during inspiration, thus increasing the efficiency of the functional hemidiaphragm. Finally, while an increase in the expiratory intercostal muscle tone will tend to decrease rib cage volume, by virtue of the linkage between the abdomen and rib cage postulated by Goldman and Mead,18 it may be that the increased expiratory abdominal pressure could tend to maintain rib-cage volume.

We conclude that in patients who can generate an adequate ΔP during an obstructed inspiratory effort, a trial of CPAP may permit time for functional recovery without the need of either IPPB ventilation or surgical diaphragmatic plication. Since there is no published information available to answer the question of whether surgical plication in the infant or child with a temporary hemidiaphragmatic paralysis may have long-term adverse effects on the normal growth and development of the lung, it appears prudent to refrain from surgical intervention until permanent injury is confirmed. With convincing evidence of phrenic-nerve injury causing permanent hemidiaphragmatic paralysis, surgical plication is indicated when it has also been demonstrated that the infant can do well with CPAP alone, i.e., the functional hemidiaphragm will allow adequate ventilation when the paralyzed hemidiaphragm is stabilized.

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Serum Potassium Levels Following Transfusion of Frozen Erythrocytes

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The role of frozen, deglycerolized erythrocytes is assuming greater importance in the management of patients receiving massive transfusions.1,2 Advantages cited by the proponents of frozen erythrocytes over blood with added citrate—phosphate—dextrose (CPD) are: longer shelf life,3 prevention of alloimmunization,4 decreased risk of transfusion hepatitis,5 and improved viability of function of erythrocytes.6 Hyperkalemia, which might occur with transfusion of stored CPD blood2 is noticeably absent with transfusion of frozen erythrocytes. Although it has been demonstrated that intracellular potassium levels in frozen, thawed, deglycerolized, and washed erythrocytes tend to decrease,8 serum potassium values in patients receiving frozen erythrocytes have not previously been reported. This investigation was undertaken to study the effect of transfusion of frozen erythrocytes on serum potassium values in patients who receive such transfusions.

MATERIALS AND METHODS

Twenty-eight adult patients, 11 women and 17 men, whose ages ranged from 48 to 61 (mean 54) years,
were studied. All the patients underwent radical resections of the gastrointestinal tract for cancer treatment, and they were free of respiratory, cardiovascular, hepatic and renal disease. The patients were not taking any drugs on a regular basis. The patients were randomly divided into two groups. Patients in Group I (n = 15) received CPD-preserved whole blood eight to 13 days old, and those in Group II (n = 19) received four-to-eight-month-old frozen, thawed, deglycerolized, and washed erythrocytes that had been frozen within 24 hours after harvesting from donors. Preoperative serum electrolyte, hemoglobin, blood glucose, and arterial blood-gas values were within normal limits in all patients in both groups. Anesthesia was induced with thiopental, 275 mg, iv, and tracheal intubation was facilitated with pancuronium, 8 mg. Anesthesia was maintained with nitrous oxide, 60 per cent, in oxygen, and fentanyl, given intravenously as needed. Ventilation was mechanically controlled to maintain arterial blood $P_{CO_2}$ values between 35 and 40 torr. Rectal temperature was continuously monitored and maintained between 36.5 and 37.5 C.

The patients in both groups received intravenous fluid therapy at a rate of 10 ml/kg/h for the first two hours and 6 ml/kg/h thereafter. The first two liters consisted of dextrose, 5 per cent, in lactated Ringer's solution only. All surgical procedures lasted at least five hours, with a mean duration of 6.4 hours. Every 30 min following induction of anesthesia, arterial blood samples were analyzed for $p$H, $P_{O_2}$, $P_{CO_2}$, serum sodium and potassium, glucose, hemoglobin, and hematocrit. Arterial blood $p$H, $P_{O_2}$, and $P_{CO_2}$ values were measured with a Corning 175 blood-gas machine; serum sodium and potassium with an Orion SS30, and blood glucose with a Yellow Springs 23A. When hematocrit decreased to 28 per cent, blood that had been warmed to 37 C by use of a blood warmer was transfused into the patient. All patients needed blood transfusions during the second to fourth hour of anesthesia, when blood loss was maximum. By four hours after the induction of anesthesia, blood loss was minimal, and blood transfusions were not given thereafter.

For comparison purposes, the values for arterial blood samples drawn 30 min following induction of anesthesia were compared with those for blood drawn four and a half hours after induction. The data were subjected to statistical analysis by use of the paired $t$ test for within-group comparisons and non-paired $t$ test and chi-square test comparisons between the two groups. Values are expressed as mean $\pm$ standard error of the mean ($\pm$SEM).

**RESULTS**

Patients in Group I received 3.8 (±0.2) units of stored CPD-preserved blood, while patients in Group II received 3.7 (±0.2) units of frozen erythrocytes. The amounts of blood transfused into patients in the two groups were not significantly different. Prior to transfusion, there was no significant difference between blood glucose, arterial blood $p$H, $P_{O_2}$, hemoglobin, and hematocrit, and serum sodium and potassium values in Group I and Group II. There was no significant change in blood glucose, arterial blood $p$H, $P_{O_2}$, $P_{CO_2}$, hemoglobin, or hematocrit, or serum sodium, before or after transfusion of CPD blood or frozen erythrocytes. The only significant
change was in serum potassium. In the patients in
Group I who received CPD-preserved blood, the post-
transfusion serum potassium level was not signifi-
cantly different from the pretransfusion level, while
in patients of Group II, who received frozen, thawed
erthrocytes, serum potassium levels were signifi-
cantly lower after transfusion. In four of 13 patients
in Group II, serum potassium values decreased to
less than 3 mEq/l. Two patients had serum potassium
values of 2.4 and 2.6 mEq/l, respectively, and ventricu-
lar premature beats developed in these patients.
Following the intravenous administration of potas-
sium chloride, 30 mEq/l, in 250 ml of dextrose, 5 per
cent, serum potassium values returned to normal, and
the dysrhythmias disappeared. Thus, four of 13
patients in Group II (31 per cent) needed supple-
mental potassium therapy, while no patient in Group
I needed potassium.

**DISCUSSION**

Storage of CPD-preserved blood at 4°C causes
egression of potassium ions from the erythrocytes
into plasma, reaching abnormal levels within the first
seven days of storage.\(^9\) Few of these potassium ions
re-enter the erythrocytes on rewarming to body
temperature.\(^10\) Following transfusion of this stored
blood, excess extracellular potassium ions may be
excreted by the kidney, re-enter the original erythro-
cytes, or pass into the erythrocytes, muscle cells or
other tissues of the recipient, or remain in the plasma
of the recipient.\(^11\) Thus, transfusion with CPD-
preserved blood might produce transient hyper-
kalemia in the recipient prior to redistribution of the
egressed potassium ions.\(^7\)

However, it has been shown that frozen, thawed,
deglycerized, washed and resuspended erythrocytes
have decreased levels of intracellular potassium.\(^8\)
The potassium content of erythrocytes is about 7
mEq/10^12 erythrocytes. In frozen, thawed, deglycer-
ized and washed erythrocytes, however, potassium
values have been as low as 4 mEq/10^12 erythrocytes.\(^8\)
When these erythrocytes are transfused into a patient,
potassium ions from the recipient's plasma could
move into these erythrocytes, which are low in intra-
cellular potassium, thereby decreasing the serum
potassium levels of the recipient. This investigation
demonstrates the occurrence of hypokalemia when
frozen, thawed erythrocytes are transfused into
patients with normal serum potassium levels. Other
factors known to influence serum potassium levels,
including alkalemia, hypocarbica, and blood glucose
differences, did not play a role in the effects seen in this
investigation.

The decrease in serum potassium following the
use of frozen erythrocytes could be more important
in patients needing massive blood transfusions to
maintain blood volume and oxygen transport, or in
premature infants and neonates, where exchange
transfusion is performed using frozen erythrocytes.

In conclusion, when frozen, thawed, deglycerized,
washed and resuspended erythrocytes are transfused,
serum potassium levels of the recipient should be
monitored, and if hypokalemia occurs, potassium
supplementation therapy should be instituted to
prevent the occurrence of dysrhythmias.

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