Acute Alterations of Body Composition after Open Intracardiac Operations

By Albert D. Pacifico, M.D., Stan Digerness, B.A., and John W. Kirklin, M.D.

SUMMARY

The body composition of patients with heart disease is acutely altered by surgical intervention. Interrelations and causes of the alterations have not been clear. Twenty patients were studied preoperatively and again 2 to 4 days after open intracardiac operations. In nine, measurements were made of the volumes of total body water, extracellular water, plasma, and red cells, and of the amounts of total exchangeable sodium and potassium. In an additional four patients total exchangeable sodium and potassium were measured, and in another seven only exchangeable sodium was measured. Calculations were made of the intracellular and extracellular distribution of water and potassium. The significant changes (P < 0.05) occurring during the interval between studies were increase in extracellular water (7%), interstitial water (12.5%), and exchangeable sodium (9.4%), decrease in total exchangeable potassium (8.5%) and amount (8.7%), and concentration (6.9%) of calculated intracellular potassium. Uptake of sodium and water by the patient during cardiopulmonary bypass and postoperative loss of intracellular potassium with its secondary renal excretion are postulated as being etiologic. These findings imply that sodium intake in the early postoperative period should be low, water intake no more than urinary and insensible losses, and that potassium should be administered.

Additional Indexing Words:
Exchangeable sodium  Exchangeable potassium  Extracellular fluid
Interstitial fluid

The acute changes in body composition resulting from open intracardiac operations have complex etiology, are difficult to study, but contribute importantly to the morbidity and mortality from surgery. Previous investigations have shown that blood volume is usually less 24 to 48 hours after these operations than preoperatively, and that the volume of extracellular water is increased. Changes in amounts and distribution of sodium and potassium have not been clearly defined. Therefore, the present study was made. When possible, the data and related data from other investigations are used to develop appropriate explanations for the findings.

Methods

Twenty adult patients were studied (table 1). Complete studies were performed in patients 1 through 9. Total exchangeable sodium (Naₑ) was measured in patients 10 through 20, and total exchangeable potassium (Kₑ) in patients 10 through 13. All patients survived the postoperative period.

A rotating disc oxygenator was used during all operations except one (patient 5) in which a bubble oxygenator primed with 5% glucose in water was used. The disc oxygenator was primed with blood preserved by acid-citrate-dextrose solution which was heparinized and diluted to a hematocrit of about 0.30. The priming solution had a concentration of sodium and potassium of 138 and 3.1 mEq/L of serum water, respectively. Glucose concentration was 1,060 mg/100 ml.
Clinical Data on Preoperative Status of Patients

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<th>Treatment</th>
<th>Edema</th>
<th>Wt. (kg)</th>
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Abbreviations: AVD = aortic valve disease; MVD = mitral valve disease; ASD = atrial septal defect; PS = pulmonic stenosis; D = digitalis; T = diuretic.

Usually about 4,000 ml of diluted blood was in the machine at the beginning of cardiopulmonary bypass. It is difficult to estimate the amount of retention of perfusate by the patient because of external blood loss and occasional additions of whole blood or salt solution or both during cardiopulmonary bypass.

Postoperative blood administration was directed primarily by left atrial and systemic pressures. Generally, it was similar to the amount of blood lost postoperatively. Intravenous fluid therapy consisted of 500 ml/m² of body surface area/24 hr of 5% dextrose and water and 10 mEq/m²/24 hr of potassium chloride, on the day of operation. On the first postoperative day and thereafter as required, doses were increased to 750 ml/m²/24 hr and 20 mEq/m²/24 hr, respectively. No sodium was administered.

Sequential studies were conducted preoperatively within 7 days of operation. In each of the patients 8 days of oral sodium loading (360 or 920 mEq of sodium in the total period) had preceded the preoperative studies, for testing of the renal response to an exogenous sodium load. Studies were made according to the following schedule. The volumes of total body water (TBW) and extracellular water (ECF) were simultaneously measured during a fasting state before and 48 hr after operation (postoperative day 2) from blood samples obtained following injection of tritiated water and Na¹²³Br 12 hr previously. Extracellular water was calculated from the bromide space, using the formula of McMurrey and associates. Measurements were all made at the same time of day in view of known diurnal variations. Plasma volume (PV) and red cell mass (RCM) were measured preoperatively and on postoperative day 2, using radiiodinated serum albumin (¹²⁵I) and radiocromated red blood cells (¹⁶⁷Cr) as the respective indicators. Radioactivity was measured in blood samples obtained 20 min after injection. Exchangeable sodium (Naₑ) was measured in the fasting state preoperatively and on the third postoperative day from serum samples obtained after injection of NaCl 24 hr earlier. Serum rather than urine was used because of the small quantity of sodium in the urine postoperatively. Aliquots of serum were sequentially counted and separation of Na²⁴Na from Na¹²³Br was accomplished by differential rates of decay using the formula:

\[ 24Na = \frac{Bx_1 - x_2}{B - A} \]

A and B represent the 24 hr decay corrections for Na²⁴Na and Na¹²³Br, respectively, and x₁ and x₂ initial and final sample counts obtained 24 hr apart. Exchangeable potassium (Kₑ) was measured preoperatively and on the fourth postoperative...
ALTERATIONS OF BODY COMPOSITION

day from urine samples obtained 24 to 26, 26 to 28, and 28 to 30 hr after intravenous injection of 42KCI. Radioactivity was measured in a deep well scintillation counter* modified by replacement of the sodium iodide crystal with a plastic scintillation crystal which was relatively insensitive to gamma radiation. This allowed greater than 99% separation of 24K from 24Na.

Plasma and red cells were separated by centrifugation and concentrations of 125I, 51Cr, 82Br, and 24Na determined by measuring the radioactivity in respective samples in the deep well scintillation counter. Tritium concentration in plasma water was measured after initial vacuum distillation of samples and subsequent counting in a liquid scintillation counter.†

Serum sodium and potassium concentrations were measured with a flame photometer, from the same serum samples used for determination of exchangeable sodium. The per cent of water which was water was determined with a refractometer and conversion tables.7 Studies indicated no significant differences between values obtained for serum water by this technic and a technic of oven drying and weighing of samples. Concentrations of sodium, (Na)i, and potassium, (K)i, in mEq/L of serum water were calculated by dividing their concentration in serum by the concentration of water in serum. Osmolality was determined from these samples by the method of freezing point depression.

Spaces were calculated using standard isotope dilution formulae and appropriate corrections applied for measured urinary loss. Chest drainage had stopped before postoperative studies were begun. Interstitial water (ECF-PV) was calculated as the difference between volume of extracellular water and plasma volume.

The amount of sodium and potassium in extracellular water was calculated using a factor for each patient to correct plasma concentrations of sodium and potassium for plasma water and the Gibbs-Donnan effect. Total intracellular potassium (Kic) equals Kii - extracellular K. Concentration of potassium intracellularly, (K)iic, is calculated as Kii/ICW, intracellular water (ICW) being the difference between total body water and extracellular fluid. These values are presented in the tables, but in interpreting them, cognizance is taken of the large errors that can exist in this type of derived data.

Results were analyzed using standard statistical equations.8 Comparison of preoperative values with predicted values for normal individuals of the same weight, age, and sex and with postoperative values was made using the method of paired difference analysis. Regression equations were calculated, assuming a linear relationship, using the method of least squares and the probability (P) of a correlation coefficient (r) being obtained by chance was evaluated by the t-test.

Results

The complete data on the nine patients are in tables 2 and 3. The values for exchangeable potassium in 13 patients and for exchangeable sodium in 20 are in table 4.

Preoperative studies were done to provide a base line from which changes occurring as a result of surgery could be determined. The comparison of these data with predicted normal values is nonetheless interesting. Preoperatively, the amount of exchangeable sodium was larger than predicted normal in seven of the nine patients with detailed studies, the mean difference from predicted normal being +208 mEq (+8.6%). Exchangeable potassium was less in each case, the mean difference from predicted normal being -730 mEq (-25.2%). Total body water was not different from predicted normal values. Extracellular fluid was increased 7.5% and intracellular water decreased 7.7%, but the differences were not statistically significant. Average intracellular concentration of potassium was low, the mean value being 120 mEq/L.

Postoperatively, on the third day, exchangeable sodium was higher than preoperatively in six of the nine patients with detailed studies, and in 15 of the 20 patients in whom Na was measured either alone or with other studies. Mean changes in the two groups were +232 mEq (+7.0%) and +274 (+9.4%), respectively. The concentration of sodium in serum water was not significantly different from that preoperatively. Extracellular fluid on the second postoperative day was higher than preoperatively in eight of the nine patients studied, and the mean increase of 1.16 L (+7.0%) was statistically significant. Interstitial water increased significantly (+1.69 L, or 12.5%). Blood volume (BV) was not significantly different from preoperatively on the

†Beckman, Fullerton, California.

Circulation, Volume XLI, February 1970
Table 2

Preoperative Values for Body Composition

<table>
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<th>Patient</th>
<th>(N\textsubscript{4})\textsubscript{e} (mEq/L)</th>
<th>(K\textsubscript{4})\textsubscript{e} (mEq/L)</th>
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<th>K\textsubscript{e} (mEq)</th>
<th>TBW (L)</th>
<th>ECF (L)</th>
<th>ECF-PV (L)</th>
<th>K\textsubscript{1e} (mEq/L)</th>
<th>PV (L)</th>
<th>RCM (L)</th>
<th>TBV (L)</th>
<th>OSM (mOsm/L)</th>
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<th>N\textsubscript{a} + K\textsubscript{e}</th>
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Comparison of preoperative with predicted normal

| Normal | 2766 | 2962 | 35.59 | 16.28 | 19.31 | 13.32 | 2.96 | 1.73 | 4.69 |
| \* \text{sd} | 667 | 847 | 9.22 | 3.74 | 5.55 | 3.08 | 0.67 | 0.49 | 1.16 |

Difference

| Mean | 208 | -730 | -0.52 | 1.16 | -1.67 | 0.89 | 0.27 | -0.02 | 0.24 |
| \* \text{sd} | 232 | 302 | 3.28 | 1.77 | 3.42 | 1.43 | 0.77 | 0.51 | 0.94 |
| % | 8.6 | -25.2 | -0.5 | 7.5 | -7.7 | 6.6 | 11.3 | 0.6 | 7.5 |
| \(P\) | \(<0.05\) | \(<0.001\) | \(>0.1\) | \(>0.05\) | \(>0.1\) | \(=0.1\) | \(>0.1\) | \(>0.1\) | \(>0.1\) |

* \text{sd} = standard deviation.
Table 3

Early Postoperative Values for Body Composition

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<th>K√</th>
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<th>ECF</th>
<th>ICW</th>
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<th>X₁</th>
<th>(K)₁</th>
<th>PV</th>
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<td>(mEq)</td>
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Change from preoperative

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*sd = standard deviation.
second postoperative day. Exchangeable potassium was reduced on the fourth postoperative day compared with preoperatively in eight of the nine patients with detailed studies and in 12 of the larger group of 13 patients (table 4), the mean differences of −202 mEq (−8.3%) and −209 mEq (−8.5%), respectively, being significant. There was no statistically significant change in intracellular water and total body water. The concentration of potassium in serum water was not significantly different postoperatively. The calculated value for the amount of potassium intracellularly was reduced on the fourth postoperative day as compared to preoperatively (−203 mEq or −8.7%), as was the concentration of potassium in intracellular water (−8.7 mEq/L or −6.9%). These changes were statistically significant.

Some correlations between the data are in table 5. Although there was a high correlation between bromide space and sodium space both preoperatively and postoperatively, postoperative changes in the two spaces were not correlated. This correlation appeared to be prevented by the data from three patients (patients 1, 2, and 8), in whom the mean postoperative increase in sodium space was 3.03 L greater than that of the bromide space. These three patients had the greatest postoperative depression of calculated intracellular potassium concentration. Although exchangeable potassium was highly correlated with the calculated volume of intracellular water both before and after operation, changes in exchangeable potassium after operation did not correlate with changes in the volume of intracellular water. This was due primarily to patients 1 and 8, in whom intracellular water was considerably increased after operation while considerable decrease in exchangeable potassium occurred.

Average total body cation concentration (Na<sub>e</sub> + K<sub>e</sub>/TBW) was 148.1 mEq/L preoperatively and 144.8 postoperatively, compared with a value for the sum of the concentrations of sodium and potassium in serum water of 152.1 preoperatively and 148.4 mEq/L postoperatively.

### Table 4

**Mean Values for Na<sub>e</sub> and K<sub>e</sub> for Entire Group**

<table>
<thead>
<tr>
<th></th>
<th>Preoperative</th>
<th>Postoperative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Na</td>
<td>K</td>
</tr>
<tr>
<td>Preoperative</td>
<td>3024 (+ 587)</td>
<td>2341 (± 710)</td>
</tr>
<tr>
<td>Change in mEq</td>
<td>274 (± 396)</td>
<td>-209 (± 486)</td>
</tr>
<tr>
<td>%</td>
<td>9.4 (± 6.5)</td>
<td>-8.5 (± 8.5)</td>
</tr>
<tr>
<td>N*</td>
<td>20</td>
<td>13</td>
</tr>
</tbody>
</table>

*N = no. of patients studied.

### Table 5

**Relations Between Several Pairs of Variables**

<table>
<thead>
<tr>
<th>y</th>
<th>x</th>
<th>r*</th>
<th>p</th>
<th>r</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na&lt;sub&gt;e&lt;/sub&gt; + K&lt;sub&gt;e&lt;/sub&gt;</td>
<td>TBW</td>
<td>0.993</td>
<td>&lt;0.001</td>
<td>0.988</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Na&lt;sub&gt;e&lt;/sub&gt; + K&lt;sub&gt;e&lt;/sub&gt;</td>
<td>TBW</td>
<td>0.990</td>
<td>&lt;0.001</td>
<td>0.987</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Br space</td>
<td>Na space</td>
<td>0.925</td>
<td>&lt;0.001</td>
<td>0.973</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Na&lt;sub&gt;e&lt;/sub&gt;</td>
<td>ECF</td>
<td>0.934</td>
<td>&lt;0.001</td>
<td>0.963</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>K&lt;sub&gt;e&lt;/sub&gt;</td>
<td>ICF</td>
<td>0.943</td>
<td>&lt;0.001</td>
<td>0.924</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Change from preoperative

| ΔNa<sub>e</sub> + K<sub>e</sub> | ΔTBW  | 0.820    | <0.01 |
| ΔBr vol. | ΔNa space | 0.418 | >0.10 |
| ΔK<sub>e</sub> | ΔICF  | 0.084    | >0.10 |

*r* = correlation coefficient.

*Circulation, Volume XLI, February 1970*
ALTERATIONS OF BODY COMPOSITION

mEq/L postoperatively. Cation space, Na_\text{a} + K_\text{a}/(Na)_s + (K)_s, was highly correlated with total body water both preoperatively and after operation, and the correlation coefficient between changes in the two was 0.820.

Discussion

The purpose of this study was to describe the alterations in body composition resulting from events in the operating room during intracardiac surgery and in the early postoperative period. The group of patients studied is homogeneous in that all underwent cardiopulmonary bypass by a standard technic and all had similar treatment postoperatively. It would have been ideal had all patients had the same intracardiac lesion, the same degree of heart failure prior to surgery, and the same intracardiac operation. This ideal was impossible to achieve. The similarity of the acute alterations of body composition from patient to patient in the early postoperative period suggests that the complex events associated with cardiopulmonary bypass are the most important determinants of the changes observed, not the preoperative state of the patient, the nature of the intracardiac lesion, or the mechanical correction of it. In contrast, the body composition several months after operation is probably primarily determined by the new hemodynamic state resulting from the mechanical correction achieved by the operation.

Renal response to an exogenous sodium load was tested in many of the patients prior to the preoperative measurement of body composition, as part of a separate project. The numbers of patients suitable for the prolonged preoperative hospital stay required for clinical investigation, and other considerations, made it seem advisable although not ideal to use some of the same patients for body composition and sodium tolerance studies. In our practice, patients are not brought to a dry, steady state prior to open intracardiac operations but come to surgery with varying degrees of fluid retention and heart failure. The patients in this study were then a reasonable sample for the purpose of this study, which was concerned with changes from the preoperative values rather than with preoperative values per se. The comparison with normal values of the body composition of this heterogeneous group of patients with heart disease are actually surprisingly similar to those that have been made by other investigators.6,9

The isotopic dilution technics used are open to the usual criticisms of such methods, but probably are adequate for studying the changes in question. Others have accepted these technics as valid for study of patients with heart disease.6,9,10 The equilibration time for each isotope was selected on the basis of previous studies. The measurement of red cell mass with 51Cr is generally accepted as valid, and no delay in equilibration has been found after intracardiac surgery (unpublished observations from this laboratory). Previous study showed no delay in equilibration of radioiodinated serum albumin after open intracardiac operations,11 and a comparison of preoperative and postoperative plasma volume by this technic, therefore, is valid. We have previously studied the equilibration curves of injected tritiated water and have found them to be the same postoperatively as preoperatively (unpublished studies by Cain and Friedman from this laboratory). Studies have not been made of possible delay in equilibration of 24Na in the early postoperative period.

An equilibration period of 24 hr for measurement of exchangeable potassium was recommended by Corsa et al.12 and has generally been used by others since. Examination of the curves published by Moore and colleagues supports the idea that this is an adequate period although it gives a value slightly less than that after 40 hours.13 Exchangeable potassium values calculated from the last two periods of urine collection used in this study (26 to 28 and 28 to 30 hr after injection of 42K) are not statistically significantly different from those calculated from the urine collected 24 to 26 hr after injection preoperatively, and thus equilibra-
tion seemed virtually complete. Postoperatively, the values calculated from the urine collected 26 to 28 hr after injection were significantly larger than those calculated from urine collected 24 to 26 hr after injection, but those calculated from urine collected 28 to 30 hr afterward were not. There is, therefore, no evidence of delayed equilibration. When mean values and differences were calculated from the last period of urine collection, they were similar to those obtained using the mean of the three collection periods (table 6).

$^{82}$Br has been extensively used for the measurement of the volume of extracellular fluid, although some cellular penetration probably occurs. Change in the shape of the early part of the dilution curve occurs early after surgery, but Breckenridge and associates have shown that equilibration is nonetheless virtually complete 8 hr after injection of $^{82}$Br both preoperatively in patients with heart disease and early after open intracardiac operations. These authors also measured changes in the volume of extracellular water before and early after intracardiac surgery using simultaneously a constant infusion technique with the nonelectrolyte marker inulin and $^{82}$Br by the usual technique. As found by others the volumes measured by the marker inulin were smaller than those measured with $^{82}$Br, but the actual increases in volume between preoperative and early postoperative measurements by the two markers were nearly identical. Considerable confidence exists then that the changes in extracellular fluid reported in the present study are real. Confidence in the individual measurements in this study is enhanced by the fact that there was a close preoperative and postoperative relation between cation space and total body water.

### Table 6

**Comparison of Individual and Mean Values for $K_e$ (mEq)**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Preoperative*</th>
<th>Postoperative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24-26 hr</td>
<td>26-28 hr</td>
</tr>
<tr>
<td>1</td>
<td>2140</td>
<td>2098</td>
</tr>
<tr>
<td>2</td>
<td>2190</td>
<td>2266</td>
</tr>
<tr>
<td>3</td>
<td>2142</td>
<td>2333</td>
</tr>
<tr>
<td>4</td>
<td>1742</td>
<td>1873</td>
</tr>
<tr>
<td>5</td>
<td>1556</td>
<td>1509</td>
</tr>
<tr>
<td>6</td>
<td>1269</td>
<td>1290</td>
</tr>
<tr>
<td>7</td>
<td>1265</td>
<td>1221</td>
</tr>
<tr>
<td>8</td>
<td>3055</td>
<td>3375</td>
</tr>
<tr>
<td>9</td>
<td>2385</td>
<td>2702</td>
</tr>
</tbody>
</table>

| Mean§  | 2289           | 2231          | 2062    | 2020 |          |          |          |      |
| $\mu \pm SD$ | $\pm 787$ | $\pm 740$ | $\pm 700$ | 642 |          |          |          |      |
| Mean change (mEq) | 9.3 | 8.3 | $<0.01$ | 0.01 |          |          |          |      |
| Mean change (%) | 9.3 | 8.3 | $<0.01$ | 0.01 |          |          |          |      |

* $hr$ = urine collected and measured 24-26 hr after injection of $^4$K, etc.
† Samples improperly collected and therefore not measured.
‡ Mean values for the changes are averages of paired differences.
§ Values are based on all 13 patients.
with the slope of the regression equation relating them being nearly 1; and that average total body cation concentration (Na⁺ + K⁺/TBW) was similar to the sum of the determined concentrations of serum sodium and potassium. The latter finding also supports the idea that average intracellular and extracellular cation concentrations are similar, both preoperatively and postoperatively.

Acute changes in the distribution of body water do occur early after intracardiac surgery as it is usually done, according to the results of this and other studies. Total body water a few hours after operation, 24 hr after operation, and in the present study 48 hr after operation has not been found to be statistically significantly different from that before operation. The idea that in fact total body water is somewhat increased at these times is nonetheless given by the fact that most studies do show a mild but variable increase. All studies demonstrate a significant increase in the volume of extracellular water and particularly of interstitial fluid at these periods, compared with the preoperative volume. Comparison of the various studies indicates that the increase is greater 24 hr after operation than 48 hr after it. The reduction in the volume of extracellular and interstitial fluid between 24 and 48 hr is probably primarily the result of the diuresis that usually occurs at this time, and when diuresis does not occur, the volume of extracellular fluid can be expected to remain elevated. Estimations of changes in the volume of intracellular water by the rather gross method of subtracting the volume of extracellular fluid from that of total body water have not provided evidence for a significant change from the preoperative volume at these periods. Recent studies by Flear et al. suggest that cells do swell after trauma and major surgery.

The patient's unsteady state in the early postoperative period is evidenced by the finding in other studies of increased interstitial fluid 24 hr after operation and decreased plasma volume. The distribution of intravascular and extravascular extracellular fluid has been altered by some mechanism not yet identified. By the second postoperative day, in this study, plasma volume was not significantly different from the preoperative volume. By 2 weeks after operation, when elevated jugular venous pressure is often apparent in such patients, plasma volume is often increased over the preoperative value, and by an amount proportional to the increase in extracellular fluid.

Exchangeable sodium is significantly increased during at least the first 3 days after operation. Since virtually no sodium was given to the patients orally or intravenously between the preoperative and postoperative study, the uptake of sodium and postoperative study, the uptake of sodium was measured to be constant during the time when there was a circulatory system common to the patient and the pump oxygenator with its large and different "intravascular volume." Presumably, the increase in volume of extracellular fluid occurred at the same time. The absence of significant change in serum sodium concentration suggests that the increase in water, nearly all of which was extracellular, was generally appropriate to the increase in exchangeable sodium. The precise explanation for the presumed removal of sodium and water by the subject from the perfusate circulated through its vascular system by the pump oxygenator is not clear. The plasma colloidal osmotic pressure was no doubt reduced initially by the diluted perfusate. Some anoxia of the capillary walls may have increased their permeability to albumin and allowed it to leak out of the vascular system. Both of these factors may have contributed to the movement of water and sodium out of the intravascular compartment during and for some hours after cardiopulmonary bypass. This same phenomenon tends to occur during artificial perfusion of isolated organs. The persistence of the increase in exchangeable sodium to the third postoperative day implies minimal sodium excretion in the early postoperative period. This same conclusion was reached in a previous study, in which patients undergoing aortic valve replacement were found to excrete an average
of 12 mEq/24 hr in the first 3 days after operation in contrast to 55 mEq/24 hr preoperatively.23

The data from this investigation indicate that exchangeable potassium is less 3 or 4 days after cardiopulmonary bypass than it was preoperatively. A recent study by Clark and colleagues,24 in which whole body potassium was measured by use of a total body counter, showed a decrease in whole body potassium of about 200 mEq between the preoperative study and that 48 hr later, a value similar to that in the present study. The reduction is probably the result of urinary loss of potassium in the early postoperative period. Previous studies have shown potassium in the amounts of 50 to 100 mEq/24 hr is excreted in the urine in the early days after open intracardiac surgery.23, 25 This could be a primary renal event resulting from neurohumeral mechanisms set in motion by operation or the result of liberation of potassium from cells and its subsequent and secondary excretion by the kidney. The latter hypothesis seems more likely. The study by Clark and colleagues suggests that the decrease of total body potassium early postoperatively is not greater than that occurring after other major surgical procedures, but this issue is not settled.

The calculated postoperative intracellular concentration of potassium is less than the preoperative value. Presumably, the intracellular concentration of sodium has increased by an amount similar to the decrease in potassium. Such derived data are subject to large errors. Nonetheless, reduction in intracellular potassium concentration in very stressful situations is suggested by other studies. The movement of sodium into, and potassium out of, cells is suggested by the studies of Flear and Crampton in heart failure26 and by Flear et al.20 during major surgery. Cellular hypoxia and stress to the organism seem the possible common denominators in all these situations, and it has been suggested that these result in alterations of permeability of cell membranes.27 Tissue analysis technics are required for further analysis of this problem.

It is tempting to suggest that both the preoperative and postoperative values for intracellular potassium concentration are too low to be real, and they may be. However, if exchangeable potassium is being underestimated, then exchangeable sodium is being overestimated since there is such close agreement between cation space and total body water, and between total cation concentration and the sum of the concentrations of serum sodium and serum potassium. This seems unlikely. Also, the ratio Na+/K+ of 1.34 preoperatively and 1.58 postoperatively is similar to Olesen’s value of 1.86 in the edematous cardiac patients9 (predicted normal being 0.92).

Some therapeutic implications evolve from these data. Since in the early postoperative period exchangeable sodium is large, sodium excretion is small, and the volume of interstitial and extracellular water large, no sodium should be given during the early postoperative period, and water intake should be only enough to cover known insensible water loss and minimally adequate urine flow. When there is a large urine flow during this period, no attempt should be made to quantitatively replace the water lost. If evidence of pulmonary edema or congestion develops, prompt treatment should include efforts to decrease total body sodium and water using a potent diuretic agent. If cardiac arrhythmias occur during the early postoperative period, consideration should be given to administering large amounts (up to 100 to 150 mEq/24 hr) of potassium intravenously in view of the decreased exchangeable potassium usually existing at this time.

The data also suggest that cardiopulmonary bypass by present technics results in abnormalities in the early postoperative period that can be clinically significant.

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ALTERATIONS OF BODY COMPOSITION


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ALBERT D. PACIFICO, STAN DIGERNESS and JOHN W. KIRKLIN

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