Medical Intelligence

The Recovery and Intensive Care Unit, A Clinical Laboratory

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PRIOR TO THE OPENING of a new Special Care Unit in January, 1969, the Recovery Room of Memorial Hospital served a double purpose. Although most patients were discharged within 24 hours after operation, approximately 5 per cent remained in the unit for two days to several weeks. With a recovery-room population averaging 7,000 patients per year, the combined unit provided an excellent opportunity for the study of complications occurring in the immediate postoperative period. The clinical and investigational information obtained in this way has improved the diagnostic acumen and therapeutic approach of the anesthesiologists in charge of the unit, with a resultant reduction in morbidity and mortality of patients subjected to major operations. Much of the success of the unit has been due to the proximity of a well-equipped laboratory, staffed with a research chemist and technicians available for emergency determinations 24 hours a day, seven days a week.

The major postoperative complications fell into seven categories: cardiac, respiratory, depletion of circulating blood volume, electrolyte imbalance, acid–base changes, clotting problems and diminution of urinary output. In each of these groups, monitoring devices and routine or special laboratory determinations played a vital role in therapy. Since the same diagnostic procedures can assist in the evaluation of other problems, a brief discussion of the most frequently encountered complications will be followed by a more detailed review of the available diagnostic procedures and their application to the patient.

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Cardiac Complications

In a series of 2,000 routine postoperative electrocardiograms, the main abnormalities fell into three groups: arrhythmias, bradycardia (pulse rate <50/min) and tachycardia (pulse rate >120/min in an adult). Although most arrythmias were benign and required no therapy, the series included potentially dangerous variations in rhythm, such as atrial fibrillation or flutter, nodal tachycardia, multifocal ventricular premature contractions, ventricular tachycardia and ventricular fibrillation. Bradycardia seemed to occur most often following surgical operations on the breast and perineal structures. In addition, an occasional patient had a hyperactive carotid sinus or developed complete A-V dissociation. The most common postoperative cardiac complication was severe tachycardia. The major factors responsible for marked elevation of pulse rate included hypovolemia, hypoxemia, cardiac decompensation, severe pre-existing cardiac disease, myocardial infarction, and metastasis of cancer to the heart. Relative overloads of electrolyte-containing fluids, plasma expanders or blood were primarily responsible for the development of cardiac decompensation, especially in patients with pre-existing myocardial disease.

It is comparatively easy to overlook a myocardial infarction in the immediate postoperative period since pain is rarely a prominent symptom. In the Memorial Hospital series the main presenting sign was sudden unexplained tachycardia, with or without hypotension. Tachycardia > 120 beats/min was also the first indication of pulmonary embolus in several patients. Metastasis of cancer to the heart must be suspected in any patient with widely disseminated cancer who develops abnormalities of rate or rhythm unexplained by other factors. It occurs most frequently in association with the leukemias, lymphosarcoma, melanoma, mammary and pulmonary neoplasms.

Respiratory Complications

The main respiratory complications in the series were central or peripheral depression, obstruction of the upper airway, bronchospasm, atelectasis, pneumonitis, pneumothorax, pulmonary embolism and instability of the thoracic cage. In most cases, peripheral respiratory depression resulted from the residual effects of muscle-relaxing drugs employed during anesthesia or from the use of depolarizing antibiotic agents such as colistin (Coly-Mycin M). The main factors responsible for central respiratory depression were cerebrovascular hemorrhage or thrombosis and excessive pressure from neurosurgical packs. Emergency tracheostomy, done only rarely, was necessitated primarily by injury to the vocal cords or recurrent laryngeal nerves or by failure to perform intraoperative tracheostomy during procedures involving the mandible or maxilla.

Bronchospasm, atelectasis and pneumonitis could be anticipated in patients with preexisting tracheobrochitis, severe pulmonary disease, or irradiation to the chest wall or lungs. Bowden and Schweizer [1] described the mechanism of production of tension pneumothorax in operations involving the lower cervical region. This complication also occurred subsequent to nephrectomy, adrenalectomy or esophagectomy. A few major chest wall resections produced sufficient instability of the thoracic cage to necessitate prolonged respirator therapy. Although pulmonary embolus usually occurs later in the postoperative course, a sufficient number have developed within the first few days to warrant further diagnostic procedures in any patient with bronchospasm, dyspnea or unexplained tachycardia.

Genitourinary Complications

The main genitourinary problem was postoperative diminution of urinary output or anuria. In a few cases this could be attributed to the nephrotoxic effects of colistin or similar antibiotic drugs, ureteral obstruction owing to disease or operation, or pre-existing severe renal disease. The cause in most cases, however, was an inadequate volume of circulating fluid. Prompt restoration of urinary output followed therapy with plasma expanders, blood, and electrolyte-containing fluids. Cystoscopy or transurethral resection of the prostate occasionally was followed by transient bacteremia, characterized by shaking chills and a high temperature.

Depletion of Circulating Fluid Volume

Hypovolemia due to blood loss, plasma loss, or a combination of blood and plasma deficiency is a frequent complication of surgical operations for cancer. Plasma loss results primarily from the sequestration of fluid outside the intravascular space: for example, massive extirpations with large raw surfaces, intestinal obstruction, pleural effusion, or peritonitis. Combined with blood loss, this constitutes the third or "mixed" category of hypovolemia, as distinguished from pure blood or plasma deficiency. Although the symptoms and signs (cool, clammy skin, decreased blood pressure, tachycardia, diminished urinary output, and low central venous pressure) are the same for all types of hypovolemia, the treatment varies with the cause. Primary blood loss responds to transfusion, plasma deficiency to the volume expanders (dextran, plasmanate) and "mixed" deficiency to a combination of plasma expanders and blood. The laboratory techniques available for the diagnosis of the various categories and the institution of appropriate therapy will be discussed subsequently.

Electrolytic Imbalance

In addition to depletion of the total volume of intravascular fluids, major operative procedures may produce large, fluctuating, and even life-threatening shifts in essential body electrolytes. The most common electrolytic disturbances and the conditions in which they occur are shown in table 1. Depletion of chloride ion resulting from prolonged gastric or intestinal suction can produce severe metabolic alkalosis. Since postoperative digitali-

TABLE 1. Electrolytic Abnormalities

Depletion of Cl^- ion	prolonged gastric suction
	diarrhea
Depletion of Na^+ ion	intestinal tube drainage
	pancreatic, biliary, intestinal fistulae
	diarrhea
Depletion of K^+ ion	same as Na^+
	prolonged diuretic therapy
Elevation of K^+ ion	renal failure
Elevation of BUN	renal failure
	gastrointestinal tract bleeding
	fluid depletion

zation may be required as an emergency measure, potassium levels should be determined routinely in all patients receiving prolonged diuretic therapy. Although elevated BUN values are usually associated with renal failure, they can also be found in patients with fluid depletion or severe gastrointestinal bleeding. Knowledge of these facts may prevent unnecessary therapy directed to restoration of nonexistent renal problems.

Problems in Acid–Base Balance

Disturbances in acid–base balance can be grouped into four categories: respiratory acidosis and alkalosis; metabolic acidosis and alkalosis. The main factors responsible for each of these changes are shown in table 2. The acid–base abnormality most frequently seen was an increase in hydrogen ion concentration due to respiratory or metabolic acidosis or a combination of the two. Although the cause of the acidosis is readily explained by pulmonary, cardiac or metabolic disease in the majority of patients, no satisfactory reason has been advanced for the occasional appearance of an excessively high level of lactic acid in a seriously ill patient. This situation has occurred in patients treated with phenformin hydrochloride (Dbi) for diabetes mellitus and in those treated with chemotherapy for advanced cancer, probably due to interference with some aspect of cellular metabolism. The two main causes of alkalosis in the postoperative period are excessive zeal in respirator therapy (respiratory alkalosis) and prolonged nasogastric suction (metabolic alkalosis). Accurate and frequent measurement of blood gases, bicarbonate, total carbon dioxide and electrolytes is essential for the diagnosis and effective treatment of conditions involving abnormalities of acid–base balance.

TABLE 2. Disturbances in Acid–Base Balance

Respiratory Alkalosis	Metabolic Alkalosis
Respirators	Ingestion of large quantities of alkali (ulcer therapy)
Hysterical hyperventilation	Prolonged vomiting or nasogastric suction
Central nervous system disease	High intestinal obstruction
Early salicylic acid poisoning	Cushing's disease
High altitudes	Cortisone administration (hypochloremic alkalosis)
Respiratory Acidosis	**Metabolic Acidosis**
Depression of the respiratory center (drugs, anesthesia, disease)	Uncontrolled diabetes mellitus (ketone acids)
Emphysema, asthma, atelectasis, pneumonia	Renal disease (phosphate, sulfate)
Congestive heart failure	Diarrhea (fluid loss from the colon and lower small intestine)
Muscle-relaxing drugs	Vomiting nonacidic fluids
	Shock (lactate)
	Unexplained lactic acidosis

Clotting Problems

Bleeding and clotting problems in the postoperative period can be traced to hereditary defects, acquired disease, or the complications associated with operation and multiple blood transfusions. In general, they fall into three groups: deficiency or malfunction of platelets, decrease in plasma clotting factors, and fibrinolysis. The main pathologic conditions associated with each of these categories are shown in table 3. Platelet problems are amenable to therapy with platelet concentrates or fresh whole blood, clotting factors can be restored with fresh frozen plasma or antihemophilic plasma, and fibrinolysis responds to epsilon-aminocaproic acid (Amicar). Since specific therapy is available, early diagnosis is essential for reduction in morbidity and mortality resulting from hemorrhagic diatheses.

TABLE. 3. Clotting Problems

Deficiency or malfunction of platelets	Hepatic disease, uremia, extracorporeal circulation, massive blood replacement, consumption coagulopathy, bone marrow depression from chemotherapy and irradiation
Deficiency of clotting factors	Hepatic disease, hemophilia, extracorporeal circulation, massive blood replacement, consumption coagulopathy, anticoagulant therapy
Fibrinolysis	Hepatic disease, massive blood replacement, extracorporeal circulation, consumption coagulopathy

Methods Employed in the Care of the Postoperative Patient

Although the success of a Recovery or Intensive Care Unit depends primarily upon the ability of the physicians and nurses in charge, the proper use of monitoring equipment, biochemical determinations and other laboratory measures is important in the early diagnosis and treatment of complications. In addition, the data obtained provide valuable information for improvements in therapy.

The average patient admitted to the Recovery Room requires only careful observation, a hematocrit determination, and routine fluid therapy. Endotracheal tubes are removed after measurement of tidal volume with a Wright respirometer. Extensive monitoring is reserved for the poor-risk patient or the patient who has sustained severe operative trauma or complications. In these cases minimal good care includes continuous electrocardiographic recording, monitoring of central venous pressures, and accurate measurement of intake and output. Other diagnostic procedures are employed as indicated.

In the ideal situation routine intraoperative ECG monitoring should be continued in the Recovery Room, but this is not always possible. The Memorial Hospital's series of recovery room electrocardiograms indicates that most serious postoperative cardiac problems can be detected if tracings are obtained for all patients with: 1) severe arrythmias, especially if they were not present preoperatively; 2) tachycardia > 120 beats/min (myocardial infarction or pulmonary embolism); 3) bradycardia < 50 beats/min (complete A-V dissociation); 4) unexplained cyanosis; 5) unexplained hypotension; 6) prolonged hypoxia; and 7) those patients in the process of digitalization or treatment with other cardiac drugs.

Fluids administered in the postoperative period include volume expanders (dextran, plasmanate, blood) and solutions containing dextrose and electrolytes. Since the volume expanders fall in a separate category, the present section will be confined to the electrolyte-containing solutions. The volume and composition of each of these solutions depend upon accurate appraisal of the patient's requirements.

Volume requirements can be assessed by three methods: measurement of intake and output, daily weight measurement, and con-

TABLE 4. Normal Acid–Base Values, Astrup Technique

Oxygen tension (Pa_{O_2})	100 mm Hg
Carbon dioxide tension (Pa_{CO_2})	38–42 mm Hg
Buffer base	46–52 mEq/l
Base excess	+2.3 to −2.3
Standard bicarbonate	21.3–24.8 mEq/l
Actual bicarbonate	23–26.6 mEq/l
Total carbon dioxide (CO_2)	24–28 mEq/l

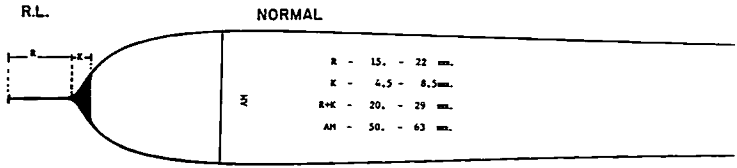

FIG. 1. Normal thromboelastograph. In Thromboelastograph terminology all figures are doubled.

tinuous monitoring of central venous pressure. To facilitate accurate intake and output determinations, the Memorial Hospital Recovery Room adopted the practice of discontinuing all residual electrolyte- or dextrose-containing fluids at 8 AM every day, marking the end of a 24-hour period; new solutions are started at that time. In addition to hourly urine volumes via an indwelling catheter, output measured should include drainage from other sources such as gastric, intestinal or thoracic tubes. Urinary specific gravity should be ascertained at intervals, and tests for acetone and sugar and microscopic examinations performed as indicated. All seriously ill patients are weighed daily. A bed scale which eliminates the necessity of moving the patient from bed is now available.

Catheters for central venous pressure measurement are inserted into a brachial or cer-

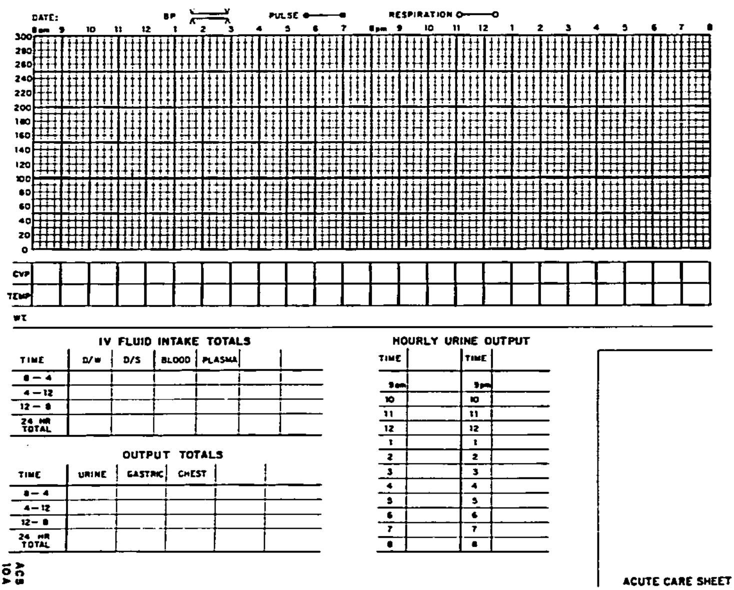

FIG. 2. Front of Recovery Room–Intensive Care Unit record.

vical vein and the zero point of the manometer placed on a level with the anterior axillary line of the supine patient. In the absence of radiographic visualization, the following criteria have been adopted as indicative of the accurate placement of the catheter tip in the right atrium or superior vena cava: 1) rapid, unimpeded flow of fluid during reading; 2) pulsation with each heart beat; 3) fluctuation of 3 cm or more with respiration. Although there is no specific demarcation between low, normal, and high levels, a rapid shift in level should be regarded as significant. The figures adopted by Ryan and Howland [2] as abnormal were a decrease of 10 cm water or more and an increase of more than 7 cm water compared with the baseline value.

Knowledge of the function of central venous pressure is essential for its effective employment as a monitoring device. In spite of its frequent use for this purpose, central venous pressure is not a reliable index of the total volume of fluid required for adequate replacement. The volume replaced should be determined by blood pressure and urinary output. Central venous pressure is a measurement of the state of myocardial competence and, as such, is correctly employed to monitor the rate of fluid replacement and to indicate the presence of impending or existing heart failure.

The types and numbers of biochemical determinations necessary to assess the electrolytic composition of postoperative fluids depend on the nature of the operation and the condition of the patient. In most cases daily determinations of sodium, potassium, chloride, total carbon dioxide and BUN are sufficient. Measurement of potassium is especially important for patients on diuretics, in renal

TIME	MEDICATION	DOSE	ROUTE	GIVEN BY

TIME	ANTIBIOTIC	DOSE	ROUTE	GIVEN BY

I V's AS ORDERED

INHALATION THERAPY

TIME	TYPE OF Rx	TIDAL VOLUME	TURN C DB	SIGH	DEFLATE CUFF	SUCTION & TC
8am						
9						
10						
11						
12						
1						
2						
3						
4						
5						
6						
7						
8pm						
9						
10						
11						
12						
1						
2						
3						
4						
5						
6						
7						
8						

COMMENTS AND OBSERVATIONS

FIG. 3. Back of Recovery Room–Intensive Care Unit record.

failure or in need of digitalization. In addition to these routine determinations, other biochemical tests required in specific cases include measurements of magnesium, calcium, creatinine, total protein, serum glutamic oxalic transaminase, 5'-nucleotidase, glucose, lactate, pyruvate, excess lactate, inorganic phosphate, adenosinetriphosphate (ATP) and adenosinediphosphate (ADP). Enzymatic methods [3] employing the Beckman spectrophotometer are used for lactate, pyruvate, ATP and ADP. Excess lactate is calculated from Huckabee's formula.[4] The levels of these organic compounds and that of inorganic phosphate have proved valuable in estimating the severity of hemorrhagic and septic shock and the effectiveness of treatment. The Memorial Hospital Special Care Unit laboratory is also equipped with a Perkin-Elmer atomic absorption spectrophotometer, which permits determination of the concentrations of practically all biochemical constituents.

Hypovolemia requires, in addition to electrolyte-containing solutions, the administration of a volume expander. Since therapy is dependent upon the cause of the hypovolemia, methods must be employed to determine the reason for the diminution in circulating fluid volume. The majority of cases can be diagnosed by the use of serial large-vessel hematocrits. In the presence of the clinical signs and symptoms of hypovolemia, a persistently low hematocrit indicates blood loss, whereas an elevated hematocrit represents hemoconcentration owing to sequestration of fluid unavailable to the general circulation. At times normal hematocrits are found in patients who have hypotension, tachycardia, low central venous pressure and decreased urinary output. Since this may represent a combination of plasma and whole-blood deficiency, estimation of blood volume may furnish valuable information. The Atomium Volemetron provides a rapid and easy method for blood volume determination based on the dilution principle. (Operating instructions are printed on the working face of the device.) After resetting the machine, a small dose of radioactive iodine attached to albumin (Rhisa) is placed in the center well and measured. A premixed venous sample is drawn from the patient, the measured dose of Rhisa injected, and postmixed samples are obtained at the end of the mixing period (usually 10 and 20 minutes). After the residue in the dose syringe has been subtracted, the syringe is discarded, premixed and postmixed samples are placed in the end wells, and total blood volume is computed. The ratio of plasma to erythrocyte mass is calculated from the hematocrit.

The value of blood volume determination must be judged by correlation with the condition of the patient and inherent problems. Since Underwood and Howland [5] have shown that the blood volume of each person remains essentially the same throughout adult life, a preoperative determination is almost essential for accurate evaluation of postoperative volume. Blood volume determinations are relatively worthless during active bleeding. There is also a limit to the number of valid measurements which can be made in the same individual.

One of the most important procedures in the case of a seriously ill patient is evaluation of acid–base status. This is mandatory on a daily basis for patients on continuous respirator therapy. In addition, acid–base balance studies provide valuable information in cardiac, respiratory and metabolic derangements. The Astrup technique for acid–base balance studies, employing the Radiometer apparatus, was described by Siggaard-Andersen and Engel [6] in 1960. The technique, which takes approximately ten minutes, is based on the pH values of three samples of blood: 1) whole arterial blood; 2) arterial blood equilibrated with gas at a high carbon dioxide tension; 3) arterial blood equilibrated with gas at a low carbon dioxide tension. The results are plotted on a nomogram. Table 4 gives the normal values of the various parameters obtainable from the nomogram. Arterial oxygen tension (Pa_{O_2}) is determined by an oxygen electrode, type E5044, and a thermostatic cell, type D615, attached to the Radiometer. The Astrup technique provides a rapid, reliable method of separating the metabolic (buffer base, base excess, standard bicarbonate, actual bicarbonate) from the respiratory (Pa_{CO_2} and Pa_{O_2}) phase of acid–base balance.

				Blood gas studies									Blood volume				Chemistries									Special studies
Date	Time	Hgb	Hct	Act pH	O_2 sat	PO_2	Act pCO_2	Base exc	Buff base	Stan HCO_3	Act HCO_3	Total CO_2	TBV	RCM	PV	Time blood drawn	CO_2	CL	K	Na	BUN	Ca	Pro	Plat count	Glu	

NAME ________ CASE NO. ________ ROOM NO. ________

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FIG. 4. Laboratory record, Recovery–Intensive Care Unit.

In patients with postoperative hemorrhagic diatheses, a definitive identification of the cause of the bleeding or clotting problem usually can be established by a coagulation laboratory. These studies are time-consuming, and the patient's condition may require specific therapy before results are available. Since Ryan and Howland[7] have shown that the thromboelastograph provides relatively rapid information about deficiencies of clotting factors, platelets, fibrinogen and fibrinolysis, it has become an important addition to the laboratory facilities in the Recovery Room. The thromboelastograph is a mechanical-optical system with a slowly oscillating metal cup. A free-flowing sample of venous blood is drawn through an 18-gauge or larger needle or plastic cannula into a plastic syringe. The blood is placed in the cup of the thromboelastograph within five minutes of removal. A steel cylinder attached to a torsion wire is then lowered into the cup. The oscillations of the cylinder, which becomes attached to the revolving cup by fibrin strands during clot formation, are transmitted to a mirror attached to a torsion wire. The mirror in turn reflects a fixed light source onto two scales, one a direct visual read-out, the other a roll of photographic film. The deflections of the needle of the visual read-out are either plotted manually or recorded automatically by way of a photosensitive strip and direct read-out recorder.

A normal thromboelastograph is shown in figure 1. The line R indicates the time elapsed between venipuncture and a 1-mm deflection on each side of the scale zero point. This represents the clotting time, with a normal value of 7.5 to 11 minutes (timed with a stopwatch). Values lower or higher than these suggest either hypercoagulability or a deficiency of clotting factors. The total amplitude of the clot (AM) should have a minimal 25-mm deflection on each side of the zero point. Failure to attain this amplitude indicates depletion of fibrinogen or platelets, the latter confirmed with a platelet count. Fibrinolysis is shown by a rapid decrease in a previously normal total amplitude.

The final essential factor in the use of the Recovery and Intensive Care Units as a clinical laboratory is the maintenance of accurate and complete records. Although the exact form of the records may vary with the hospital, they should contain detailed and clear information about all aspects of patient care. Examples of such records are shown in figures 2, 3, and 4.

In a hospital with a large percentage of major operations the entire postoperative course of the patient may be influenced by the preventive and therapeutic measures employed in the Recovery and Intensive Care Units. The diagnostic acumen of anesthesiologists and nurses in the unit at Memorial Hospital has been strengthened by close clinical observation and effective use of monitoring equipment as well as the ready-availability of laboratory facilities. Among other things, studies in the combined unit have led to improvements in methods for the prevention, early diagnosis and treatment of respiratory problems, cardiac arrhythmias, coronary occlusion, nausea and emesis, anuria, various types of hypovolemia, and hemorrhagic shock. The facilities provided by the recently opened Special Care Unit should add much additional information to the knowledge already acquired.

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Surgery

SERUM ENZYMES Fifty-six patients scheduled for extensive surgical procedures underwent preoperative and postoperative (four consecutive days) determinations of the following enzymes: serum glutamic oxalacetic transaminase (SGOT), serum glutamic pyruvic transaminase (SGPT), and lactic acid dehydrogenase (LDH). Postoperative incidences of increase in LDH (five patients) and in SGOT (three patients) were not significant. None of the increases were of significant magnitude to suggest acute myocardial or pulmonary disease. There was no correlation between these enzyme increases and degree of muscle trauma or duration of anesthesia (less than six hours). Four of eight patients receiving 15 or more units of blood had significant increases in the enzymes studied. Serum enzyme determinations can be of value in diagnosing acute myocardial or pulmonary disease even in the early postoperative period. (*Harrah, J. D., and others: Serum Enzyme Alterations after Extensive Surgical Procedures, Ann. Surg. 169: 300 (March) 1969.*)