64-12

TITLE PAGE

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PRINCIPAL INVESTIGATOR

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INSTITUTION

Medical College of South Carolina

SUBJECT OF THE REPORT

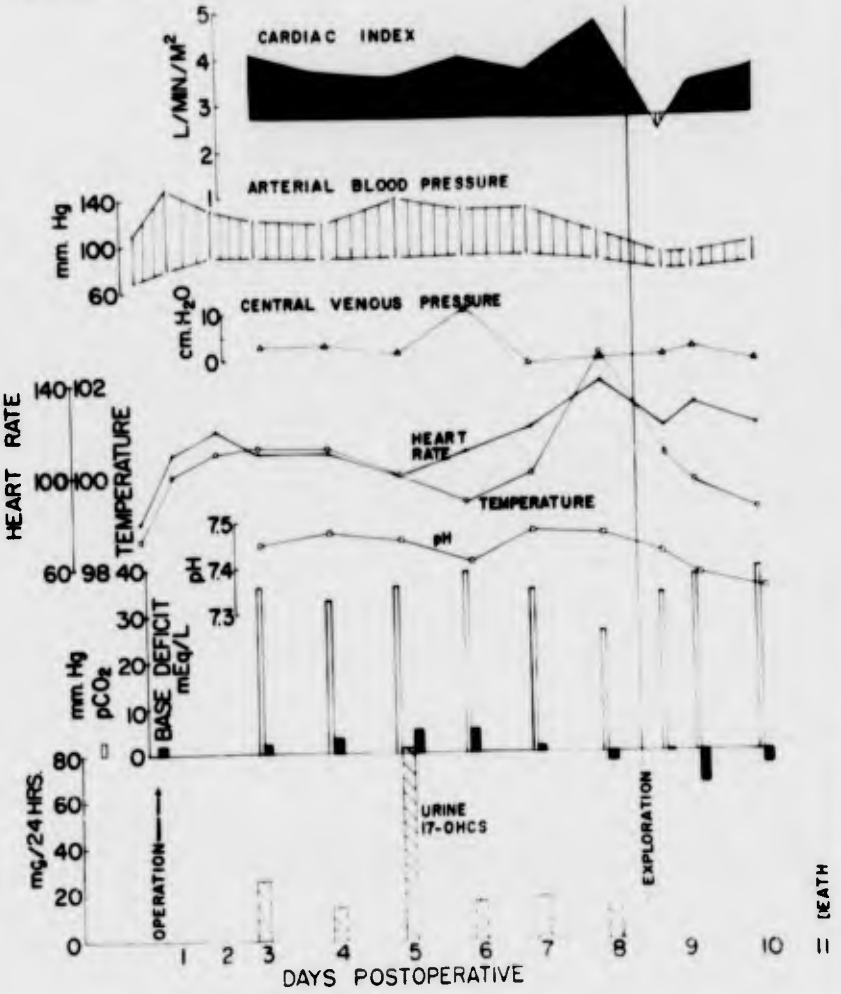
THE CARDIAC OUTPUT AND VASCULAR RESPONSE TO TRAUMA

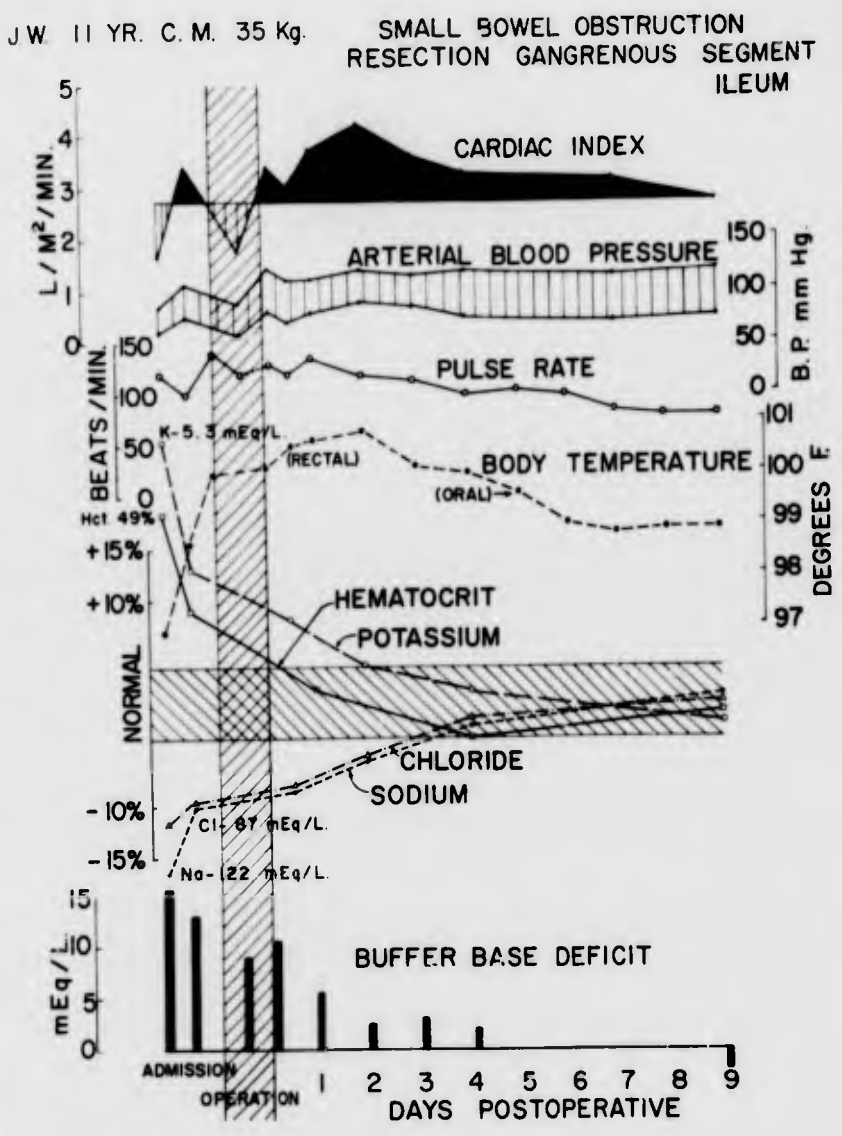
CONTRACT NUMBER

DA-49-193-MD-2312

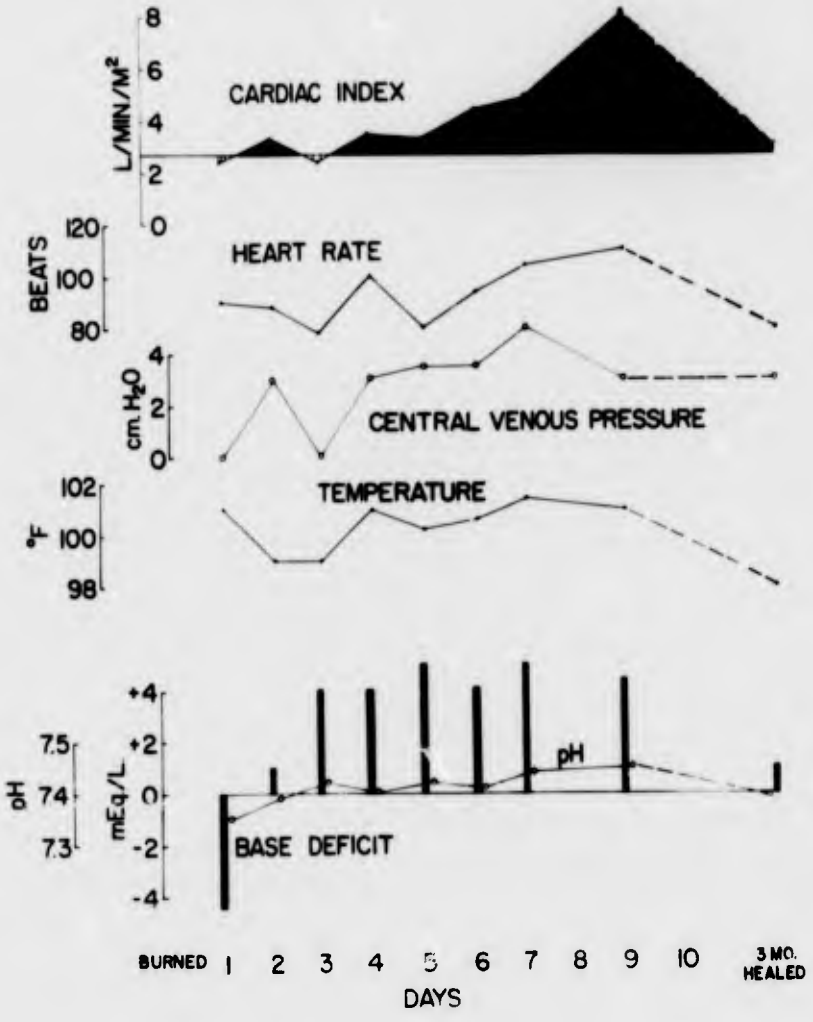
RESECTION OF ILEUM & COLON FOR CARCINOMA DIFFUSE PERITONITIS. DEATH.

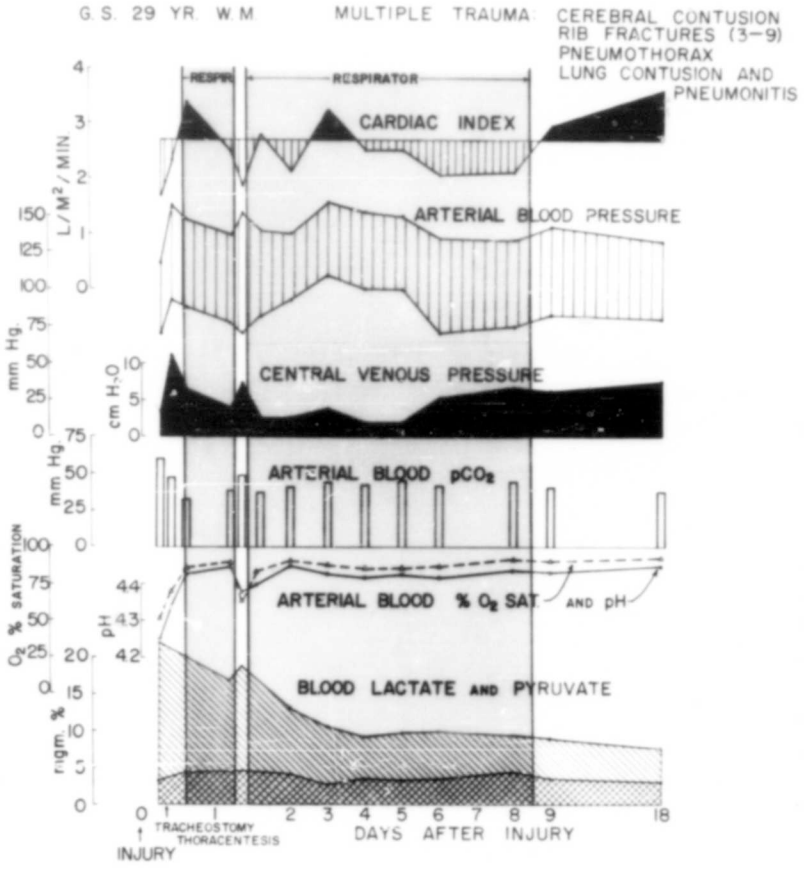
BP 37 YR. M.



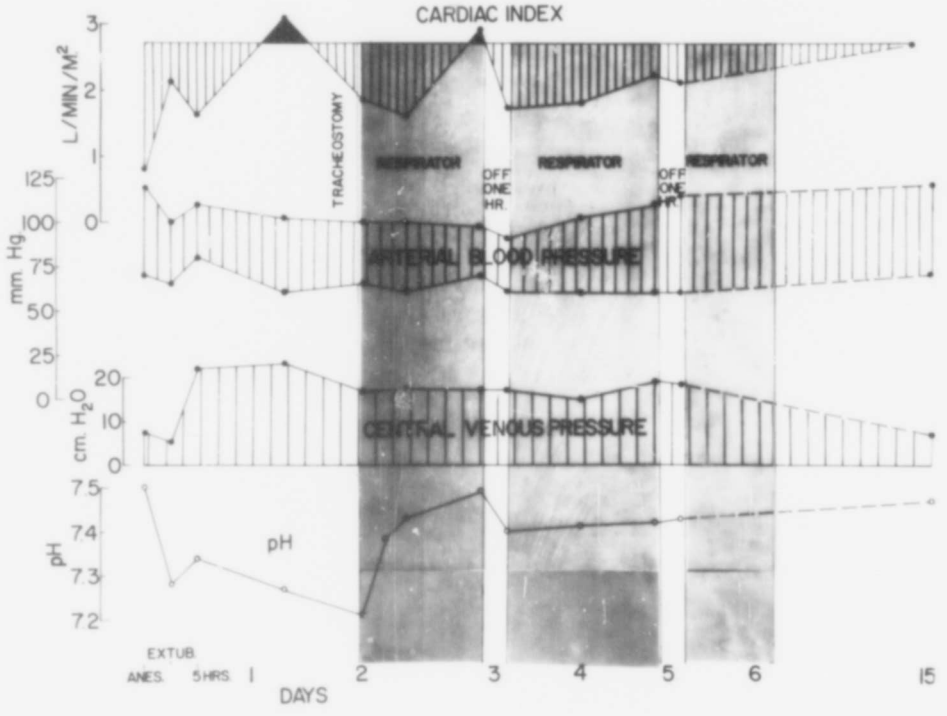

J.W. 11 YR. C. M. 35 Kg.
SMALL BOWEL OBSTRUCTION
RESECTION GANGRENOUS SEGMENT
ILEUM
CARDIAC INDEX
L/M²/MIN.
ARTERIAL BLOOD PRESSURE
B.P. mm Hg.
PULSE RATE
BEATS/MIN.
K-5.3 mEq/L.
(RECTAL)
BODY TEMPERATURE
(ORAL)
DEGREES F.
Hct 49%
+15%
+10%
HEMATOCRIT
POTASSIUM
NORMAL
CHLORIDE
SODIUM
-10%
-15%
Cl- 87 mEq/L.
Na- 122 mEq/L.
mEq/L.
BUFFER BASE DEFICIT
ADMISSION
OPERATION
DAYS POSTOPERATIVE

DEEP THERMAL BURN 40% BSA H.F. 22M

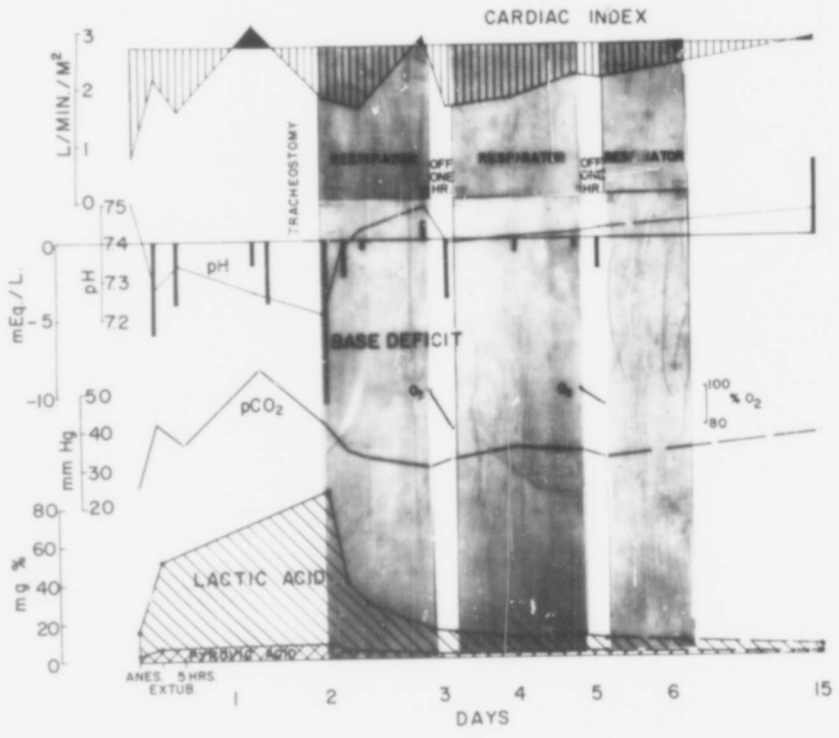


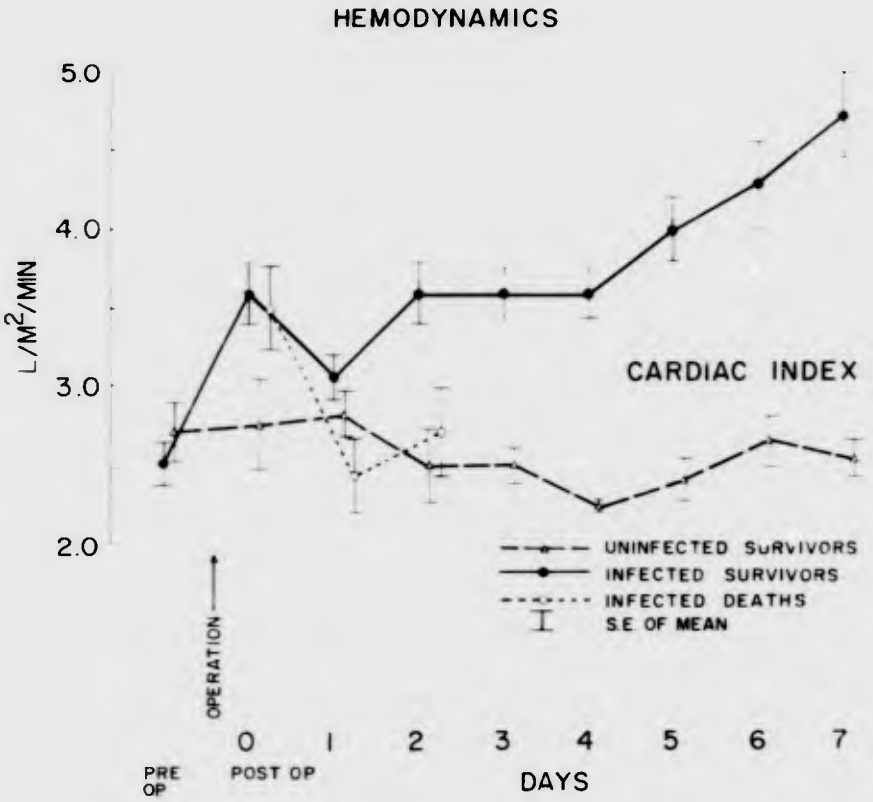

G.S. 29 YR. W.M. MULTIPLE TRAUMA: CEREBRAL CONTUSION
RIB FRACTURES (3–9)
PNEUMOTHORAX
LUNG CONTUSION AND
PNEUMONITIS
RESPIR.
RESPIRATOR
CARDIAC INDEX
L/M²/MIN
ARTERIAL BLOOD PRESSURE
mm Hg
CENTRAL VENOUS PRESSURE
cm H₂O
ARTERIAL BLOOD pCO₂
mm Hg
ARTERIAL BLOOD % O₂ SAT AND pH
O₂ % SATURATION
pH
BLOOD LACTATE AND PYRUVATE
mgm. %
INJURY
TRACHEOSTOMY
THORACENTESIS
DAYS AFTER INJURY

MITRAL INSUFFICIENCY VALVE PROSTHETIC REPLACEMENT F.J. 36 M



MITRAL INSUFFICIENCY: VALVE PROSTHETIC REPLACEMENT F.J. 36 M




HEMODYNAMICS
5.0
4.0
3.0
2.0
L/M²/MIN
CARDIAC INDEX
UNINFECTED SURVIVORS
INFECTED SURVIVORS
INFECTED DEATHS
S.E. OF MEAN
OPERATION
0
1
2
3
4
5
6
7
PRE OP
POST OP
DAYS

A B S T R A C T

Preparing Institution: The Medical College of South Carolina

Title of Report: THE CARDIAC OUTPUT AND VASCULAR RESPONSE TO TRAUMA

Principle Investigator: George H. A. Clowes, Jr., M.D.

Number of pages, illustrations and date: 19 pages, 6 illustrations; 3/31/64

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Washington 25, D.C.

Clinical and experimental observations indicate that only a very slight increase of cardiac output is requisite for maintenance of normal metabolism and uncomplicated recovery after a major operation. Patients with extensive sepsis or gangrene and experimental animals with induced abscesses must satisfy circulatory requirements more than double the basal value. Failure of the circulatory system to meet this demand results in acidosis and sudden death. Experiments indicate that an inflammatory area behaves in a fashion similar to an arterio-venous aneurysm.

A series of patients extensively burned illustrate this principle. The cardiac outputs, low during the shock period, rose to normal with fluid volume replacement. As sepsis appeared about the fifth day, cardiac indices of 6 $L/M^2/min$ appeared. Those unable to maintain these excessive outputs died. In experimental burns an increase of pulmonary vascular resistance and a decrease of compliance has been found related to blood protein denaturation and red cell agglutination.

Fever, water evaporation, and excess respiratory work also have been demonstrated as contributing to increased circulatory demand. Observations of patients with respiratory complications indicate that an efficient respirator is capable of reducing the cardiac output requirements by as much as 30% while improving the metabolic situation. Further clinical observations and experimental studies are in progress to determine the causes and effects of inadequate cardiovascular function following trauma.

The objective of this project is to determine the normal cardiovascular and respiratory responses which lead to recovery from trauma, inflammation, and gangrene. The accumulated clinical and experimental observations obtained during the two and one-half years in which this project has been active have delineated a relatively clear cut picture (8). The second part, more difficult of attainment, is directed toward an understanding of what constitutes an abnormal or inadequate response. This has been pursued simultaneously by analysing the cardiovascular, respiratory, and metabolic derangements of the patients and experimental animals which failed to recover. The third part, studies to determine experimentally the mechanisms by which the body makes the necessary circulatory adjustments in the circulation to permit recovery, has been started during the past year. An approach has been made by following the circulatory behavior in adrenalectomized conscious animals in the hope of increasing understanding of the part played by the adrenal cortex in the maintenance of cellular function.

As a byproduct, but a very important one, the relationship of the respiration to the circulation has been studied in patients with severe pulmonary disease or thoracic trauma. Several of these have been placed upon respirators. This has permitted accurate assessment of the circulatory requirements and the metabolic alterations when the work of respiration is removed. Experimental procedures to evaluate more accurately the beneficial long term effects of respirators are now being designed.

This report describes briefly the techniques employed. The results obtained in each part of the project as outlined above are presented to be followed by a consideration of the meaning of this information in the light of our present knowledge of the metabolism of trauma (18) (19) (26) (29). Finally, a number of thoughts on the importance of these findings to the care of wounded and sick patients are discussed.

METHODS

Clinical hemodynamic measurements were carried out by methods outlined in previous reports. In brief, the cardiac output in patients was measured by the dye dilution technique employing indocyanine green (13) (16). Inlying arterial and venous catheters were placed at the outset of each study not only for dye injection but for recording central venous and arterial pressure.

The cardiac output of conscious dogs was recorded electronically or by means of dye dilution employing catheters previously placed into the femoral vessels under anesthesia and conducted through a subcutaneous tunnel to the flank or back. An abdominal bandage has been devised to prevent the animals from disturbing the stopcocks on the ends of the catheters which are secured to the skin. For some of the experiments an electromagnetic flowmeter was employed to estimate cardiac output. The probe was chronically implanted at the base of the aorta (28) (*). This technique has the great advantage of permitting frequent or continuous observations without the necessity of withdrawing blood. However, all of the flowmeters at intervals were checked by and calibrated against simultaneous dye curve values in each animal.

Measurements of the patients' ventilation to date has been accomplished with a Collins respirometer. This is satisfactory for this purpose but inadequate for determining oxygen consumption. More sophisticated methods will have to be employed in the future to obtain good steady state values (20) (21). When the patient is connected to the Engstrom respirator, excellent values can be obtained for both ventilation and oxygen consumption whether the apparatus is functioning or not (12). Ventilatory and compliance measurements in the experimental animals of the burn series were made with a pneumotachograph and the differential of pressures between the airway and the esophagus. This method is to be improved with the help and

*Manufactured by Medicon - Division of Statham Instruments, Los Angeles, Cal.

advice of Dr. Richard Peters at the University of North Carolina.

The arterial blood concentrations of electrolytes (sodium, potassium, and chloride), lactate (4), pyruvate (14), epinephrine (32), norepinephrine (32) are being determined at the times of the majority of the hemodynamic observations. In addition, the method of Astrup (3) is used for pH and pCO_2, for oxygen and carbon dioxide content the method of Van Slyke and Neill (31). Catecholamine concentrations in plasma are measured by a modification of the method of Von Euler (32).

Water balance and urinary output of the patients is carefully followed during the period of study. Aliquots of urine from the twenty-four hour pooled collection are analysed for nitrogen (23), catecholamine (32), and cortisol (5) to assess the daily excretion of each of these substances.

CLINICAL OBSERVATIONS

In the past year 59 patients have been studied:

Burns	7
Trauma	14
Infections and gangrene	12
Pulmonary or circulatory insufficiency treated with respirator	14
Assorted operative procedures	12

At the outset, each patient to be studied was placed in the Intensive Care Unit. There arterial and venous inlying plastic catheters were inserted. To avoid clotting they were filled with dilute heparin in saline solution (0.5 mgm per cc). By this means the arterial catheters could be kept functioning from three to five days. Subsequent hemodynamic observations spaced at greater intervals were made by individual arterial punctures. The hemodynamic values are based upon two or more determinations made within a few minutes of each other. Cardiac outputs, calculated from planimetry of dye curves replotted on semilogarithmic paper, were converted to cardiac indices for purposes of comparison from patient to patient. Surface area values were based upon weight, height, and sex (11).

In the majority of instances arterial blood samples for chemical analysis were taken at the time dye dilution curves were made. All urine was collected on a twenty-four hour basis and acidified by the addition of hydrochloric acid 6N. Other tube drainage and fluid loss was measured. At the same time strict account of the nature and amount of all fluid intake was maintained to establish fluid and electrolyte balance.

The nature of the disease states studied during the past year made it virtually impossible to obtain basal control values prior to the period of observation. Therefore, in the majority of instances subsequent measurements, as late as three months after recovery, were relied upon to provide such information. In other cases when the patient died or could not be followed up knowledge from previous experience (6) (7) gave evidence of predicted normal values for a given individual.

CLINICAL RESULTS

Sepsis and Gangrene: Exclusive of burns there were 12 patients observed in this group. In all but one the disease was established prior to the onset of the study. There were nine with various types of infection: peritoneal abscess, liver abscess, empyema, gangrene of the leg. The composite results from these patients are given in Table I. It should be noted that those who maintained a normal metabolic status throughout their illness exhibited cardiac outputs varying from 72 to 110% above normal basal values. By contrast, three who were in a moderate state of shock or were in apparent circulatory decompensation had outputs near the normal basal value.

Four patients under study had intestinal gangrene. Two died with ischemia of almost the entire small intestine and a portion of the colon. One proved unresectable at operation. Certain of the data from his study are given in Figure 1. A third patient recovered uneventfully following resection of the ileum and cecum. Her cardiac index which was 2.1 $L/M^2/min$

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shortly after admission rose to 4.7 $L/M^2/min$ following rehydration with 4.5 liters of fluid. Simultaneously her hypotension disappeared and the blood total catecholamine concentration decreased from 9 to 2 u/L. Her cardiac index was 3.5 the day after operation. The similar course of a fourth patient, a 35 kg boy with a gangrenous loop of small bowel which was resected, is given in Figure 2.

Burns: Seven additional patients with extensive thermal burns were studied during the past year. An analysis of these plus those observed in previous periods of this contract has been recently made. These are the results in summary:

A detailed analysis is made of the circulatory and metabolic behavior in 12 patients with thermal burns involving 35% to 90% of the body surface. The respiratory tract was injured to some extent in eight. This study demonstrates the interrelated effect of alterations in cardiac index, blood volume, and metabolic demand which increases after surface infection occurs. Within 18 hours post burn, study was undertaken in all but one patient. Basal values were obtained after recovery of the survivors.

A pattern developed with early fall in cardiac index to values between 0.7 and 1.8 $L/M^2/min$. This was accompanied by a decrease in blood volume, and increase in hematocrit to an average of 54% despite fluid therapy. A concomitant metabolic acidosis of 8 ± 5 mEq/L was accompanied by a compensatory respiratory alkalosis. Correction of blood volume increased cardiac index to values of 3 $L/M^2/min$ or more. The metabolic acidosis in turn was reduced, although a dilution of the hematocrit did not always follow. Those surviving a week invariably showed rising cardiac index to values between 4 and 7 $L/M^2/min$ in the presence of infection. This response appeared essential, for when it occurred neither acidosis nor alkalosis was present.

Eight patients failing to meet the increased demand died. Of these, one had organic heart disease and never exceeded 0.86 $L/M^2/min$. Two developed severe G.I. bleeding, and the remainder rose to cardiac indices as high as 6.6 $L/M^2/min$ and died shortly thereafter. We interpret this as acute, high output heart failure secondary to inability to meet the tremendously increased circulatory demand.

This study points out the magnitude of this demand occasioned by energy expenditure from fever to 103°F, water evaporation, and the presence of inflammation in the infected burn areas.

A typical example of the course of a patient who underwent a 32% burn is given in Figure 3. This illustrates the normal basal cardiac output and metabolic status following correction of blood volume. On the fifth day as surface infection started, temperature, pulse rate, and cardiac index started up. The latter reached a recorded maximum of 6.2 $L/M^2/min$ on the ninth day. Three months later after complete skin grafting and recovery it was found to be 2.8 $L/M^2/min$. During most of his illness this man remained slightly alkalotic and hypernatremic.

Trauma: Fourteen additional patients with trauma and shock were studied during the past year. They ranged in age from 16 to 63 years. There were 10 in shock for a portion of their course. The injuries included crushed chest, cerebral and spinal damage, gunshot wounds of the abdomen, extremities and other areas, and fractures. Many had mixed problems requiring therapy of various types.

Those in shock with hypovolemia had cardiac indices ranging from 0.6 to 1.8 $L/M^2/min$ and various degrees of metabolic acidosis. Two died from uncorrected exsanguination. The others responded to therapy with blood fluids and in four cases the use of a respirator.

A comparison of the hemodynamic behavior during hypovolemic shock in man and in the conscious intact dog was published (33). The case histories and data published were largely drawn from data obtained from patient studies conducted under this contract. For details the reader is referred to the reprints of this article which are included with this report. From this work it can be concluded that the conscious dog is an excellent subject for a shock model in contrast to that which is anesthetized. Neither in man nor the dog did cardiac failure appear to be the precipitating cause of death. Further, it was of particular interest that the animals exhibiting the highest blood concentrations of catecholamines were those which died during or after the period of hypovolemia.

Respiratory Problems: Fourteen patients with severe respiratory or circulatory deficiencies requiring the use of a respirator were studied within the past year. Combined with those previously observed satisfactory data from 35 patients is available. Analysis of this is now being undertaken for the preparation of a paper on the relationship of cardiovascular function to that of the respiratory system (9).

Three patterns of metabolic and cardiovascular response to complete assumption of respiratory effort have been defined. The first is illustrated by Figure 4. When respiratory function is grossly inadequate, as in this patient who had a crushed chest, application of a respirator with a cuffed endotracheal or tracheostomy tube improves both oxygenation of blood and corrects the respiratory acidosis. Subsequently, as the general metabolic state improves, the cardiovascular system regains its capacity to meet circulatory demands and the cardiac output rises.

A second type of response is found in patients with emphysema, pulmonary fibrosis, or other pulmonary abnormalities requiring excessive respiratory effort. When the patient is connected to the respirator the cardiac output decreases from values above 4 $L/M^2/min$ to more nearly

normal basal values.

The third pattern is observed in patients with the "low output syndrome". This is particularly common among those who have undergone cardiac surgery. An example is given in Figure 5. An average cardiac index of 1.45 $L/M^2/min$ as found in a number of these patients proves inadequate to maintain the normal metabolic status. Although the cardiac output may not improve much for a few days the application of total respiratory support relieves the necessity of perfusing extensively the muscles of respiration. The inadequate cardiac output then becomes adequate for support of the remainder of the body. The use of a respirator may be needed for several days to two weeks before improved cardiac function makes it possible for the patient to continue respiration on his own.

EXPERIMENTAL OBSERVATIONS

During the course of the past year, three experimental projects have been underway in the laboratory. The first of these was completion of the project on the circulatory requirements to maintain a normal metabolic status in the presence of severe sepsis. The preliminary data and conclusions were reported at the meetings of the Federated Societies in 1963 (1). This work was completed and presented to the Society of University Surgeons in 1964 (2). The second project is directed toward a further understanding of the mechanisms by which circulation is maintained under adverse biochemical conditions encountered in trauma and illness. The circulatory and metabolic behavior of a series of adrenalectomized animals have been followed to determine the cause of death and how it may be prevented by substitution therapy.

The third project concerns the circulatory and metabolic changes encountered in acute burns. This has been jointly pursued with Dr. William H. Lee, Jr., whose group is examining the protein denaturation and hemagglutination accompanying this type of trauma.

The Increase of Circulatory Requirements in the Presence of Inflammation:

Dr. Misa Albrecht, working with the principal investigator, carried out the preparation and followed the animals which were subjected to a standard thoracotomy. This was used to implant an electromagnetic flowmeter at the base of the aorta in the majority of animals. The experiments were thereafter carried out in a conscious state to avoid the circulatory abnormalities produced by anesthesia. The animals were trained to lie quietly upon the table in the laboratory, and appeared to be in a basal state at the time observations were made. These included hemodynamic and chemical determinations. The measurements of the chronically implanted sinewave electromagnetic flowmeters were checked by dye dilution curves. A difference existed of only 9% between the values obtained by the two methods.

Seventeen animals recovered uneventfully (Group I). They maintained an average basal cardiac index of 2.6 $L/M^2/min$ with little variation for a week after thoracotomy. In a second series of animals (Group II), 17 in number, a gangrenous abscess was induced in the muscles of the thigh by injection of calcium chloride solution at the time of anesthesia for the thoracotomy. Although the average fever was but one degree centigrade above that of Group I, the animals of Group II exhibited a progressive and significant increase of cardiac output to an average of 4.7 $L/M^2/min$ during the first postoperative week. This is illustrated in Figure 6. At the same time, there was an accompanying decline of the total peripheral vascular resistance to 46% of the control animals. Five animals, not included in Group II, spontaneously evacuated their abscesses. Thereafter, their cardiac outputs and pulses promptly fell to near basal values. The third group of 13 animals, those which failed to raise the cardiac output following the induction of the thigh abscess, died in three to five days (Group III). All three groups of animals showed insignificant

metabolic differences until shortly before the deaths of the Group III animals. At that time, despite an average cardiac index of 2.2 $L/M^2/min$, the moribund septic animals developed a progressive metabolic acidosis.

In 11 experiments Dr. Michael Weidner, by means of electromagnetic flowmeters chronically implanted around the iliac arteries, has demonstrated a greater flow of blood to the leg of a dog which contains an abscess. Regional blood flow measurements by the use of radioactive crypton (17) confirm this finding. Previously it had been noted that venous blood obtained from the femoral vein on the side with the abscess in the thigh contained a higher oxygen content than that from the opposite side. More data are being obtained concerning this phenomenon which bears out the concept that an inflammatory area behaves in a fashion similar to an arterio-venous aneurysm.

Adrenalectomy: Drs. Veselin Vujovic and Misa Albrecht carried out a study of the postoperative course in adrenalectomized animals. To increase understanding of the importance of the corticoids in recovery from surgical procedures the hemodynamic and metabolic patterns of adrenalectomized animals were compared with intact controls and with adrenalectomized dogs given various forms of substitute therapy. This work has been submitted for consideration for the Fundamental Forum of the American College of Surgeons 1964.

Cardiac output determinations, blood pressure measurements, and blood sampling for gasses and electrolytes were done serially without pain in conscious animals before and after bilateral flank adrenalectomy incisions.

The 11 untreated adrenalectomized animals died between six and 25 hours postoperatively. The cardiac output declined to 60% of the basal value at three hours and to 20% just before death. Although there was little change in central venous pressure, the arterial blood pressure fell proportionately to the output with little evidence of increased peripheral

vascular resistance. The average blood potassium concentration rose to 5 mgm % while sodium remained relatively constant. The buffer base deficit increased to 11 mEq/L, but was compensated by a low pCO_2 of 25 mm Hg until the terminal period. Five adrenalectomized animals treated with infusion of glucose and water and six given glucose and saline solution survived for slightly longer periods. They exhibited the same vascular and metabolic behavior. The administration of DOCA to 14 animals altered the course but little. Two which drank water survived two and five days respectively. The remainder died within 15 hours. By contrast, the 12 animals given hydrocortisone 1 mgm/kg wt/24 hours behaved similarly to the 12 sham operated control dogs. Their cardiac outputs were slightly lower but remained near the basal preoperative values with no evidence of metabolic derangements. All drank water, but failed to eat as well postoperatively as the intact animals. When the hydrocortisone was discontinued at the end of a week, all died within two days of progressive circulatory inadequacy.

The Rheology, Circulatory and Metabolic Behavior of Acute Severe Thermal Burns: With Dr. William H. Lee, Jr., a series of experiments have been conducted in which severely burned dogs were followed to determine if hemagglutination and blood protein denaturation (24) (25) plays a part in the well known metabolic and hemodynamic alterations of this condition.

The hind legs of ten animals anesthetized with barbital were burned in boiling water for 30 seconds. They were given no treatment except blood replacement volume for volume of the samples taken for dyedilution curves and chemical determinations. The replacement blood had been drawn from the experimental animal the previous week and stored in plastic bags with citrate. This maneuver avoided the possibility of reactions from incompatible blood.

The blood was examined at intervals for viscosity and protein changes as well as the usual electrolyte, blood gas, and catecholamines. By means of a pneumotachograph and pressure differentials between the airway and esophageal pressures an estimate was made of changes in lung compliance. The hemodynamic parameters were follwed in the usual way with inlying catheters and previously implanted electromagnetic flowmeter probe at the base of the aorta.

A control series of five animals merely anesthetized were submitted to all of the procedures and observations except the burn. These dogs showed little or no change in a 36 hour period.

On the other hand, within an hour the viscosity of the blood rose and lung compliance decreased in the majority of the burned animals. There was considerable variation in the rate and duration of the development of these changes. During the first twelve hours there was an increase of alpha 3 and beta globulin coating the red cells accompanied by a decrease in the total blood protein. Sludging of blood was demonstrated in the conjunctival vessels.

These changes were associated with the usual rise of hematocrit and reduction of blood volume. The total peripheral vascular resistance increased approximately 55% while the pulmonary vascular resistance rose to 225% of the basal value as cardiac output steadily declined. The metabolic acidosis increased as did the blood catecholamine concentration.

These are preliminary experiments and refinements of technique for measurement of compliance are being developed. Also, a series of experiments are to be carried out with serial lung biopsies to evaluate the parenchymal pulmonary changes as observed in perfusion (27).

DISCUSSION

A variety of aspects of trauma have been examined. Certain of the observations seem relatively well confirmed. Others are in a preliminary

stage. Among the former are those concerning the need for increase of circulation in the presence of inflammation or gangrene. Both the clinical and experimental data indicate that a marked increase of cardiac output is needed to avoid an increase of the peripheral vascular resistance and inadequate perfusion of normal tissues. Preliminary experiments by Dr. Michael Weidner and the principal investigator suggest that an inflammatory area acts in a fashion not unlike that of an arterio-venous aneurysm. This helps to explain why the individual who is incapable of sustaining a high cardiac output succumbs to extensive infection. This is particularly well demonstrated in the patients with severe burns in whom the cardiac output tended to rise dramatically on the fourth or fifth day. It points to the great practical importance of steps to support the circulation under these conditions. Also, an explanation is offered in part for the great improvement and reduction of energy expenditure (20) when the infection is eliminated by drainage, debridement or other measures.

The observations on the chronic circulatory effects of respirators in dealing with serious injury or illness appear to be of real practical value. There are three patterns of beneficial response: 1) The cardiac output increases to normal or higher values as the oxygenation and metabolic state is improved in patients with chest or head injuries which impair respiration. This is a reflection of a generalized improvement in cellular function. 2) In patients with respiratory disorders such as emphysema the cardiac output usually falls from abnormally high levels to less than basal values when the work of respiration is relieved. The reduction of circulatory demand in all probability is due to relief from the need to perfuse so extensively the overworked muscles of respiration. This was pointed out by Cournand et al (10) as the cost of respiration. 3) Of importance to patients with circulatory inadequacy is the improvement in the metabolic state when they too are no longer required to

perfuse excessively the muscles of respiration. What had been inadequate cardiac output for maintenance of normal body demands for circulation may become adequate. This has been particularly evident in a number of patients following cardiac surgery or in those with arteriosclerotic heart disease. Dammann (30) has made similar observations.

The experimental work on the adrenalectomized animals has been undertaken in the hope of employing the cardiovascular system as a means for understanding the need and purpose of the elevated corticoid secretion normally encountered in stress (18) (26). Although in a preliminary state, these data suggest that hydrocortisone is essential for the normal maintenance of cardiovascular metabolism and activity. Also, it becomes apparent that the failure encountered in the adrenalectomized dogs is not simply the result of hyperkalemia affecting the myocardium (15). Rather it is a generalized lack of reactivity in all portions of the system including the arteriolar and venous mechanisms of contraction. Much remains to be accomplished in employing this experimental preparation to delineate the relationship of the metabolic state, the catecholamine concentration, and the corticoids to reactivity and cellular function.

Much has been written about "blood sludging" as an important facet of trauma (22). By means of the techniques now available to us for the study of the circulation as a whole in animals with their cardiovascular reflexes intact it is expected that much can be learned concerning the relationship of red cell agglutination to metabolic and circulatory changes in trauma. An understanding of these phenomena may make it possible to make observations in the injured patient and to apply it to his care. The burn appears to be a well known standard trauma with which to start. Certain changes in the blood proteins and red cellular coating have been demonstrated both in perfusion and trauma (24) (25). It is expected that the experiments now in hand may permit an objective comparison of the circulatory, cellular,

and metabolic advantages of preventing red cell aggregation. Further, the data from these observations may explain something of the pulmonary and respiratory complications associated with extensive trauma, especially that accompanying burns.

TABLE I

FIVE PATIENTS WITH INTESTINAL GANGRENE (2 NON RESECTABLE)

	Basal or Recovery	Maximal Disease	Prior to Death or Shock Phase
Hemodynamic			
Cardiac Index ($L/M^2/min$)	2.9	4.7 to 6.2	2.1 to 3.6
Mean Arterial Blood Pressure(mm Hg)	95	105 to 110	65 to 83
Central Venous Pressure (cm H_2O)	5	3 to 8	-1 to 3
Acid-Base Balance			
Buffer Base Deficit (mEq/L)	+2	-1 to -3	-6 to -8
Arterial pCO_2 (mm Hg)	42	37 to 41	32 to 42
Arterial pH	7.37	7.36 to 7.41	7.31 to 7.36
Metabolic			
Arterial blood oxygen (% sat.)	93	92 to 96	91 to 95
Blood lactate (mgm %)	15	23 to 31	31 to 36
Pyruvate (mgm %)	4	5 to 8	7 to 10

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