From the point of view of prognosis alternobaric vertigo itself seems to be essentially benign. However, because of its potentially deleterious effects all possible steps should be taken to avoid it—for example, diving should not be undertaken when the person has a cold, nor preferably immediately after a cold when it is more difficult than usual to clear the ears. The correct use of nasal decongestants is also recommended in cases where pressure equilibration is difficult despite the absence of recent infection. Great care should be taken always to keep pressure equilibration timed with external pressure change and to avoid unnecessarily rapid ascents and descents. Intermittent swallowing during ascent, though not necessary for pressure equilibration, may possibly facilitate it, thus further reducing the risk. Divers who are inclined to vertiginous reactions of the type described should avoid pressure exposures which make the use of stage decompression necessary.

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Summary

The occurrence of vertigo in connexion with external pressure variations has been studied among sport divers by means of a questionnaire.

The phenomenon, which is here called "alternobaric vertigo," appears from this investigation to be a serious potential menace to divers.

Some aetiological mechanisms and preventive or therapeutic measures which might prove important are discussed.

Appendix. Questionnaire

1. I *have/have not* undergone medical examination in connexion with diving. Date.....
2. The result *was/was not* satisfactory, owing to
3. In connexion with diving I have *always/often/seldom/never* had difficulties with pressure equilibration.
4. In case of difficulties with pressure equilibration I have *more/equal* difficulties with the *right (and) left* ear(s). I *usually/never/also/only* have difficulties with the *nasal sinuses/cheeks/forehead*.
5. To obtain pressure equilibration I *usually open the mouth* (move the jaw)/*swallow/blow against the clamped nose/do nothing special*.
6. When I dive I *always/often/occasionally/seldom/never* experience vertigo (a whirling sensation).

7. The vertigo usually appears *at the surface* (upon ascent)/*during ascent/during descent/at the bottom*. The greatest depth reached in dives in which vertigo was experienced wasmetres. (Not necessarily the same as the depth at which the vertigo appeared.)

8. The visibility in the water when the vertigo appeared wasmetres.

9. When I had vertigo I had *not/possibly/for certain* a ruptured *right/left* eardrum. I *wore/did not wear* a hood. I *can/cannot* induce vertigo by forced blowing against the clamped nose.

10. I *believe/do not believe* that the vertigo was due to sea-sickness. It *may/cannot* have been caused by breathing *impure air/food-poisoning/or*

11. When I had vertigo I *never/sometimes/always* wore breathing apparatus.

12. The vertigo I had was *very/rather/scarcely/not at all* troublesome. Mention if possible how many times you have had vertigo and how troublesome it was (e.g., difficulty in finding the way to the surface, swimming ashore, etc.)

13. When I dive I *always/often/occasionally/seldom/never* have nausea. The nausea is then *always/sometimes/never* connected with the vertigo mentioned above.

[A number of questions treating nausea as an entity separate from the vertigo were then put. The results will be presented in a separate publication.]

14. If you have had vertigo, mention how long it persisted and what you did to eliminate it

15. Additional information

[In an additional inquiry 15 of the subjects who had had vertigo (including some of the most serious cases) were asked for their experiences of vertigo on land.]

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Estimations of Blood Volume During Course of Renal Failure

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Oliguric renal failure may be associated with a considerable dislocation of the normal partitioning of the body fluids, but relatively few studies of such changes have been made in man. We have performed serial estimations of blood volume in 50 patients with oliguric renal failure. Observations were made throughout the course of the disease, and the effects of haemodialysis and of peritoneal dialysis have been observed. This paper outlines some of the results, which have provided

information on the fluid shifts occurring as a result of renal failure, and have also on occasion materially assisted in the management of these patients.

Method and Materials

An automatic isotope dilution technique was employed, using a machine, the Volemetron, which can be set for iodinated serum albumin, or chromated red cells, or both (Williams and Fine, 1961). Because of its greater simplicity, we have used iodinated

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serum albumin on most occasions. A result can be obtained at the bedside within 15 minutes as a direct dial reading. The accuracy of the machine is high; the error for a single determination is below 2%, and after five consecutive estimations is still less than 5% (Williams and Frank, 1962). Quantitative errors of volumetric measurement are eliminated by providing a direct assay of radioactivity, and the accuracy

FIG. 1.—Blood volume (B.V.) estimations before and immediately on starting dialysis are shown. In this and subsequent figures the red-cell volume (R.C.V.) is stippled and plasma volume (P.V.) clear. Blood added: 1,200 B.V., 516 R.C.V., 684 P.V. Calculation of blood added: 1,220 B.V., 520 R.C.V., 700 P.V.

is thus greater than that obtained from existing dye dilution and indirect radioisotopic methods, especially in repeated studies (Grep *et al.*, 1963). Our observations, both *in vitro* and in patients, confirm these levels of accuracy. A representative study is shown in Fig. 1. Blood volumes are compared before and immediately at the beginning of haemodialysis, when a known amount of blood has been added to the circulation. The close correlation between measured and calculated volumes is evident.

Results

The 50 patients studied were drawn from a larger group of 127 patients referred to our unit over a period of 18 months with acute or chronic renal failure. The majority (40) of the 50 patients were suffering from acute oliguric renal failure, seven had acute exacerbations of chronic renal disease, and three were treated by renal transplantation. The largest group (32) was of acute renal failure after operation or trauma. In all, 148 estimations have been performed on the 50 patients.

1. Shifts in Blood Volume During the Course of Acute Renal Failure

Patients with acute renal failure who are studied from the onset of their illness, if managed by suitable fluid and electrolyte restriction, will usually show a relative constancy of blood volume. Fig. 2 gives the results of serial studies in a woman aged 29 with cardiac arrest and renal failure due to haemorrhage from a central placenta praevia who was referred on the third day of oliguria. There has been minimal change in blood volume over the course of three haemodialyses, but the increase

FIG. 2.—Blood volumes are shown by the histograms and haematocrit levels by the circles. D1, D2, and D3 refer to times of haemodialyses.

in red-cell volume due to dialysis has caused a 13% rise in haematocrit to give acceptable levels of red-cell, plasma, and total blood volume at the end of the study, when diuresis was beginning.

2. Fallibility of Haematocrit or Haemoglobin Levels

The peripheral large vessel haematocrit or haemoglobin level cannot predict either the direction or extent of shifts in blood volume, and we have repeatedly observed, in both acute and chronic renal failure, relatively small shifts in blood volume associated with progressive and severe diminution in red-cell volume, with a falling haematocrit, unless this is corrected by haemodialysis or by transfusion. We have in such instances combined ultrafiltration with packed cell infusion during haemodialysis to restore red-cell mass without danger of circulatory overloading.

Case Report (Fig. 3).—A woman aged 63 with *Escherichia coli* septicaemia from pyelonephritis was clinically overhydrated when first seen, and a peritoneal dialysis caused an initial fall in blood volume of approximately 1 litre. Subsequent blood volumes remained constant, but red-cell volume progressively fell to below

FIG. 3

1 litre, lowering the haematocrit to 17%. Haemodialysis with ultrafiltration and packed cell infusion caused a slight rise in blood volume (220 ml.). The red-cell volume rose by 800 ml. to give a near normal haematocrit of 33% and plasma volume over the same period fell by 580 ml.

The unreliability of the haematocrit has been seen on many other occasions when significant acute shifts in blood volume have been accompanied by haematocrit shifts in similar or in opposite directions.

3. Value of Estimations in Renal Failure in Surgical Patients

Surgical causes have accounted for 59 of a total number of 127 cases referred to our unit. In these patients the complications of severe blood loss, or of extrarenal electrolyte losses from vomiting, ileus, or fistulae, can often greatly increase the difficulties of achieving metabolic balance. Monitoring the blood volume in these instances can be of material assistance.

When acute loss of blood prejudices survival it is again stressed that the peripheral haematocrit is of little or no value in estimating the volume of replacement fluid required, and it will in time merely reflect the haematocrit of bank blood (Moore, 1959).

Case Report (Fig. 4).—A man aged 25 with Peutz-Jeghers's syndrome had a jejunojejunal intussusception which was treated by operative reduction. He developed signs of peritonitis and of oliguric renal failure after operation, and was transferred to our unit on the fourth day. Immediate reoperation was required and the gangrenous segment of jejunum was resected. A fall in blood volume of over 1 litre immediately after operation (BV1 and BV2) was unaccompanied by any change of haematocrit, and over the

succeeding five days transcapillary refilling of the circulation had resulted in an increase in blood volume to the preoperative level (BV₁) with a stable haemodilutional anaemia (Lister *et al.*, 1963). Haemodialysis was required on the ninth day, but he developed massive gastro-intestinal bleeding during the diuretic phase. Replacement therapy was guided by blood-volume estimations, and after 48 hours replacement appeared to be adequate with normal volume parameters (BV₇). However, recurrent bleeding lowered the blood volume to near shock levels despite massive transfusion, and at operation on the 13th day multiple acute gastric ulcers were found. Despite vagotomy and gastrectomy he died from suture leakage and peritonitis on the 15th day.

FIG. 4

Gastro-intestinal haemorrhage of a degree to threaten survival has occurred in 7 of our 59 surgical patients, and is a considerable hazard in this group, as has been described by Shackman *et al.* (1960). It has occurred in dialysed and non-dialysed patients, is often due to multiple gastric or duodenal ulcers, and has been treated conservatively except in the case described. Serial measurements of blood volume are of great value in assessment of volume replacement in such patients.

Case Report (Fig. 5).—A man aged 45, weighing 105 kg., had an appendicectomy for a perforated gangrenous appendicitis. He subsequently developed an *E. coli* septicaemia with severe renal failure, complicated by jaundice and recurrent severe haematemeses. He required haemodialysis on three occasions. A progressive slight

FIG. 5.—D1, D2, and D3 refer to times of haemodialyses.

fall in total blood volume was noted with a declining haematocrit despite repeated transfusions over the course of his illness. During this time loss of weight was considerable. He made a complete recovery, and four months later when his original weight had been regained his blood volume had returned to a stable level of just below 8 litres.

4. Monitoring Fluid Removal During Peritoneal Dialysis and Haemodialysis

When late presentation to the unit is associated with severe overhydration, removal of fluid may be of pressing urgency.

We have found peritoneal dialysis to be considerably superior to haemodialysis for fluid removal, and by using hypertonic solutions very rapid shifts can be achieved. However, injudicious use of the hypertonic solutions can readily precipitate hypovolaemia with signs of peripheral circulatory failure (Burns *et al.*, 1962), and monitoring of the blood volume during the procedure adds further precision and safety to the method.

Case Report (Fig. 6).—A man aged 46 presented with a five-day history of bilateral renal pain followed by anuria. He was stuporous when admitted, with gross oedema and congestive heart failure. Immediate peritoneal dialysis removed 2 litres of fluid over the course of 24 hours and his blood volume fell by a similar figure (BV₂). A history of phenacetin ingestion and confirmatory retrograde pyelograms led to the diagnosis of papillary necrosis with obstruction. Bilateral nephrostomies with removal of necrotic papillae from the pelvi-ureteric junctions were done on the eighth day and he subsequently improved with a maintained diuretic response. Blood volume remained constant but a progressive anaemia was revealed with a decline in red-cell volume and

FIG. 6.—Weight is indicated by the closed circles.

haematocrit. The nephrostomy tubes were ultimately removed and his subsequent health has been good, with a stable but elevated blood urea.

When fluid removal during haemodialysis is required monitoring of shifts in blood volume gives precise control. Considerable fluid removal by ultrafiltration, as measured by an increase in the volume of the bath and by decrease in weight of the patient, can be combined with infusion of packed red cells during dialysis, so that anaemia may be corrected without fear of circulatory overloading, while maximal fluid removal is possible without danger of precipitating oligoemia. It is our practice routinely to use regional heparinization during haemodialysis, so that normally about 500 ml. of electrolyte solution is infused during dialysis. However, when fluid removal is of vital importance, the heparin infusion on the arterial side has been delivered in a bottle of packed erythrocytes, so that a minimal amount of fluid administration obtains from the protamine infusion on the venous side (250 ml. in five hours).

5. Differentiation Between Depletional Oliguria and Intrinsic Renal Failure

The difficulties of differentiation between depletional oliguria from renal circulatory insufficiency, which is reversible, and the oliguria of established intrinsic renal failure are well known. Physical signs, blood indices, and urine composition are all of value in distinguishing the two (Shackman *et al.*, 1960). The estimation of blood volume will on occasion be of material assistance, and serial estimations aid in assessment of the efficiency of treatment.

We have also on several occasions used mannitol infusions in an attempt to promote a diuresis when volume studies have indicated adequate circulatory filling. Although clinical proof

of its efficacy is difficult to provide, we, like others (Moore, 1963), have little doubt that on occasions its use will avert the development of renal failure. We have studied its volume-expanding effects which are transient, and with care in its use no complications have been seen.

Case Report (Fig. 7).—A 67-year-old woman with a dissecting aneurysm of the thoracic aorta treated by fenestration required 4 litres of blood during operation, with a blood-volume increase of only 500 ml. She was severely oliguric for 36 hours despite further

FIG. 7

blood transfusion, but administration of mannitol was followed by a brisk and sustained diuresis. Her blood volume had increased towards a predicted normal level, and she did not subsequently develop renal failure.

Discussion

Although there has been some variation depending on the technique of estimation, data from an experimental animal model (Harris *et al.*, 1952; Hamburger, 1957; Schloerb, 1961) and body composition studies in small series of patients (Sirota and Kroop, 1951; Remenchik *et al.*, 1958) have indicated that acute oliguric renal failure is associated with an increase in total body water and in extracellular fluid volumes. These findings were qualitatively supported by indirect evidence from detailed balance studies (Bluemle *et al.*, 1956). Most of these studies were performed on patients who had been oliguric for some time prior to referral, and who had been treated by a liberal fluid intake, so that iatrogenic volume expansion may have contributed largely to the results.

Our results in patients referred at an early stage of uncomplicated oliguric renal failure indicate that, with adequate control of intake, blood volume will remain relatively unchanged throughout the course of oliguria. However, a progressive diminution in red-cell mass is a common finding, so that plasma volume expands at the expense of red-cell volume. Patients presenting late with uncontrolled fluid intake may have hyper-

volaemia at the time of admission, and will require fluid removal by dialysis.

Although many workers have felt that correction of anaemia during the oliguric phase is unnecessary and potentially hazardous, we have found that with the additional control provided by volume studies, and with care in fluid balance and in timing of dialysis, blood-volume indices may be kept constant during the course of renal failure. The use of blood-volume measurements to monitor haemodialysis so that red-cell administration is combined with fluid removal by ultrafiltration enables considerable precision of control to be achieved without prejudice to the circulation. It is stressed that haematocrit or haemoglobin levels alone, particularly in surgical patients, are of no value in determining either the direction or the extent of shifts in blood volume.

In addition, and particularly in surgical patients, serial estimates of blood volume can be of considerable aid in treatment when haemorrhage or abnormal electrolyte losses complicate the control of fluid balance.

Summary

Accurate and rapid estimation of blood volume at the bedside is possible, using a semi-automatic isotope dilution machine. Serial studies can provide useful information on the partitioning of body fluids during the course of renal failure.

Accurate monitoring of haemodialysis, combining fluid removal with packed cell administration as required, is assisted by volume studies. Control of fluid removal by peritoneal dialysis is similarly facilitated by this technique.

In surgical patients, in whom bleeding and other extrarenal losses often compound the difficulties of management, serial estimates can immeasurably assist in the diagnosis and rational management of renal failure.

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