Water Metabolism after Cardiac Operations Involving a Gibbon-Type Pump-Oxygenator

I. Daily Water Metabolism, Obligatory Water Losses, and Requirements

By George S. Sturtz, John W. Kirklin, Edmund C. Burke, and Marschelle H. Power

Daily water metabolism of 21 patients was studied for 3 days after intracardiac surgery and whole-body perfusion. The average obligatory water losses of these patients were approximately 500, 750, and 750 ml. per M.² of body surface per day on the first, second, and third postoperative day, respectively. A simple system, which combines knowledge of the estimated postoperative water requirement with the known daily change in body weight, was devised to manage accurately water metabolism after intracardiac surgery.

The purpose of this investigation was the determination of the daily water metabolism, the daily obligatory water losses, and the daily water requirement in children subjected to cardiac operations involving extracorporeal circulation of blood through a Gibbon-type pump-oxygenator.

All components of daily water metabolism—water input, metabolic water,!* urine output, insensible water loss, and abnormal losses such as those from thoracic-tube drainage and emesis—were determined. From these data the daily water balance was calculated.

However, our prime interest centered upon the measurement of the daily obligatory water losses, which were the obligatory urine water, the insensible water loss, and the abnormal losses. The obligatory water losses may be defined as those that occur at a constant rate irrespective of the body's state of hydration. Gamble,² in his studies of life-raft rations, emphasized the obligatory nature of the insensible water loss and the urine water loss; these losses occurred in thirsting and fasting subjects despite the body's need for water conservation. In the postoperative patient abnormal losses, such as those from thoracic-tube drainage and emesis, must be regarded as obligatory losses. The daily obligatory water losses together represent the amount that would be lost on a postoperative day if a patient received no water. Hence, we have assumed that the amount of the daily obligatory water losses (minus the metabolic water) is a reasonable estimate of water need on a given day in our postoperative patients.

Incidental to our main objectives was an evaluation of the concentration of water in the serum.³,5 We wished to learn whether such an evaluation would offer a reliable method of determining the status of body water in our patients.

Materials and Methods

Twenty-one children who underwent a cardiac operation were studied. Extracorporeal circulation by means of a Gibbon-type pump-oxygenator⁶ was carried out in each case (table 1).

Anesthesia was induced in each patient with cyclopropane; tracheal intubation was carried out after the induction. During operation the patient was maintained at a light level of anesthesia with ether and oxygen. Preoperatively, each patient received a small dose of pentobarbital sodium (Nembutal), and morphine sulfate in a dose of 1.0 mg. per 10 pounds of body weight. Operation was carried out with the patient supine. Exposure was obtained through bilateral anterior thoracotomy. Potassium asystole was induced in 18 of the 21 patients.

All balance studies were carried out in the Domitilla Cardiovascular Unit of Saint Mary's Hospital.

From the Mayo Clinic and the Mayo Foundation, Rochester, Minn. The Mayo Foundation, Rochester, Minn., is a part of the Graduate School of the University of Minnesota.

Abridgment of portion of thesis submitted by Dr. Sturtz to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Master of Science in Pediatrics.

* The term “metabolic water” includes the water of oxidation and the preformed water of catabolized protein, fat, and carbohydrate.¹

Circulation, Volume XVI, December 1957

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The unit was staffed by graduate nurses, one of whom was in attendance at all times during the study of each patient.

Each patient was in an oxygen tent throughout the study. The tent was filled with water mist generated by 2 Mist O₂, Gen* units.

Each patient was studied for 72 hours from the start of the operation. The patient was covered by a sheet during the study period, and no clothing was worn. The room temperature was 75 to 78 F. The studies were conducted between October 1, 1956, and February 14, 1957. All children operated on during this period were studied and the data on each of them are included in this paper.

Each patient was weighed nude each morning of the study period. The first weight of each patient was obtained in the operating theater at the end of the operation. Appropriate deductions were made for thoracic catheters, urethral catheters, bandages, intravenous catheters and needles, and clamps used to occlude the catheters during weighing.

Body weights were determined on 2 scales, 1 in the operating theater and 1 in the cardiovascular unit. Each of these scales was accurate to within ±0.1 Gm.

Blood was drawn from each patient before and after extracorporeal circulation, and 4, 7, and 10 hours after the end of operation. We attempted to obtain a blood sample every 12 hours but this was not always feasible in these severely ill patients. The blood samples drawn during the first 2 days of each study were obtained from a catheter whose tip was in the inferior vena cava. Blood samples drawn on the third day of study were usually obtained from the superficial veins of the arm. Two milliliters of serum from each blood sample were used to determine the osmolality by freezing-point depression with a Fiske osmometer. The osmometer was calibrated with known molar solutions of sodium chloride; measurements of osmolality† were thus expressed as equivalent to milliosmols of sodium chloride per 1,000 Gm. of water.

† The term in common usage “osmolality” has been employed in this paper in preference to the more accurate term “osmolality.”

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Table 1.—Data on the Twenty-One Children in this Study

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (years)</th>
<th>Height (cm.)</th>
<th>Weight (Kg.)</th>
<th>Surface area, M²</th>
<th>Anatomic diagnoses</th>
<th>Operation, (hr:min.)</th>
<th>Perfusion (min.)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>119</td>
<td>20.7</td>
<td>0.8</td>
<td>Ventricular septal defect</td>
<td>4:00</td>
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</tr>
<tr>
<td>2</td>
<td>5</td>
<td>113</td>
<td>18.0</td>
<td>0.8</td>
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<td>3:55</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>104</td>
<td>14.8</td>
<td>0.7</td>
<td>Atrial septal defect; pulmonary stenosis, valvular</td>
<td>3:40</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>142</td>
<td>33.8</td>
<td>1.2</td>
<td>Ventricular septal defect; subacute bacterial endocarditis, healed</td>
<td>3:45</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td>14</td>
<td>163</td>
<td>45.2</td>
<td>1.5</td>
<td>Congenital aortic stenosis, valvular</td>
<td>4:30</td>
<td>37</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>145</td>
<td>36.6</td>
<td>1.2</td>
<td>Ventricular septal defect</td>
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<td>21</td>
</tr>
<tr>
<td>7</td>
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<td>4:10</td>
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<td>0.5</td>
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<tr>
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<tr>
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<tr>
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<td>117</td>
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<td>123</td>
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<td>18</td>
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<td>3:45</td>
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<td>19</td>
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<td>1.0</td>
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<td>71</td>
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<tr>
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<td>1.0</td>
<td>Ventricular septal defect</td>
<td>4:45</td>
<td>61</td>
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</table>

* Mist O₂, Gen, Mist Equipment Co., Oakland, Calif.
Urine was collected by means of a retention catheter in the bladder, which was connected by plastic tubing to a glass bottle. The first urine-collection period was 11 hours, the second 7 hours, and the rest 6 hours each. In 4 cases all collections of urine were at intervals of 6 hours. The output of urine was measured at the end of each collection period in glass cylinders calibrated in 10-ml increments. Two milliliters of urine from each collection period were used to determine osmolarity.

Stools occurred only twice in the 60 patient-days of study. On each occasion the amount passed was very small and its weight was estimated. Amounts of vomited material of less than 15 ml were estimated. Larger volumes were measured.

Blood loss was replaced volumetrically throughout the postoperative period. A careful record was kept of the hourly blood loss and blood replacement; the cumulative balance was recorded hourly. Thus blood balance was accurately known during the period of study and proved not to be a factor in the water balance.

Thoracic-tube drainage was included in the abnormal losses only when it was serous and when it was not replaced with blood. No sweating was observed at any time during the study of any patient in this series; if sweating did occur, this loss is included in the insensible weight loss. Surface area was calculated from nomograms constructed from the equation of Du Bois and Du Bois. All water-balance data in this paper are expressed in terms of 1 M² body surface per 24 hours.

The input of water was predominantly by the intravenous route. Only on rare occasions was a patient allowed any water by mouth during the course of the 72-hour study. All intravenously given fluid consisted of 5 per cent solution of dextrose in water; any fluid given orally was tap water. No electrolyte or solid food was given at any time to any patient during the course of study. The volume of intravenously administered fluid was measured by means of the scale on the side of the bottle. All fluid given was assumed to weigh 1 Gm. per ml. The first study period was usually 20 hours. The data of this period were corrected to 24 hours. There were 21 first-day studies, 20 second-day, and 19 third-day. One patient died 46 hours postoperatively. The urine collection of the third day of 1 patient was lost.

Calculations. The concentration of water in the serum or urine was calculated by dividing 1,000 ml. of water by the number of milliosmols (m-osm.) in the sample; the units of the answer were milliliters of water per milliosmol of solute. The equation is thus

\[
\text{serum or urine water concentration} = \frac{1,000 \text{ ml.} H_2O}{\text{milliosmols}}.
\]

The total excretion of urine solute was calculated by multiplying the urine volume (ml.) by the urine osmolarity (m-osm./1,000 ml.). The equation is

\[
\text{urine volume (ml.)} \times \text{urine osmolarity (m-osm./1,000 ml.)} = \text{total urine-solute excretion (m-osm.).}
\]

Obligatory urine water was calculated on the assumption that the average minimal concentration of water in the urine of a postoperative patient who does not have renal or endocrine disease is 1.0 ml./m-osm. of urine solute. This figure was selected since it represents the average minimal value in our group of patients (section C of figs. 1 to 10). Gamble found 0.7 ml./m-osm. as the obligatory urine water of patients who we maintained without fluid intake for 96 hours. We believe our figure is physiologically more appropriate in postoperative patients. The equation is

\[
\text{urine solute (m-osm.)} \times 1 \text{ ml./m-osm.} = \text{ml. of obligatory urine H}_2\text{O}.
\]

The difference between the total volume and the obligatory volume of urine represents the free water in the urine.

In this study the volume of the urine was assumed to be identical with the volume of the water; no correction was made for solids in the urine. This introduced a small systematic error in the data.

The insensible weight loss was determined by the method of Newburgh and associates. The insensible water loss was assumed to be 90 per cent of the insensible weight loss. The metabolic water was calculated for each day of study of 4 patients. This was achieved after the directions of Newburgh and associates.

**Results**

Daily Water Metabolism (Section F of figs. 1 to 10). The input of water ranged between 440 and 1,620 ml. per M.² per day. It was usually 600 to 900 ml. Water inputs greater than 1,000 ml. occurred generally on the third day of study in patients who were progressing satisfactorily (figs. 1, 4, 6–8). One patient (fig. 9) received 1,020 ml. per M.² per day during the first day of study to facilitate the administration of norepinephrine.

Metabolic water was assumed to be 270 ml. per M.² per day, except for 4 patients for whom urinary nitrogen data were available. Calculation of metabolic water for these patients (12 periods) on the assumption that intravenously administered glucose represented carbohydrate burned, gave values rang-
Fig. 1 (case 2). Note excess water input on the third day and the associated increased concentration of water in the serum and urine. Free urine water composed most of the third day's output of urine.

Fig. 2 (case 5). There were a large volume of urine, considerable free urine water, and an increased concentration of water in the urine during the last 24 hours of the study.

The output of urine ranged from 110 to 1,170 ml. per M. per day. During most days of study, the output was directly dependent on the amount of solute excreted (D and E of fig. 5). However, some patients who received a moderate water load had an increased volume of urine due to considerable free urine water on the third day of study (figs. 1–3).

The abnormal losses were generally small. On some days there were no abnormal losses.
FIG. 5 (case 8). Water balance was maintained adequately throughout the study period. Note the low concentration of water in the urine and the almost complete absence of free urine water. The volume of urine was for the most part dependent on the amount of solute excreted.

Occasionally these losses were quite large (figs. 6 and 8).

The mean value for insensible water loss was 469, 420, and 321 ml. per M.² per day on the first, second, and third day, respectively (table 2).

FIG. 6 (case 10). Although negative water balance was present on each day, the concentration of serum water rose progressively. The low concentration of urine water and the small amount of free urine water suggest nearly maximal conservation of renal water.

During 60 patient-days of study the calculated water balance ranged between a negative balance of 490 ml. per M.² per day and a positive balance of 570 ml. per M.² per day (section F of figs. 1 to 10; the patient with a
positive balance of 570 ml is not represented in the figures). There was a fair correlation between the calculated water balance and the water balance determined by daily body weights. Calculations suggested that body water was maintained within ±2 to 3 per cent of the previous day's status during most periods of study.

In the course of determining the insensible weight loss, the body weight of each patient was determined immediately after operation and each day thereafter. The body weight decreased during 55 of the 60 study periods. Most patients lost approximately 200 to 400 Gm. per M.² per day (section A of figs. 1 to 10). However, 5 patients were observed to gain weight during a study period, 4 of whom are represented (section A of figs. 4, 8–10), and water-balance calculations in each instance revealed that the patient was in positive water balance of approximately 500 ml per M.² per day (section F of figs. 4, 8–10).

It was estimated during the calculation of metabolic water that the patients were catabolizing approximately 150 Gm. per M.² per day of body solids. Taking this factor into consideration, we were able to estimate the water balance by means of the daily change in body weight. For example, a patient who lost 400 Gm. per M.² per day was estimated to be in negative water balance of 250 Gm. per M.² per day, while a patient who gained 400 Gm. per M.² per day was estimated to be in positive water balance of 550 Gm. per M.² per day. Thus the water-balance data derived by determining the gains and losses of water (section F of figs. 1 to 10) were checked against the water-balance data derived by the daily change in body weight (section A of figs. 1 to 10). There was a fair correlation between these 2 estimates.

Daily Obligatory Water Losses. The mean value for urine-solute excretion was 294, 465, and 548 m-osm. per M.² per day on the first, second, and third postoperative day, respectively (table 3). Thus the mean value for obligatory urine water was 294, 465, and 548 ml per M.² per day on the first, second, and third postoperative day, respectively.

The mean value for insensible water loss was 469, 420, and 321 ml per M.² per day on
Table 2.—Insensible Water Loss (Milliliters per Square Meter per Day)

<table>
<thead>
<tr>
<th>Case</th>
<th>Postoperative day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>850</td>
</tr>
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</tr>
<tr>
<td>20</td>
<td>650</td>
</tr>
<tr>
<td>21</td>
<td>750</td>
</tr>
</tbody>
</table>

Mean: 469 ± 49  420 ± 30  321 ± 31
Standard deviation: ±224  ±135  ±133

Table 3.—Excretion of Urine Solute (Milliosmols per Square Meter per Day)

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</tr>
</thead>
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<td>20</td>
<td>470</td>
</tr>
<tr>
<td>21</td>
<td>60</td>
</tr>
</tbody>
</table>

Mean: 294 ± 23  465 ± 33  548 ± 30
Standard deviation: ±106  ±146  ±130

The first, second, and third postoperative day, respectively (table 2).

The abnormal losses were small in most patients. However, we arbitrarily assumed them to be zero on the first postoperative day and 150 ml. per M.² per day on the second and the third day. The reason for this assumption will be mentioned.

Daily Water Requirement. The problem of water requirement was approached by assuming that the daily obligatory water losses represented a reasonable starting point for estimating the amount of water needed. A simple equation was derived that the volume of daily water need equals the obligatory urine water plus the insensible water loss plus the abnormal losses minus the metabolic water (which is a gain in available body water). Thus, if V represents the volume of daily water need, Ouw the obligatory urine water, IW the insensible water loss, AL the abnormal losses, and MW the metabolic water (water of oxidation and preformed tissue water), then

\[ V = OUW + IW + AL - MW. \]

All the above symbols have as their units ml. per M.² per day. The metabolic water was assumed to be 270 ml. per M.² per day for each day of study. The abnormal losses were arbitrarily assumed to be zero in the calculation of the first day's obligatory losses; this was done to aid in achieving slight negative water balance on this very important day. The abnormal losses were arbitrarily assumed to be 150 ml. per M.² per day on the second and third days; this is a reasonable approximation of what was found in this group of patients.

Substituting into the formula the data of the first 24 hours yields:

\[ V = OUW + IW + AL - MW \]
\[ V = 294 + 469 + 0 - 270 \]
\[ V = 493 \text{ ml. per M.}^2 \text{ per day.} \]
It is thought that 500 ml. per M.\textsuperscript{2} per day represents a reasonable estimation of the amount of water patients similar to these would need in the first 24 postoperative hours to keep them near zero water balance, provided there were no abnormal losses. If abnormal losses do occur they will place the patient in negative water balance, which seems most desirable on this day.

Substituting into the formula the data of the twenty-fourth to the forty-eighth hour yields:

\[ V = OUW + IW + AL - MW \]
\[ V = 465 + 420 + 150 - 270 \]
\[ V = 765 \text{ ml. per M.}^2 \text{ per day.} \]

Substituting into the formula the data of the forty-eighth to the seventy-second hour yields:

\[ V = OUW + IW + AL - MW \]
\[ V = 548 + 321 + 150 - 270 \]
\[ V = 749 \text{ ml. per M.}^2 \text{ per day.} \]

We have rounded off the estimate of water needs to 750 ml. per M.\textsuperscript{2} per day for the second and third days. It is thought that this figure represents a reasonable estimation of the amount of water patients similar to these would need on the second and third postoperative days to keep them near zero water balance. The estimation of abnormal losses that were added to the calculations for the second and third days simplifies clinical management; it saves volumetric addition to the daily water input as abnormal losses occur.

*Serum Water Concentration (Section B of figs. 1 to 10).* The concentration of water in the serum was very low immediately after perfusion. It returned to normal within 12 hours in every case except 1. This phenomenon will be discussed in a subsequent paper.\textsuperscript{10}

There was considerable variance between the balance data and the serum water concentration in certain patients. One patient was in negative water balance during each 24-hour period of study. Yet the water content of his serum rose gradually throughout the study (fig. 3). Another patient was in negative water balance for the study period as a whole; his serum water concentration rose steadily throughout the study. A patient who was in positive water balance during the first 48 hours of study showed little variability of his serum water content (fig. 10). A rise of serum water concentration to the upper physiologic limit was observed in a patient who was in marked negative balance throughout the study (fig. 6). A value at the upper physiologic limit was noted during the fiftieth hour of study in a patient who was in slight negative balance for the first 48 hours of study (fig. 7). An abnormally low value was found in 1 patient at the fiftieth hour of study; this patient was in positive water balance during the first 48 hours of study (fig. 9).

Since some patients exhibited increased serum water in the face of negative water balance, while others showed unchanged or even decreased serum water with positive water balance, it seems that serum water in this group of patients was not a reliable reflection of the status of body water.

*Urine Water Concentration (Section C of figs. 1 to 10).* The concentration of water in the urine of most patients remained close to 1.0 ml. per m-osm. during the first 36 hours of study (section C of fig. 5). It was slightly more than this value after the perfusion of some patients (fig. 7). No high values for urine water content were observed during the first 36 hours of study. Some patients who received a moderate water load on the third day of study had a rise in their urine water concentration (section C of figs. 1 and 2). A few patients (section C of figs. 9 and 10) had values for urine water content of more than 1.0 ml. per m-osm. throughout the study.

**Discussion**

*Daily Water Metabolism.* Some of our patients received a water input greater than 1,000 ml. per M.\textsuperscript{2} per day. This seems to be an excessive amount in light of our measurements of obligatory water losses and calculations of the daily water requirement. We no longer administer large amounts of water to such patients.
Although our calculations of metabolic water are in approximate agreement with previously published figures, the many variables affecting this calculation suggest acceptance of the results with caution. The assumption of Newburgh and others that 25 per cent of total energy output is represented by vaporization of water was derived from data collected under controlled environmental conditions. In the humid atmosphere surrounding our patients, dissipation of heat by vaporization of water was probably somewhat less than that observed under conditions of lower humidity. Such being the case, our values for metabolic water are underestimations of unknown degree. These do not, however, seriously affect the final calculations of water balance.

The data on output of urine (section D of figs. 1 to 10) reveal that most patients in the first 36 hours of study excreted predominantly obligatory urine water, that is, urine with an osmolarity of approximately 1,000 m-osm. per l. and a specific gravity of 1.025. This is strong evidence of antidiuresis during this time. It appears that such patients would tolerate poorly a large water load during this time.

Thirst was a striking symptom in almost every child in this series. It was present in most patients, even those who were in positive water balance. It is felt that thirst is an unreliable symptom. Wynn's observation of thirst among patients with water intoxication substantiates our observation.

Although our prime objective in this investigation was to determine the daily obligatory water losses, we found the daily change in body weight a very useful clinical means of assessing a patient's water balance. It is our opinion that the daily change of body weight was the simplest, the most nearly accurate, and the most informative method of evaluating water balance. As soon as a patient was weighed in the morning it was possible to determine the change in body weight from the previous day. By assuming that 150 Gm. per M.2 per day of body solids were catabolized it was possible to estimate immediately the water balance.

Daily Obligatory Water Losses. The daily obligatory urine water is determined by the amount of solute excreted. Previously reported data suggest that the excretion of urine solute is about 200 m-osm. per M.2 per day in patients receiving adequate amounts of water and dextrose. Thus the much larger excretion by our patients seems unusual; it may be related to the surgical trauma or to the relief of heart failure. Our unpublished observations on children following other types of operation suggest that the increase in urine-solute excretion is probably a normal physiologic accompaniment of operation.

The mean value for insensible water loss for all periods of study was 406 ml. per M.2 per day. This figure is approximately 50 per cent of that reported by Heely and Talbot in their comprehensive study of hospitalized children. No single value greater than 850 ml. per M.2 per day was encountered in our 60 study periods (fig. 11).

Every patient was in an oxygen tent throughout the period of study; the tent was filled with water mist generated by 2 Mist O2 Gen units. It is probable that the vapor pressure of the water in the tent was nearly 100 per cent saturated for the tent temperature. It is also probable that some particular, liquid water generated by the 2 Mist O2 Gen units was retained in the lungs. It is theoretically possible to block completely all pulmonary loss of water, or to gain water via the lungs, if the air is warm enough and the water vapor pressure is high enough. Thus it is thought that our data on
insensible water loss are not a measure of the
water of vaporization alone; rather they reflect
the loss of vaporized water minus the liquid,
particulate water gained via the lungs.

One group of investigators decreased mark-
dedly the insensible weight loss of newborn in-
fants by placing them in an "atmosphere super-
saturated with water."13 They were able to show
that the decrease in insensible weight loss was
due to a decrease in pulmonary water loss. Other investigators14 showed that the insensible
water loss decreased about 40 per cent when
the relative humidity was raised from 20 per
cent to 80 per cent. Both of these studies
suggest that our low values for insensible water
loss may have been the result of the large
water content of the atmosphere within the
oxygen tent.

Daily Water Requirement. It may be said
that our estimations of daily water need are
only mean values; therefore, the variability of
the daily losses in this series suggests that one
cannot achieve accurate water balance in any
given patient. This statement is a truism. One
cannot predict the daily losses in a particular
patient before they occur. However, the use of
a mean value is the best available method for
estimating water need in a particular type of
patient.

The use of the estimated daily water require-
ment together with the daily change in body
weight makes accurate water balance possible
in patients such as ours. For example, a patient
may be noted to gain 200 Gm. per M.2 per day
of body weight on the first postoperative day.
Since approximately 150 Gm. per M.2 per day
were lost by the catabolism of body solids and
were replaced by water, it can be estimated that
the patient was in positive water balance
of approximately 350 ml. per M.2 per day.
Knowing this, one would be inclined to give
about 450 ml. per M.2 per day of water on the
second day instead of 750 ml. per M.2 per day.

Or another patient may be noted to lose
1,000 Gm. per M.2 per day of body weight on
the first postoperative day. Since approxi-
mately 150 Gm. per M.2 per day were lost
as catabolized body solids, it can be estimated
that the patient was in negative water balance
of approximately 850 ml. per M.2 per day for
the first day. This is 500 to 600 ml. per M.2 per
day more than was desired. One should add
500 to 600 ml. per M.2 per day of water to the
estimate of water need for the second day
which is 750 ml. per M.2 per day. Thus, the
amount of water would be 1,250 to 1,350
ml. per M.2 per day for the second day.

We have found that the technic of combining
knowledge of the estimated water requirement
with knowledge of the daily change in body
weight is an invaluable aid in the daily manage-
ment of water metabolism after cardiac opera-
tions involving extracorporeal circulation.

SUMMARY

Various aspects of water metabolism were
studied in 21 postoperative patients who had
undergone intracardiac operations using extra-
corporeal circulation.

The body weight decreased daily in most of
the patients. The usual weight loss was 200
to 400 Gm. per M.2 of body surface per day.
The concentration of water in the serum was
found to be low immediately after perfusion
and it returned to normal in 7 to 10 hours. A
disturbing lack of correlation between the
serum water concentration and the water-
balance data was noted. The concentration of
water in the urine remained near its minimal
value in the first 36 postoperative hours in
most cases. It remained in this range during
the final 36 hours except in these patients who
received a moderate water load. Metabolic
water was found to be 276 ml. per M.2 per day
as a mean value for 12 study periods; this cal-
culation is considered to represent an approxi-
mation only. The output of urine was almost
to entirely obligatory urine water except in a
few patients who received a moderate water
load on the third day of study. The obligatory
urine water was 294, 463, and 548 ml. per
M.2 per day on the first, second, and third day,
respectively. The insensible water loss averaged
406 ml. per M.2 per day for 60 study periods.
The small insensible water loss was presumed
to be related to a decreased pulmonary water
loss and possibly decreased skin evaporation.

A simple equation was derived to estimate
the daily water need. The water input neces-
sary to maintain balance was calculated to be
500, 750, and 750 ml. per M.² per day for the first, second, and third postoperative day, respectively.

It was considered that the body water was maintained within ±2 to 3 per cent of the previous day’s status during most days of study.

Conclusions

Patients similar to ours can be maintained in water balance with 500, 750, and 750 ml. per M.² per day of water input on the first, second, and third postoperative day, respectively.

The daily change in body weight is the simplest, the most nearly accurate, and the most informative method of evaluating postoperative water balance. A decrease in body weight of 200 to 400 Gm. per M.² per day in the first few postoperative days appears to be the most desirable course. Provided the body weight is measured daily, it is possible to manage adequately water balance in the usual patient after extracorporeal circulation without such determinations as the concentration of water in the serum and urine, the excretion of urine solute, and insensible water loss.

The serum water concentration is of little value in assessing the postoperative water balance of patients undergoing intracardiac operations involving extracorporeal circulation.

The symptom of thirst is not reliable in patients such as these.

Acknowledgment

It is a pleasure to acknowledge the splendid cooperation given to us by Sister Maristella and the nurses of the cardiovascular unit, by Miss Lenore Rivers and Miss Catherine Ryan, and by Drs. William S. Lyons, Theodore T. Myre, Dwight C. McGoon, Manly B. Levin, and Richard A. Lim.

Summario in Interlingua

Varie aspectos del metabolismo de aqua esseva studiate in 21 patientes postoperatori qui habeva esse subjecte a operationes intracardiac con le utilisation de un circulation extracorpore.

Le peso corporee decesceva de die in die in le majoritate del patientes. Le usual perdita de peso esseva 200 a 400 g per m² de superficie corporee per die. Esseva trovate que le concentration de aqua in le sero esseva base immediatemente post le perfusion e que illo retornava a valores normal in le curso de 7 a 10 horas. Esseva noteate un disquietante absentia de correlation inter le concentration de aqua in le sero e le datos del balancia de aqua. Le concentration de aqua in le urina remaneva in le vicinitate de su nivello minimal durante le prime 36 horas post le operation in le majoritate del casos. Illo remaneva in iste mesme vicinitate durante le proxime 36 horas (i.e. usque al fin del periodo studiate), excepte in patientes qui recipeva un moderate carga de aqua. Esseva constatate que le aqua metabolic amontava a un valor medie de 276 ml per m² per die super le base de 12 periodos studiate, sed iste calculation es considerate solmente como un approximation. Le excretion de urina consisteva quasi completamente de aqua urinari obligatorii, excepte in alcuin patientes qui recipeva un moderate carga de aqua le tertie die del studio. Le aqua urinari obligatorii amontava a 294, 463, e 548 ml per m² per die le prime, secunde, e tertie die, respectivemente. Le perdita insensible de aqua amontava a un valor medie de 406 ml per m² per die super le base de 60 periodos studiate. Iste bassa perdita insensible de aqua esseva presumibilemente relationate a un reduction del perdita pulmonar de aqua e possibilemente etiam a un reduction del evaporation cutaneec.

Esseva derivate un simple formula pro estimare le requirimento diurne de aqua. Le ingestione de aqua que es necessari pro mantenuer un balancia esseva calculate a 500, 750, e 750 ml per m² per die pro le prime, secunde, e tertie die postoperatori, respectivemente.

Esseva estimate que le aqua corporee esseva mantenite a intra ±2 a 3 pro cento del valores pro le ultimo die ante le operation durante le majoritate del dies includite in le studio.

Es concludite que patientes simile a illes del presente reporto pote esser mantenite in balancia de aqua per medio de un ingestione de 500, 750, e 750 ml per m² per die le prime, secunde, e tertie die postoperatori, respectivemente.

Le alteration diurne del peso corporee es le plus simple, le plus aproximativamente ac-
accurate, e le plus illuminante metodo pro evalu-
tar le balanzia de agua postoperatori. Un re-
duction del peso corporee per 200 a 400 g per
m² per die durante le prime dies post le opera-
tion pare representar le plus desirabile curso.
Si le peso corporee es constatate omne die, il es
possible regular de manera adequate le balan-
cia de agua in le patiente usuale emergente ab
operationes con utilisation de circulation extra-
corporee, sin recurso a determinationes del con-
centration de agua in le sero e le urina, del
excretion de soluto urinari, del perdita insensi-
bile de agua, etc.

Le concentration de agua in le sero es sin
grande valor in le evalutation del balanzia
postoperatori de agua in patientes subjicite a
operationes intracardiac con le utilisation de
un circulation extracorporee.

Le symptoma del sete non es digne de confi-
dentia in patientes de iste genere.

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Water Metabolism after Cardiac Operations Involving a Gibbon-Type Pump-Oxygenator: I. Daily Water Metabolism, Obligatory Water Losses, and Requirements

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_Circulation_. 1957;16:988-999
doi: 10.1161/01.CIR.16.6.988

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231

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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/16/6/988

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