fluidor num using "dddd";\
field fldpacu num using "dddd";\
field adairsup num using "d";\
field adoxsup num using "d";\
field adloc num using "d";\
field disoxsup num using "d";\
field disloc num using "d";\
field sedpacu num using "d";\
field narcpacu str 4 using "dddd";\
field prespacu str 6 using "dddddd";\
field antiemet str 7 using "ddddddd";\
```

```
field antihyp str 5 using "ddddd";\
field revagent str 6 using "dddddd";\
enddef
```

APPENDIX X

ARRES Data Entry Screens

SCREEN 1

**** Post Anaesthesia Care Unit (PACU) ****

Do you like to **A**dd a record, **E**dit a record,
Delete a record or just **Q**uit the program : _

Date: Case#: Admit time: Discharge time:

Patient Name: HUPID: O.R.#:
Sex(**M/F**): Age: Weight: Height:

Surgical Service(None[U], Gen, Ct, Vas, Trans, Pls, Oral, Neuro, Oto, Ortho, Gyn, Urol, Ob, Trauma):

Procedure Acuity Level (1,2,3,4,5): d
Physical status(1,2,3,4,5): d Emergency(0,1):
Type of Anesthetic (None[U], Local, Ams, Regional, General):

In O.R. An. Ind. PRFS St. Surg. St. Close End Surg. Out O.R. dd:dd dd:dd
dd:dd dd:dd dd:dd dd:dd dd:dd

Cell Saver (No[0], Yes[1]): d Estimated Blood Loss: dddd

SCREEN 2

**** Post Anaesthesia Care Unit (PACU) ****

Do you like to **A**dd a record, **E**dit a record,
Delete a record or just **Q**uit the program : _

Date: Case#: Admit time: Discharge time:

Patient Name: HUPID: O.R.#:
Sex(**M**/**F**): Age: Weight: Height:

Start of Anesthesia dd:dd Start of Surgery dd:dd Admit in the PACU dd:dd

A-Line(0,1): d Central(None[0], CVP[1], Swan[2]): d

** Pre- Medications **
Sedative(0,1): d
Narcotic: dddd Anticholenergic: dddd
Fentanyl " Atropine
Morphine "MS" Scopolamine
Meperidine "Demerol" Clycopyrrolate
Other Other

High SBP ddd Low SBP ddd Hi Pulse ddd Low Pulse ddd High O2Sat Low O2Sat ddd ddd

Total Fluid: dddd Total blood products: dddd

SCREEN 3

**** Post Anaesthesia Care Unit (PACU) ****

Do you like to **A**dd a record, **E**dit a record,
Delete a record or just **Q**uit the program : _

Date: Case#: Admit time: Discharge time:

Patient Name: HUPID: O.R.#:
Sex(**M/F**): Age: Weight: Height:

Discharge to(Floor[1], ICU[2], Missing[3]): d

Urine O.R. : dddd Urine PACU : dddd
Fluids O.R.: dddd Fluids PACU: dddd

Admission Summary
Airway Support(None[0], Nasal[1], Oral[2], Endotrach.[3], Tracheoct.[4]): d

O2 Support(None[0], Nasal[1], Mask/Humidified[2], T-Piece[3], Vent[4]): d

LOC(None[0], Alert[1], Agitated/Confused[2], Lethargic[3], Unrespon.[4]): d

Discharge Summary
O2 Support(None[0], Room air[1], Nasal[2], Mask/Humidified[3]):
LOC(None[0], Alert[1], Unresponsive[2], Lethargic[3], Confused[4]):
SEDATIVE(0,1): d

NARCOTICS(Fentanyl, Morphine, Meperedine, Other): dddd

PRESSORS(Epinephrine,Dopamine,Doputamine,Ephedrine,Neosynephrine,Other):
ddddd

ANTIEMETICS(Compazine,Tigan,Droperidol,Emetecon,Reglan,Phenergan,Other):
ddddd

ANTIHYPERTENSIVES(Labatelol, Hydrallazine, Inderal, Arfonad, Other): ddddd

REVERSAL AGENTS(Tensilon, Neostigmine, Pyristgmine, Atropine, Glycopyrrolate,Narcan, Other): ddddddd

ANTIBIOTICS(Ancef,Ampicillin,Gentamycin,Penicillin,Vancomycin, Other): dddddd

APPENDIX XI

SPSS Commands for the PACU Data Analysis

```
*SET /PRINTER ON /LENGTH 59 /EJECT ON.
*SET /MORE OFF.
*SET /MENUS EXTENDED.
GET /FILE 'PACU157.SYS'.
MISSING VALUE ALL(999).
*DATA LIST FILE='PACU157.DAT'/
*Date CaseNum AdPACU PACUSTAY SEX AGE WtPound HEIGHT
*SURGSERV ACUITY TYPEANES PSTATUS EMERG TOTALOR TOTALANE
*CELLSAV EBLOR ArtLINE CENTRAL SedAnes NarcAnes AnFent AnMS
*AnMep ANTICHO AnSBPMax AnSBPMin AnHRMax AnHRmin AnSATMax
*AnSATMin SBPMin SBPMax SBPAvg DBPMin DBPMax DBPAvg HRMin
*HRMax HRAvg SATMin SATMax SATAvg DischTO URINEOR URINPACU
*FLUIDSOR FLDPACU AIRSUP OXYGENS LOC DISOXYG DISLOC SedPACU
*NarcPACU FENTANYL MORPHINE MEPERED PRESSORS EPINEP
DOPAMINE *DOPUTAM EPHEDR NEOSYN ANTIEM COMPAZ TIGAN
DROPER EMETECON *REGLAN PHENERG ANTIHYP LABAT HYDRAL
INDERAL ARFONAD RevAgent *TENSILON NEOSTIG PYRISTG ATROPINE
GLYCORYP NARCAN MINSURG *GENANES PS_SICK CVP AIRWAY
BAGGED ALERT HYPERTEN HYPOTEN *TACHY BRADY HYPOXIC
LPACUST PACUPROB.
```

```
VALUE LABELS SEX 1 'Females' 2 'Males'/
   SURGSERV 0'None' 1'General' 2'Cardiothoracic' 3'Vascular'
4'Transplant' 5'Plastic' 6'Oral' 7'Neurosurgery'                8'Oto' 9'Orthopedics'
10'Gyn' 11'Urology'
        12'Obstetric' 13'Trauma'/
   TYPEANES 0'None' 1'Local' 2'AMS' 3'Regional' 4'General'/
   PSTATUS  1'Healthy'
        2'Mild systemic disease'
        3'Severe systemic disease'
        4'Incapacitating systemic disease'
        5'Not expected to survive'/
   EMERG    0'Not emergency'
        1'Emergency'/
   CELLSAV  0'No cell saver'
        1'Cell saver'/
   ArtLINE  0'No Arterial Catheter'
        1'Arterial Catheter'/
   CENTRAL  0'No CVP Catheter'
        1'CVP'
        2'Swan'/
   SedAnes  0'No Intraoperative Sedation'
        1'Intraoperative Sedation'/
   NarcAnes 0'No Intra-operative Narcotics in Anaesthesia'
        1'Yes Intra-operative Narcotics in Anaesthesia'/
   AnFent   0'No Intra-Operative Fentanyl'
        1'Yes Intra-operative Fentanyl'/
   AnMS     0'No Intra-operative Morphine'
        1'Yes Intra-operative Morphine'/
   AnMep    0'No Intra-operative Meperidine'
        1'Yes Intra-operative Meperidine'/
   ANTICHO  0'No Intra-operative Anticholenergic'
        1'Yes Intra-operative Anticholenergic'/
   DischTO  1'Dicharged to Floor'
        2'Discharged to Intensive Care Unit'
        3'Missing'/
   AIRSUP   0'No Airway'
        1'Nasal Airway'
        2'Oral Airway'
        3'Endotracheal Tube'
        4'Tracheostomy'/
   OXYGENS  0'No Oxygen'
        1'Nasal oXYGEN'
        2'Humidified-Oxygen Mask'
        3'T-piece'
```

```
        4'Patient Ventilated'/
LOC     999'Missing'
        1'Alert'
        2'Agitated-Confused'
        3'Lethargic'
        4'Unresponsive'/
DISOXYG 999'Missing'
        1'Room Air'
        2'Nasal'
        3'Mask-Humidified'/
DISLOC  0'None'
        1'Discharged Alert'
        2'Discharged Unresponsive'
        3'Discharged Lethargic'
        4'Discharged Confused'/
SedPACU 0'No PACU Sedatives'
        1'Yes PACU Sedatives'/
PATAGE  0'Old Patients'
        1'Young Patients'/
MINSURG 0'Minor Surgery'
        1'Major Surgery'/
GENANES 0'Not General Anesthesia'
        1'General Anesthesia'/
PS_SICK 0'Not Sick'
        1'Sick'/
CVP     0'No CVP Catheter'
        1'CVP Catheter'/
AIRWAY  0'No Airway'
        1'Airway'/
BAGGED  0'No Oxygen'
        1'Oxygen'/
ALERT   0'Not Alert'
        1'Alert'/
HYPERTEN 0'Not Hypertensive'
        1'Hypertensive'/
HYPOTEN 0'Not Hypotensive'
        1'Hypotensive'/
TACHY   0'Not Tachycardic'
        1'Tachycardic'/
BRADY   0'Not Bradycardic'
        1'Bradycardic'/
HYPOXIC 0'Not Hypoxic'
        1'Hypoxic'/
LPACUST 0'Short PACU stay'
```

```
1'Long PACU stay'/
PACUPROB 0'No PACU Problem'
1'PACU Problem'.

*** Transformations

IF (AGE GE 55) PATAGE = 1.
IF (AGE LT 55) PATAGE = 0.

IF (TYPEANES EQ 4) GENANES = 1.
IF (TYPEANES LE 3) GENANES = 0.

IF (PSTATUS GE 3) PS_SICK = 1.
IF (PSTATUS LE 2) PS_SICK = 0.

IF (ACUITY EQ 1) MINSURG = 1.
IF (ACUITY GE 2) MINSURG = 0.

IF (CENTRAL GE 1) CVP = 1.
IF (CENTRAL EQ 0) CVP = 0.

IF (AIRSUP GE 1) AIRWAY = 1.
IF (AIRSUP EQ 0) AIRWAY = 0.

IF (OXYGENS GE 2) BAGGED = 1.
IF (OXYGENS LE 1) BAGGED = 0.

IF (LOC EQ 1) ALERT = 1.
IF (LOC GE 2) ALERT = 0.

IF (SBPMAX GE 180) HYPERTEN = 1.
IF (SBPMAX LE 79) HYPERTEN = 0.

IF (SBPMIN LE 90) HYPOTEN = 1.
IF (SBPMIN GE 91) HYPOTEN = 0.

IF (HRMAX GE 110) TACHY = 1.
IF (HRMAX LE 109) TACHY = 0.

IF (HRMIN LE 60) BRADY = 1.
IF (HRMIN GE 61) BRADY = 0.

IF (SATMAX LE 89) HYPOXIC = 1.
IF (SATMAX GE 90) HYPOXIC = 0.
```

```
IF (ANSBPMAX GE 180) ORHYPER = 1.
IF (ANSBPMAX LE 179) ORHYPER = 0.

IF (ANSBPMIN LE 90) ORHYPO = 1.
IF (ANSBPMIN GE 91) ORHYPO = 0.

IF (ANHRMAX GE 110) ORTACHY = 1.
IF (ANHRMAX LE 109) ORTACHY = 0.

IF (ANHRMIN LE 60) ORBRADY = 1.
IF (ANHRMIN GE 61) ORBRADY = 0.

IF (ANSATMAX LE 89) ORHYPOXI = 1.
IF (ANSATMAX GE 90) ORHYPOXI = 0.

** T-TEST for Hypertension

T-TEST /GROUPS SEX(1,2) /VARIABLES SBPMAX.
T-TEST /GROUPS PS_SICK(0,1) /VARIABLES SBPMAX.
T-TEST /GROUPS GENANES(0,1) /VARIABLES SBPMAX.
T-TEST /GROUPS PATAGE(0,1) /VARIABLES SBPMAX.
** T-TEST for Hypotension

T-TEST /GROUPS SEX(1,2) /VARIABLES SBPMIN.
T-TEST /GROUPS PS_SICK(0,1) /VARIABLES SBPMIN.
T-TEST /GROUPS GENANES(0,1) /VARIABLES SBPMIN.
T-TEST /GROUPS PATAGE(0,1) /VARIABLES SBPMIN.

** T-TEST for Hypoxia

T-TEST /GROUPS SEX(1,2) /VARIABLES SATMIN.
T-TEST /GROUPS PS_SICK(0,1) /VARIABLES SATMIN.
T-TEST /GROUPS GENANES(0,1) /VARIABLES SATMIN.
T-TEST /GROUPS PATAGE(0,1) /VARIABLES SATMIN.

** T-TEST for Tachycardia

T-TEST /GROUPS SEX(1,2) /VARIABLES HRMAX.
T-TEST /GROUPS PS_SICK(0,1) /VARIABLES HRMAX.
T-TEST /GROUPS GENANES(0,1) /VARIABLES HRMAX.
T-TEST /GROUPS PATAGE(0,1) /VARIABLES HRMAX.

** T-TEST for Bradycardia
```

```
T-TEST /GROUPS SEX(1,2) /VARIABLES HRMIN.
T-TEST /GROUPS PS_SICK(0,1) /VARIABLES HRMIN.
T-TEST /GROUPS GENANES(0,1) /VARIABLES HRMIN.
T-TEST /GROUPS PATAGE(0,1) /VARIABLES HRMIN.

** T-TEST for long PACU stay

T-TEST /GROUPS SEX(1,2) /VARIABLES LPACUST.
T-TEST /GROUPS PS_SICK(0,1) /VARIABLES LPACUST.
T-TEST /GROUPS GENANES(0,1) /VARIABLES LPACUST.
T-TEST /GROUPS PATAGE(0,1) /VARIABLES LPACUST.

** CHI-SQUARE for Sex

CROSSTABS /TABLES SEX BY HYPERTEN /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES SEX BY HYPOTEN /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES SEX BY HYPOXIC /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES SEX BY TACHY /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES SEX BY BRADY /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES SEX BY LPACUST /OPTIONS 3 4 /STATISTICS 1.

** CHI-SQUARE for Physical Status

CROSSTABS /TABLES PS_SICK BY HYPERTEN /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES PS_SICK BY HYPOTEN /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES PS_SICK BY HYPOXIC /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES PS_SICK BY TACHY /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES PS_SICK BY BRADY /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES PS_SICK BY LPACUST /OPTIONS 3 4 /STATISTICS 1.

** CHI-SQUARE for Type of Anesthesia

CROSSTABS /TABLES GENANES BY HYPERTEN /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES GENANES BY HYPOTEN /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES GENANES BY HYPOXIC /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES GENANES BY TACHY /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES GENANES BY BRADY /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES GENANES BY LPACUST /OPTIONS 3 4 /STATISTICS 1.

** CHI-SQUARE for Age

CROSSTABS /TABLES PATAGE BY HYPERTEN /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES PATAGE BY HYPOTEN /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES PATAGE BY HYPOXIC /OPTIONS 3 4 /STATISTICS 1.
```

```
CROSSTABS /TABLES PATAGE BY TACHY /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES PATAGE BY BRADY /OPTIONS 3 4 /STATISTICS 1.
CROSSTABS /TABLES PATAGE BY LPACUST /OPTIONS 3 4 /STATISTICS 1.


*** STEPWISE DISCRIMINANT ANALYSIS

** Discriminant Analysis to predict
** the five best predictors for Hypoxia

DSCRIMINANT /GROUPS HYPoxic (0,1)
    /VARIABLES SEX AGE WTPOUND HEIGHT MINSURG GENANES PS_SICK

            EMERG TOTALOR EBLOR ARTLINE CVP SEDANES NARCANES
        URINEOR FLUIDSOR AIRWAY BAGGED ALERT
            ANSBPMAX ANSBPMIN ANHRMAX ANHRMIN ANSATMIN
    /METHOD WILKS
    /maxsteps 5
    /PRIORS SIZE
    /OPTIONS 8 1
    /STATISTICS 13 16 6.


** Discriminant Analysis to predict
** the five best variables for Hypertension

DSCRIMINANT /GROUPS HYPerten (0,1)
    /VARIABLES SEX AGE WTPOUND HEIGHT MINSURG GENANES PS_SICK

            EMERG TOTALOR EBLOR ARTLINE CVP SEDANES NARCANES
        URINEOR FLUIDSOR AIRWAY BAGGED ALERT
            ANSBPMAX ANSBPMIN ANHRMAX ANHRMIN ANSATMIN
    /METHOD WILKS
    /maxsteps 5
    /PRIORS SIZE
    /OPTIONS 8 1
    /STATISTICS 13 16 6.


** Discriminant Analysis to predict
** the five best variables for Hypotension

DSCRIMINANT /GROUPS HYPoten (0,1)
    /VARIABLES SEX AGE WTPOUND HEIGHT MINSURG GENANES PS_SICK
```

```
        EMERG TOTALOR EBLOR ARTLINE CVP SEDANES NARCANES
      URINEOR FLUIDSOR AIRWAY BAGGED ALERT
        ANSBPMAX ANSBPMIN ANHRMAX ANHRMIN ANSATMIN
  /METHOD WILKS
  /maxsteps 5
  /PRIORS SIZE
  /OPTIONS 8 1
  /STATISTICS 13 16 6.


** Discriminant Analysis to predict
** the five best variables for Tachycardia

DSCRIMINANT /GROUPS tachy (0,1)
  /VARIABLES SEX AGE WTPOUND HEIGHT MINSURG GENANES PS_SICK

        EMERG TOTALOR EBLOR ARTLINE CVP SEDANES NARCANES
      URINEOR FLUIDSOR AIRWAY BAGGED ALERT
        ANSBPMAX ANSBPMIN ANHRMAX ANHRMIN ANSATMIN
  /METHOD WILKS
  /maxsteps 5
  /PRIORS SIZE
  /OPTIONS 8 1
  /STATISTICS 13 16 6.


** Discriminant Analysis to predict
** the five best variables for Bradycardia

DSCRIMINANT /GROUPS brady (0,1)
  /VARIABLES SEX AGE WTPOUND HEIGHT MINSURG GENANES PS_SICK

        EMERG TOTALOR EBLOR ARTLINE CVP SEDANES NARCANES
        URINEOR FLUIDSOR AIRWAY BAGGED ALERT
        ANSBPMAX ANSBPMIN ANHRMAX ANHRMIN ANSATMIN
  /METHOD WILKS
  /maxsteps 5
  /PRIORS SIZE
  /OPTIONS 8 1
  /STATISTICS 13 16 6.


** Discriminant Analysis to predict
```

** the five best variables for long PACU stay

```
DSCRIMINANT /GROUPS lpacust (0,1)
    /VARIABLES SEX AGE WTPOUND HEIGHT MINSURG GENANES PS_SICK

            EMERG TOTALOR EBLOR ARTLINE CVP SEDANES NARCANES
        URINEOR FLUIDSOR AIRWAY BAGGED ALERT
            ANSBPMAX ANSBPMIN ANHRMAX ANHRMIN ANSATMIN
    /METHOD WILKS
    /maxsteps 5
    /PRIORS SIZE
    /OPTIONS 8 1
    /STATISTICS 13 16 6.
```

** Discriminant Analysis to predict
** the five best variables for PACU problems

```
DSCRIMINANT /GROUPS pacuprob (0,1)
    /VARIABLES SEX AGE WTPOUND HEIGHT MINSURG GENANES PS_SICK

            EMERG TOTALOR EBLOR ARTLINE CVP SEDANES NARCANES
        URINEOR FLUIDSOR AIRWAY BAGGED ALERT
            ANSBPMAX ANSBPMIN ANHRMAX ANHRMIN ANSATMIN
    /METHOD WILKS
    /maxsteps 5
    /PRIORS SIZE
    /OPTIONS 8 1
    /STATISTICS 13 16 6.
```