

BODY FLUID SHIFTS, SODIUM AND POTASSIUM METABOLISM IN PATIENTS UNDERGOING THORACIC SURGICAL PROCEDURES*

ELMORE M. ARONSTAM, MAJOR, M.C., U. S. A., CLAUDE H. SCHMIDT,
1ST LT., M.S.C., U. S. A. R., AND EDWARD JENKINS, B.A.

DENVER, COLORADO

FROM THE SURGICAL SERVICE AND RESEARCH AND DEVELOPMENT BRANCH,
FITZSIMONS ARMY HOSPITAL, DENVER, COLORADO

THE FOLLOWING STUDY has been undertaken to determine certain findings in patients undergoing thoracic surgical procedures, with special reference to shifts in body fluids and mineral metabolites. Although studies in gastro-intestinal problems have been extensive, as of now little investigation has been directed toward the thoracic surgical patient.^{3, 7, 9, 11, 18, 19} The more experienced thoracic surgeon has learned, through observation, to limit parenteral therapy sharply in the postoperative period, particularly in patients with poor respiratory reserve. Detailed studies of fluid shifts and mineral metabolisms may place postoperative fluid therapy and sodium and potassium therapy on a firmer, more rational basis.

METHOD OF STUDY

Twenty unselected patients undergoing routine thoracic surgical procedures for various conditions, indicated in Tables I and II, were studied pre- and postoperatively. There were 15 white males, three negro males and two white females.

The average age was 29.8, with extremes of 21 and 43 years. All patients were in relatively good physical condition with minimal evidence of weight loss prior to surgery. No patient with a history or evidence of renal disease was included in this study. The patient's general workup in-

cluded renal studies to ascertain renal function preoperatively (blood urea nitrogen, phenolsulfonphthalein test and urinalysis). On the day prior to operation, and then on the first, the fourth and either the 11th or 12th postoperative days, the following studies were performed: serum sodium and potassium; 24 hour urinary sodium and potassium; total protein, albumin and globulin; total circulating protein and hematocrit; complete blood count, plasma and blood volumes; sodium thiocyanate space; CO₂ combining power and urinalysis. A record was made of the weight, fluid intakes and fluid outputs on the above days.

Whole blood replacement of operative losses was carried out during the operation, the amount depending on the judgment of the operating surgeon, in accordance with previous experience at Fitzsimons in the estimation of blood loss in thoracic surgical procedures using both the blue dye, T-1824† and the Wangenstein Dry Weighted Sponge methods.⁸ No other parenteral therapy was used either operatively or postoperatively beyond blood replacement, with the exception of two patients who developed late complications and one other patient with an early postoperative ileus. Patients in general took only liquids by mouth for the first 24 to 48 hours; thereafter, food was generally well tolerated.

† The T-1824 and sodium thiocyanate were supplied through the courtesy of Eli Lilly and Co.

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Serum sodium and potassium concentrations were determined according to the method of Arends by flame photometry.¹ Urinary sodium and potassium levels were measured on 24 hour samples by the flame spectrophotometer using a method modified from that of Mosher, *et al.*¹³ Blood volume studies were performed with T-1824 after the procedure of Noble and Gregersen.¹⁴ Thiocyanate available fluid was estimated by the method of Bowler.¹⁵ Sodium thio-

TABLE I.—*Disease of Patients in Study.*

Diagnosis	No. of Cases
Aortic Aneurysm	1
Bronchiectasis	2
Chronic pneumonitis	1
Cystic disease of the lung	1
Pulmonary tuberculosis	13
Sarcoidosis	2

cyanate was chosen for clinical measurement of the extracellular space, as it was felt to be the best practicable agent. It is probable that thiocyanate values are always somewhat excessive, for it has been shown that some thiocyanate probably enters certain intracellular areas.¹⁰ Serum chlorides were performed using the method of Schales and Schales.¹⁷ All chemical determinations were done on fasting blood specimens which were obtained prior to injection of sodium thiocyanate and T-1824. All blood samples were drawn by one individual.

RESULTS

Under the conditions of this study, with the patient receiving only whole blood in the operating room and small amounts of fluid by mouth during the first 24 hours postoperatively, and all his fluid and nourishment by mouth throughout the entire postoperative period, it was observed that even with a small intake on the first day, an adequate urinary output (from 300 to 800 ml. per day in the first few days) was maintained. Rarely did the total fluid taken by

mouth during the first two postoperative days exceed 2500 ml. The mean intake and output values are recorded in Table III.

Urinary studies postoperatively on these patients indicated a drop in 24-hour sodium excretion from an average of 195.5 mEq. per day preoperatively to an average of 69.7 mEq. per day up to the fourth postoperative day (Table III). Twenty-four hour urinary potassium excretion (Table III) was only slightly impaired postoperatively, although a drop in excretion levels occurred on the fourth postoperative day. It was noted throughout the series that the serum sodium and potassium remained within normal limits, with the exceptions occurring only in patients in whom postoperative complications of empyema or high fever were present.

Slight changes in blood volume and plasma volume (Table IV) were noted from patient to patient on the first postoperative day. The mean average for blood transfusions during operation was 1635 ml. The mean average blood volume deficit on

TABLE II.—*Operative Procedure Performed.*

Diagnosis	No. of Cases
Excision mediastinal lymph node	2
Exploratory thoracotomy for aortic aneurysm	1
Lobectomy	2
Lobectomy and segmental resection	1
Lobectomy and wedge resection	1
Segmental resection	4
Thoracoplasty	5
Wedge resection	4

the first postoperative day was 832 ml., despite the large volume of blood given during the surgical procedure. However, with no further transfusions, the mean average blood volume was slightly above the preoperative mean by the 11th to 12th postoperative day. The mean plasma volume had returned to preoperative levels by the fourth postoperative day.

Throughout the postoperative period only minor variations were noted in total proteins. The mean total circulating proteins dropped 13.3 per cent following sur-

gery, gradually returning to normal by the 11th or 12th day (Table IV). This tends to parallel the change in plasma and blood volumes.

One of the most important findings of this investigation was the fact that 17 out of 20 patients developed an increase in extracellular fluid. The shifts in thiocyanate available fluid are presented in Table

average showed a significant gain of 1.22 liters or 7.4 per cent change with a mean of 17.52 liters.

An interesting trend was apparent through comparison with the preoperative levels on the cases which showed gain post-operatively. Eleven (55 per cent) had an average preoperative level of 14.58 liters, while those nine (45 per cent) cases show-

TABLE III.—*Electrolyte Changes Following Thoracic Surgery—20 Patients**

Electrolytes	Preop Mean	1st Postop Day		4th Postop Day		11-12 Postop Day	
		Mean	% Chg.	Mean	% Chg.	Mean	% Chg.
Serum potassium (meq)	4.8	4.8	0.0	4.6	-4.2	5.1	+6.2
Serum sodium (meq)	138.0	133.0	-3.6	140.0	+1.4	142.0	+2.9
Serum chlorides (meq)	106.0	105.0	-0.9	102.0	-3.8	106.0	0.0
Urinary potassium meq/24 hr.	59	56.2	-4.8	34.6	-41.3	53.6	-9.1
Urinary sodium meq/24 hr.	195.6	69.6	-64.4	103.8	-46.9	161.3	-17.5
Urine output ml/24 hr.	1593.0	788.0	-50.5	1633.0	+2.5	1540.0	-3.3
Oral intake ml/24 hr.	2137.0	1567.0	-26.7	2562.0	+19.9	2329.0	+8.9

*Changes relative to preoperative levels used as norm, shown with per cent change based on the group respective arithmetic means.

TABLE IV.—*Changes* in Hematological Levels Following Thoracic Surgery in 20 Patients.*

Blood studies	Preop Mean	1st Postop Day		4th Postop Day		11th Postop Day	
		Mean	% Chg.	Mean	% Chg.	Mean	% Chg.
Blood volume cc/kg	80.4	75.4	-6.2	77.9	-3.1	85.0	+5.7
Plasma volume cc/kg	43.0	38.7	-10.0	43.5	+1.1	47.8	+11.1
Hematocrit mm/%	47.2	48.7	+3.2	43.7	-7.4	44.3	-6.1
Hemoglobin Gm.	16.1	15.7	-2.5	14.8	-8.1	15.1	-6.2
Red blood cells (10 ⁶ =M)	5.20	5.26	+1.1	4.71	-9.4	4.85	-6.7
Proteins Gm. %	6.2	6.2	0.0	6.05	-2.4	6.2	0.0
Total circulating Prot. Gm.	182.8	158.5	-13.3	176.1	-3.7	196.6	+7.6
Carbon dioxide combining power Vol. %	68.9	62.8	-8.8	68.0	-1.3	64.8	-5.9

*Changes relative to preoperative levels used as norm, shown with per cent change based on the group respective arithmetic means.

V. Preoperative levels were used as the normal control for the 20 cases in this study. The mean averaged levels for the total group (20) preoperatively was 16.30 liters. On the first postoperative day, 11 (55 per cent) of the cases showed a gain of 3.75 liters or 25.7 per cent, with a mean of 18.33 liters. There were nine (45 per cent) who showed a decrease of 1.86 liters or 10.1 per cent from the preoperative level, with a mean of 16.53 liters. However, the total

ing decreases had a preoperative average of 18.39 liters. Thus, perhaps a more marked physiological adjustment was noted following surgery by those with lower preoperative levels.

A marked change was shown on the fourth postoperative day (delayed action). Seventeen (85 per cent) of the 20 cases showed a gain of 3.57 liters or 24.5 per cent change, with a mean of 18.15 liters and only three (15 per cent) showed decrease of 2.28

INDIVIDUAL FLUID AND METABOLITE FINDINGS -
FOR PRE-OPERATIVE AND POST OPERATIVE PERIODS.

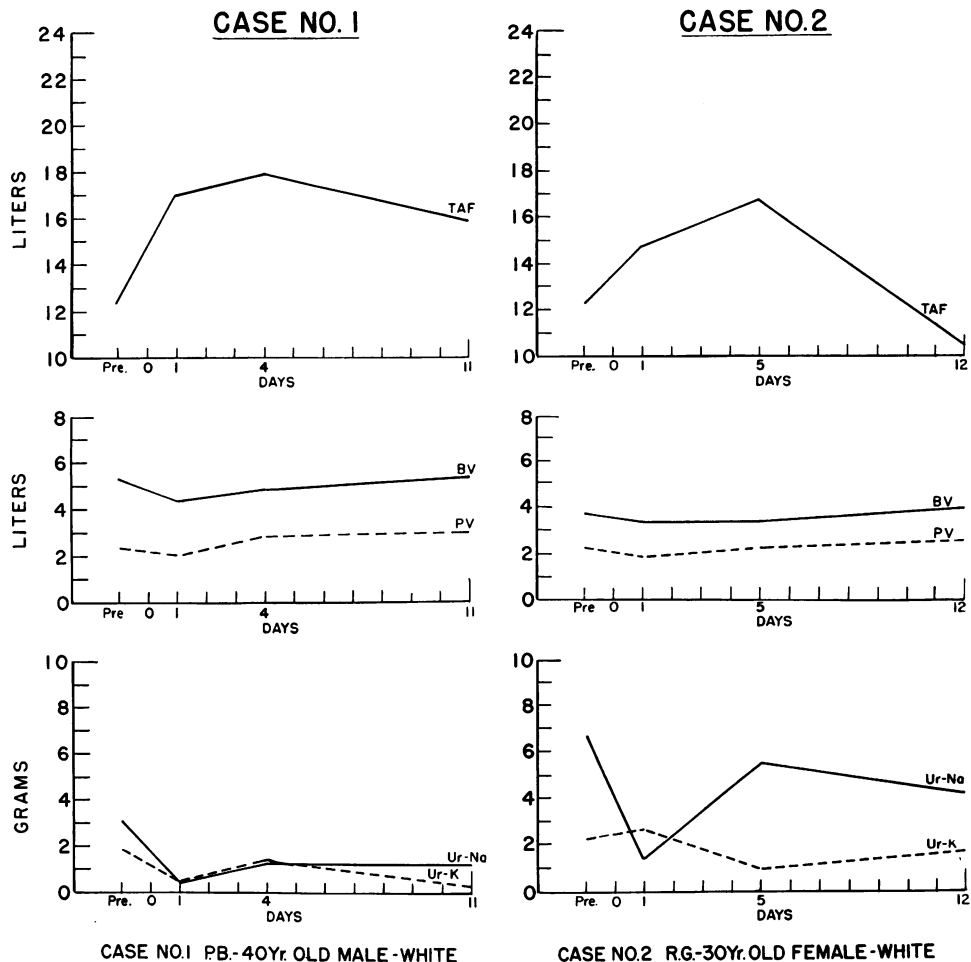


FIG. 1

liters or 12.4 per cent change, with a mean of 16.11 liters.

The total group showed an average increase of 1.55 liters or 9.5 per cent change, with a mean of 17.85 liters. On the 11th postoperative day there was a return to a proportionate balance between the two groups. Eleven (55 per cent) showed gains of 4.03 liters, 27.6 per cent change, with a continued high mean of 18.61 liters. Nine (45 per cent) of the cases showed de-

creases of 3.29 liters, 17.9 per cent change with a mean of 15.10 liters.

The only exceptions to this general rise in extra-cellular fluid were a 35-year-old man who underwent an apical posterior resection of the left upper lobe for pulmonary tuberculosis, and whose immediate postoperative course was marked by persistent bronchial fistula associated with fever and anorexia, and a 23-year-old negro male who underwent a wedge resection of the right

upper lobe for pulmonary tuberculosis. His postoperative course was marked by a persistent ileus lasting for a period of three days, necessitating parenteral intravenous therapy and gastro-intestinal intubation.

The mean and per cent change in hematocrit and hemoglobin are recorded in Table IV. Their variations are minor and seem to parallel the course of the blood and plasma levels.

were also observed. This patient's immediate postoperative course was complicated by the development of a small empyema from which was cultured a hemolytic streptococcus. This responded readily to therapy and the patient made a good recovery and was transferred to the medical service for further hospitalization. All tuberculous patients undergoing surgery are kept at least one year following operation.

Case 2.—This 30-year-old, white female patient was admitted to Fitzsimons Army Hospital in April, 1951. She was first treated for bilateral apical pul-

TABLE V.—*Extra-cellular Fluid Volume—Thoracic Surgery.*

Mean Averages	Postoperative Period									
	Pre-Op	1 Day PO	Change		4 Day PO	Change		11 Day PO	Change	
			Liter	%		Liter	%		Liter	%
Total Group (20)	16.30	17.52	+1.22	+7.4	17.85	+1.55	+9.5	17.03	+0.73	+4.3
Increases	*14.58	18.33	+3.75	+25.7	18.15	+3.57	+24.5	18.61	+4.03	+27.6
Decreases	*18.39	16.53	-1.86	-10.1	16.11	-2.28	-12.4	15.10	-3.29	-17.9

*Comparison of level changes.

CASE REPORTS

The following two case reports are offered to illustrate the results discussed above.

Case 1.—This patient was a 40-year-old, white male veteran, admitted to Fitzsimons Army Hospital October 23, 1951. He had had periodic hospitalizations for right upper lobe proven tuberculosis since 1944. In the fall of 1951, this patient became symptomatic again; the sputum was again positive, and the infiltration in his right upper lobe had increased. After initial studies in this hospital, the patient was placed on a 120 day regimen of streptomycin (2 Gm. every third day) and para-aminosalicylic acid (12 Gm. per day). On completion of this therapy, sputum and gastric cultures became negative and stability of the lesion in the right upper lobe was demonstrated. A first stage thoracoplasty was performed on January 21, 1952, and a right upper lobectomy on February 27, 1952. Studies of this patient were done before and after his right upper lobectomy and can be seen in Figure 1 and Table VI. There was a rise in this patient's extracellular fluid on the first postoperative day of 4,780 ml. By the 11th to 12th day this began to decrease gradually. A marked drop in urinary sodium excretion and urinary potassium excretion occurred. This latter, however, was an exception to the rule in our study. Small changes in the blood volume and plasma volume

monary tuberculosis in July, 1945. For over a year she underwent bed rest and bilateral pneumothorax. She was well thereafter, until 1951, when she had recurrence of symptoms. She was treated at that time as an out-patient, but was finally admitted to Fitzsimons Army Hospital on the above date. On admission, the patient had a positive sputum and evidence of bilateral fibro nodose, calcific infiltration in the upper lobes. A small cavity, 1.5 cm. in diameter, was demonstrated in the left upper lobe at the site of maximum pathologic change. From April, 1951, until the time of operation, the patient was treated with combined streptomycin (2 Gm. every third day), para-aminosalicylic acid (12 Gm. daily) and pneumoperitoneum. There was some initial clearing in the lesions; however, complete closure of the cavity was not effected. Stability persisted for several months prior to consideration of surgery. Despite the fact that this patient had a maximum breathing capacity of 48 liters/minute and resting minute ventilation of 10 liters/minute, it was felt that a left-sided thoracoplasty should be performed.

The patient underwent a first stage thoracoplasty on March 12, 1952. Studies were performed on this patient before and after operation (Illustrated in Figure 1 and Table VII). This patient became increasingly dyspneic postoperatively. Her course was complicated by a paralytic ileus, which developed on the first postoperative day. Because of inability to retain fluid by mouth, the patient

received 1500 cc. of 5 per cent glucose in water and 500 cc. of 5 per cent glucose in saline on the first postoperative day. The evening of the first night, following infusion, the patient developed pulmonary edema. The situation was reversed by oxygen, elevation of the bed and sedation. The patient was not free of dyspnea for at least 12 days following operation, and then had marked dyspnea on the least exertion. The postoperative findings on the fifth day in this patient demonstrated a gain of 4,000 cc. in the patient's extracellular fluid. Blood volume and plasma volume were rela-

that the mean average blood volume returned to normal or above normal by the 11th to 12th postoperative day without further transfusion is extremely significant. Whether this reflects regeneration of whole blood or the release of formed elements and protein from stores or shunted areas is not known. There seems little doubt, however, that though these patients clinically appear well, more blood at the time of

TABLE VI.—Case I. P. B., 40-year-old White Male.

Blood Studies	BLOOD SERUM ELECTROLYTES			
	Pre Op.	1 Day Post Op.	4 Day Post Op.	11-12 Day Post Op.
Wt. in kg.	64.4	64.4	64.4	59.9
Plasma Vol. ml/kg.	37.1	33.3	45.0	50.6
Blood Vol. ml/kg.	83.6	66.6	75.9	89.9
Hematocrit mm.	56.0	50.0	40.8	43.7
Hemoglobin Gm. %	19.3	17.1	13.4	14.2
RBC millions.	5.74	5.58	4.09	4.59
WBC thousands.	8.10	13.95	9.95	15.35
Thiocyanate Space in Liters.	12.400	17.180	18.020	15.940
Albumin Gm. %	3.53	3.35	3.24	2.85
Globulin Gm. %	2.48	2.20	1.90	2.45
A/G Ration.	1.4	1.5	1.7	1.2
CO ₂ Combining Power Vol. %	71.5	65.0	54.2	65.0
Serum K meq/l.	5.2	5.2	4.5	4.6
Serum Na meq/l.	146.7	134.3	129.1	130.4
Serum Cl meq/l.	105	112	96	96
Urinary K meq/24 hrs.	50.5	9.0	36.5	8.0
Urinary Na meq/24 hrs.	134.3	14.8	57.9	53.0
Urine Volume ml.	920	160	1620	860
Fluid Intake ml.	3180	600	2890	1920
Blood Transfused ml.		2400		
Replaced Blood.		70.8%		

tively unchanged. There was a marked sodium retention as illustrated by the urinary output curve. It is believed in this case that the factor of increased extracellular fluid may have added to the unfortunate combination of poor pulmonary reserve secondary to pulmonary fibrosis, and probably some postoperative anoxia. No further stages of thoracoplasty were considered for this patient because of her poor respiratory reserve.

DISCUSSION

From final evaluation of the foregoing results, several factors seem highly important. First, it has again become apparent that whole blood replacement in surgery has been considerably underestimated, the mean average deficit being about 800 cc. as calculated by the blue dye, T-1824, method on the first postoperative day.⁷ The fact

operation would largely correct deficits in hematocrit, total circulating protein and blood volumes in the early postoperative period. What effect more adequate transfusion would have on the volume of extracellular fluid is difficult to predict.

Second, with reference to electrolyte studies, a marked sodium retention has been observed in the early postoperative period, which gradually tends toward a normal figure by the 11th or 12th postoperative day. Of further interest in this study was the observation that contrary to other experience, thoracic patients under this plan of operative management did not show significant depression of serum sodium, serum chloride and CO₂ combining power

(Tables III and IV).^{2, 6, 12} On the first post-operative day serum sodium levels were depressed 3.6 per cent, serum chlorides 0.9 per cent and CO₂ combining power 8.8 per cent. Although there is a tendency for depression of these determinations, the degree of deficit is entirely within the range of normal values. It is felt that there has not been sufficient depression of the serum sodium and chloride levels to effect the

increased potassium excretion in the early postoperative period. Serum potassium levels and 24-hour urinary potassium levels appear within normal limits in our study. This would suggest that little indication for parenteral potassium therapy exists in thoracic surgical patients, unless complicating factors develop.

Third, our results have indicated that the extracellular fluid space expanded postoper-

TABLE VII.—Case 2. R. G., 30-year-old White Female.

Blood Studies	BLOOD SERUM ELECTROLYTES			
	Pre Op.	1 Day Post Op.	4 Day Post Op.	11-12 Day Post Op.
Wt. in kg.....	54.4	54.4	54.4	51.0
Plasma Vol. ml/kg.....	42.8	35.7	42.8	51.9
Blood Vol. ml/kg.....	69.4	63.4	63.2	78.4
Hematocrit ma.....	38.4	43.7	32.2	39.8
Hemoglobin Gm. %.....	13.7	14.8	10.8	13.4
RBC millions.....	4.48	4.83	3.41	4.50
WBC thousands.....	5.80	8.70	5.50	7.15
Thiocyanate Space in Liters..	12.33	14.84	16.76	10.45
Albumin Gm. %.....	3.25	3.47	3.09
Globulin Gm. %.....	1.82	2.15	2.06
A/G Ratio.....	1.8	1.6	1.5
CO ₂ Combining Power Vol. %	72.8	51.5	67.4	71.5
Serum K meq/l.....	5.1	4.8	5.0	5.3
Serum Na meq/l.....	147.1	126.1	151.3	152.6
Serum Cl meq/l.....	102	104	102	105
Urinary K meq/24 hrs.....	58.7	68.5	22.0	42.6
Urinary Na meq/24 hrs.....	293	59.1	239.1	183.5
Urine Volume ml.....	2330	1050	3320	2300
Fluid Intake ml.....	2880	2540	1860	2070
Blood Transfused ml.....		1000		
Replaced Blood.....		75.1%		

decrease in glomerular filtration, renal plasma flow and the diuretic response to water loads which has been suspected of playing an important part in water intoxication and in the increase of the thiocyanate space.²⁰ This problem, of course, will require more study. The mean oral intake (1567 ml.) and mean urinary output (788 ml.) on the first day in these patients, although within normal limits, is obviously smaller than preoperative figures.

Contrary to the usual findings in patients undergoing gastro-intestinal surgery, in whom gastro-intestinal intubation is employed, these thoracic patients have shown very little, if any, potassium deficit in the postoperative period, nor have they shown

actively in the absence of excessive salt and water infusions and in the presence of renal salt retention. In the presence of normal serum sodium levels, extracellular fluid space increases paralleled salt retention regularly. Therefore, we find it difficult to believe that a dilute state of extracellular ions exists in this group of patients, and feel that salt retention largely explains the extracellular fluid increase. The amount of salt these patients receive in their whole blood at the time of operation is negligible. We know that a patient can hold approximately 12 pounds, roughly six liters, of edema within his body before edema clinically becomes apparent and that about six grams of salt hold a liter of fluid in solution in the

extracellular space.¹⁵ The significance of the postoperative increase in extracellular fluid space, which may, in the presence of further infusion, particularly of saline, bring the patient to the point of clinical edema is striking when one may be dealing with a thoracic patient with poor respiratory reserve and postoperative anoxia. Pulmonary edema can rapidly be precipitated. The poor respiratory reserve seen with pulmonary fibrosis and emphysema is known to lead to increased resistance in the pulmonary circulation and pulmonary artery hypertension.¹⁶ Anoxia is closely linked to the decrease in capillary permeability leading to pulmonary edema.⁴ Increased extracellular fluid, when imposed upon the above conditions, presents a dangerous situation. In the light of the above discussion, we find it extremely difficult to consider postoperative administration of saline solution to a thoracic surgical patient unless hyponatremia exists, or water intoxication were suspected.²⁰

In this study we have discovered but one instance of a patient running a consistently low serum sodium preoperatively. We are extremely desirous of studying more of these patients. Our one case mirrored the mean findings of the group. We hope to extend this study to include the older age group, particularly those with cancer of the lung and cancer of the esophagus. We are also anxious to include cardiac patients with congenital or acquired disease.

SUMMARY

1. Thoracic surgical patients, receiving no other parenteral therapy beyond blood replacement during operation, were able to maintain adequate urinary outputs postoperatively, despite low oral fluid intake.

2. Sodium retention is marked following thoracic surgical procedures as in other general surgical procedures.

3. Serum chlorides, serum sodium levels and CO₂ combining power determinations

have remained within normal limits postoperatively in these patients.

4. Serum potassium and urinary potassium excretion is relatively unaffected in uncomplicated thoracic surgical procedures.

5. Underestimation of blood replacement at operation is a frequent occurrence and largely explains the plasma volume and total circulating protein deficits in the early postoperative period.

6. The extracellular fluid compartment is markedly expanded postoperatively in almost all cases. Its mechanism has been discussed.

7. The dangers of increased extracellular fluid postoperatively in thoracic surgical patients with poor pulmonary reserve and pulmonary hypertension and anoxia have been discussed.

8. Two case histories have been presented to illustrate the operative and postoperative courses of these patients.

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