9 Fluid Balance and Management and the Critically Ill Woman

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Midwives are often required to administer fluid replacement therapy in different situations such as shock and pre-eclampsia. Therefore, an understanding of the need for appropriate fluid replacement and the actual intended action of the fluid is crucial. Inappropriate fluid replacement could have the potential to compromise the woman's condition and lead to a clinical deterioration which would need further intensive management. This chapter will explain the physiology of fluid replacement and discuss the benefits and possible detrimental effects each fluid could cause.

Assumed prior knowledge

- Physiology of the cardiovascular and renal systems
- Physiological changes in the cardiovascular and renal system during pregnancy

Introduction

To maintain a state of physiological wellbeing, regular quantities of water, electrolytes and energy are required. A disproportionate or reduced fluid intake or loss can lead to serious physiological adjustments, significant morbidity and even mortality. A normal fluid balance should enable the body to maintain homeostasis. This chapter explores normal fluid balance and details of the fluids required to maintain this equilibrium.

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The process of normal fluid balance

The cardiovascular system is vital in its role for the distribution and absorption of gases, nutrients and metabolites, throughout the body. The normal passage of circulatory fluids is shown in Fig. 9.1. The passage between the arterial and venous systems is regulated by tube-like endothelial capillaries. The transfer of gases, nutrients and metabolites takes place at a cellular level. Oxygen, for example, carried by erythrocytes (red blood cells) is transported through the capillary wall to interact with tissue cells (Fig. 9.2). The medium through which

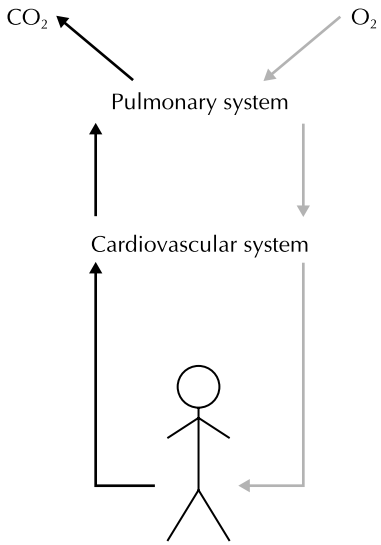

Figure 9.1 Normal passage of circulatory fluids.

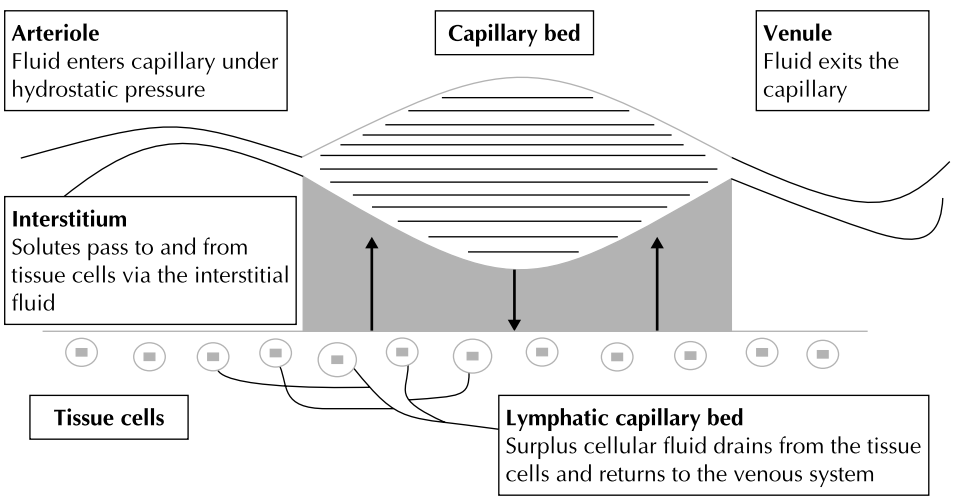

Figure 9.2 Transfer of fluids between the tissues and the arterial and venous systems.

the cells pass is the interstitium. The interstitium is a fibrous tissue and binds the capillary with the surrounding tissues. The fluid present in the interstitium allows the passage of solutes to and from the tissue cells, thus allowing the supply of gases, nutrients and hormones and the return of unused or waste products.

The fluid volume contained in the body is referred to as the total body water. This is divided between three compartments, with 25% in the vascular space, 8% in the interstitial space and 67% within the intracellular compartment. In a 70 kg male, the total body water is approximately 60% of the total body weight (around 42 L). In females, due to increased fat levels, this figure may be reduced to 50% (around 35 L).

Surplus tissue fluid is collected by the lymphatic system at the lymphatic capillary bed. Regulated by lymph nodes, the fluid is returned to the venous system, with the upper right body quadrant draining via the right lymphatic duct and the remainder via the thoracic duct.

The passage of fluid between the intracellular fluid (ICF) space and the extracellular fluid (ECF) space, which includes both plasma and interstitial fluid, is governed by osmosis. As both ICF and ECF are isotonic, an osmotic equilibrium exists at the cell membrane. ICF has potassium as its principle cat ion and is sensitive to changes in ECF sodium concentrations. A raise in serum or ECF sodium levels will cause water to pass from the ICF to the ECF. The reverse is also seen when ECF sodium concentrations are reduced. Albumin and a higher proportion of water with its dissolved oxygen are forced from the arterial end of the capillary by hydrostatic pressure, into the interstitium. The concentration of albumin remaining in the plasma is increased due to the water displacement, so increasing the colloid oncotic pressure. At the venous end of the capillary, the reduced blood pressure and raised oncotic pressure draw water containing carbon dioxide and metabolites back into the vasculature for transfer to the lungs, etc.

The extracellular space is regulated by both its tonicity and volume. Tonicity is governed by osmoreceptors in the brain, which serve to stimulate or suppress thirst, and to regulate water output. The smooth muscle that surrounds blood vessels controls either constriction (sympathetic nerve stimulation) or dilatation (parasympathetic nerve stimulation). An equal stimulus from both sympathetic and parasympathetic systems produces normal vascular tone. Reduced systemic arterial pressure in the renal system can lead to sodium and water retention in the kidney. Water retention itself can result in hyponatraemia (a sodium level of < 135 mmol/L) and, as previously mentioned, can result in a migration of water from the ECF to the ICF. Whilst this would impact upon the volume of the ECF, the total sodium level would not decrease in ratio to the fluid distribution, as electrolytes are unable to pass across the cell membrane. Other impacting factors relating to the ECF space are fluid intake (either oral or infusion therapy) and evaporation due to irregular thermoregulation and gastrointestinal conditions such as vomiting and diarrhoea. An imbalance of circulating fluid as either hypo- or hypervolaemia, will also impact on the normal process of fluid balance. This natural fluid balance may also be greatly disrupted by normal physiological changes in pregnancy related to conditions such as severe hypertensive disorders of pregnancy and postpartum haemorrhage.

Effective fluid balance in critically ill women

An effective fluid balance in any situation has but one aim; to maintain a normal balance that takes into account both the previous events and the current condition of the patient, and pre-empts foreseeable occurrences. Haemodynamics seen during pregnancy, whilst differing greatly from the baseline values, maintain a function that serves the needs of both mother and baby. In classifying a woman as being 'critically ill', we are therefore looking to have observed signs and symptoms that differ greatly from those we might normally expect to see, and can determine them to be an actual or imminent threat.

The physiology of fluid administration will show an initial expansion of the intravascular compartment. The subsequent passage across the capillary structure decrees the extent and duration of effect of the infusion. This differentiates between crystalloid and colloid solutions. Conditions that combine a decreased blood flow and oxygen transfer to the tissues that result in cellular hypoxia and potential organ dysfunction are represented as shock, which is explained at a greater depth in Chapter 8.

The most common pregnancy-related condition that affects fluid balance is pre-eclampsia. In respect of fluid management, the extremes that commonly guide treatment regimes are, on the one hand, pulmonary oedema versus renal failure on the other. Pearson (1992) argues that the woman with severe pre-eclampsia is at high risk of pulmonary oedema and as such should be fluid restricted with early diuretic therapy. Indeed, with women with a central venous pressure (CVP) of ≥ 4 mmHg, additional crystalloid infusion can raise the CVP to ≥ 10 mmHg, thus precipitating pulmonary oedema relating to the free passage of crystalloids between the intra- and extravascular spaces (Robson 1999).

However, the treatment of pre-eclamptic hypertension with hydralazine without a preload fluid dose can cause hypotension, fetal distress and oliguria (Magee et al. 2003). Reduced systemic arterial pressure in the renal system can lead to sodium and water retention in the kidney. This will cause a concentration of the urine output, seen as a darkening in colour and a thickened consistency; however this does not necessarily indicate renal failure, which affects approximately 1.5% of women in severe pre-eclampsia. Dehydration that manifests as thirst, however, indicates a depletion of 1 L or more and should be managed. Oral fluid intake will rarely result in toxicity and can be passed through the body; women can therefore be encouraged to drink at regular intervals. As such, maintenance fluids can be given as crystalloid fluids. In women with a urine output of < 100 ml/4 h, CVP can be measured. Readings of < 4 mmHg can be treated with 400 ml of 5% albumin. Careful challenges of colloid fluids, which remain in the intravascular space due to their higher molecular weight, will maintain colloid oncotic pressure – as opposed to crystalloids that are associated with a postpartum fall.

Pre-eclampsia can be considered to be a condition that illustrates a degree of distributive/vasogenic shock. Despite a relatively normal cardiac function and blood volume, the irregular distribution of blood can result in poor oxygenation of the tissues. Other shock-related disorders that can affect the distribution of body fluids are:

- *Septic shock*. As a result of the cardiac output and vasodilatation being depressed, a physiological attempt is made to direct the blood flow to critical organs at the expense of the pulmonary and renal systems. This results in an increased permeability of the capillaries, allowing water and large proteins such as albumin to migrate to the interstitium resulting in loss of proteins, hypovolaemia and interstitial oedema.
- *Anaphylactic shock*. The release of histamine, serotonin and other chemical mediators following the stimulation of the antibody–antigen complex, activates the cells of the immune system (such as mast cells and basophils) which causes vasodilatation and capillary permeability. This allows fluids to migrate from the intervascular compartment to the interstitium. The result is a fall in blood pressure and hypovolaemia resulting in tissue hypoxia.
- *Hypovolaemic shock*. This occurs when fluid leaves the cardiovascular space either to an internal space (as seen in distributive shock, burns or internal haemorrhage) or to external loss.

Fluid management

When considering the management of fluids in the critically ill woman, it is imperative not to lose sight of the fundamentals of fluid balance. The fluid volume contained in the body (total body water) is divided between three compartments, with 25% in the vascular space, 8% in the interstitial space and 67% within the intracellular compartment.

The composition of ECF and ICF is shown in Table 9.1.

Table 9.1 Composition of extracellular and intracellular fluids.

Intracellular fluid (28 L)		**Extracellular fluid (14 L)**	
Sodium	14 mmol/L	Sodium	150 mmol/L
Potassium	150 mmol/L	Potassium	4 mmol/L
Bicarbonate	10 mmol/L	Bicarbonate	27 mmol/L
Protein	74 mmol/L	Protein	Plasma = 16 mmol/L
			ISF = 2 mmol/L

ISF, interstitial fluid.

By looking at routine throughput of fluids and the metabolism of electrolytes (Table 9.2), a maintenance baseline of daily requirements can be identified. Intravenous fluids are distributed in differing ways between the intracellular, interstitial and plasma compartments (Table 9.3) and so the choice of fluid type is of vital importance.

Table 9.2 Example of daily input versus output.

Input H_2O 2500 ml/day	Output H_2O 2500 ml/day
Fluids 1400 ml	Urine 1500 ml
Food 750 ml	Skin 500 ml
Metabolism 350 ml	Lungs 400 ml
	Faeces 100 ml
	Sodium 50–90 mmol
	Potassium 50–90 mmol

Table 9.3 Distribution of fluid between the intracellular, interstitial and plasma compartments.

	Intracellular	Interstitial	Plasma
Isotonic saline	0%	80%	20%
Water (dextrose solution)	67%	25%	8%
Colloids	0%	0%	100%

From Table 9.3 we can see that a normal saline solution, whilst good for the maintenance of water and electrolyte homeostasis, will only be able to compensate for a blood volume loss of up to 20%. A colloid however, with a high molecular weight of > 10 000 Da, will stay entirely in the intravascular space. A combination therapy will therefore allow the crystalloid to provide tissue hydration, whilst a colloid infusion will hydrate the vasculature. It is important to note that simply infusing fluids will not correct electrolyte or component imbalance. Regular laboratory testing will show deficiencies or accumulations that result from the woman's condition and their response to fluid therapy. For example, during massive fluid resuscitation, full blood count tests will ensure that the woman's blood components are not simply diluted to an anaemic degree, simply for the sake of restoring volume. Any fluid infused must be able to perform its required function; that is, the distribution and absorption of gases, nutrients and metabolites throughout the body.

Principles of fluid management

Accurate fluid balance recording

This should include all oral/intravenous and otherwise introduced fluids. Balanced against these should be all excreted fluids such as urine output, vomit/diarrhoea and haemorrhage. It is best if all factors that relate to a patient's

fluid balance are recorded on a single 24-hour sheet. In the critical care scenario, this should ideally be a component of their daily care record, which combines observations with treatment regimes, along with an area for staff to document their own comments. In this way, we reduce the possibility of events either being passed over or taken out of context. This should be implemented for any patient whose condition gives rise for concern.

Maintenance fluids

If a patient is able to safely drink fluids, they should be encouraged to do so. Any dehydration that manifests as thirst indicates a depletion of > 1 L. A background infusion of crystalloid fluid such as Hartmann's solution or 0.9% sodium chloride at 90 ml/h will offset the normal excretion of water by the body. In cases of vomiting or fasting, not only does the patient lose fluid but she is also prevented from any normal maintenance. During fasting a woman can lose 420 ml water in 4 hours, rising to 1260 ml in 12 hours. Sodium and potassium loss under the same conditions are equal at 12 mmol at 4 hours, rising to 35 mmol at 12 hours. In addition, stress may also induce the release of antidiuretic hormone (ADH), aldosterone and cortisol. This can then lead to water and sodium retention with the loss of potassium. Thus, if fluid balances are compromised for more than 24 hours, the potassium levels of the patient should be considered.

Possible invasive central venous monitoring

In cases of proven oliguria (< 0.5 ml/kg/h) or undue haemorrhage, the insertion of central venous monitoring should be considered. A low CVP, often indicative of left atrial filling pressures, could be indicative of a hypovolaemic state. However, when the reading rises above 6 cmH_2O, the filling pressures are often underestimated and there is an increased risk of pulmonary oedema. A raised CVP in isolation of supporting tests proves little in regard to fluid status but may be a precursor to fluid overload or myocardial dysfunction. As such, the insertion of a pulmonary artery catheter can be considered. In underloaded patients, the CVP will fall off soon after volume loading, despite a temporary rise being seen.

The risks of insertion should, however, be taken into account. Coagulopathy may cause bleeding and be impossible to control. Poor oxygenation or lung disease may further deteriorate with accidental lung damage. The potential for sepsis is also increased with the introduction of invasive catheters. Unless there is expertise available in both the insertion and management of catheters, and the interpretation of results, central vein cannulation should not be attempted. In cases of severe refractory hypertension where drugs such as nitroglycerine or nitroprusside are used, invasive monitoring in an intensive care unit is required. A set protocol should be available for the implementation of invasive monitoring.

Selective colloid expansion

In cases of confirmed low blood pressures or low CVP readings, fluid challenges of 200–300 ml boluses of colloid can be administered. Colloid and plasma

substitutes contain high molecular weight molecules (> 10 000 Da), together with electrolytes. The size of the molecules prevents passage through normal capillary membranes and, as a result, they remain in the intravascular space. The efficiency of colloids in volume replacement is, however, reduced in cases where damage to the capillary membrane has occurred (Vincent 2000). In pre-eclampsia, the combination of controlled vasodilatation (i.e. using hydralazine) with limited colloid loading can improve cardiac function whilst reducing vascular resistance. Whilst fluid overload is definitely to be avoided in light of the potential for the development of pulmonary oedema, limited fluid challenges prior to vasodilatation are imperative to prevent a sudden hypotensive crisis. In order to optimise intravascular volume, additional volume can be added and/or agents to cause vasoconstriction of the vessels can be used.

Any fluid administration should be managed with a specific end point in mind. To that end, fluids must be flexibly titrated with constant reference to the principle aims of administration and to the emerging physiological effects observed through measurements taken from the woman. Indiscriminate loading of fluids has in the past been the cause of fluid overload and ineffectual treatment and, hence, a move to severely restrict fluid therapy for fear of adverse outcome. Adult respiratory distress syndrome resulting from pulmonary oedema is second only to cerebral haemorrhage as the immediate cause of death in women with pregnancy-induced hypertensive disorders (Lewis, 2004).

Types of fluid

Accurate fluid selection must be made based on the expected function of the fluid, for example to replace electrolytes or to replenish volume. Fluids to be used consist of three categories: crystalloids, colloids and blood products.

Crystalloids

A large number of the crystalloid fluids are isotonic, which means that an equal solute concentration exists inside and outside the cell, encouraging the cell to stay the same size. Fluids found within this category include:

- Normal saline (0.9% sodium chloride in water): 154 mmol/L sodium and 154 mmol/L chloride.
- Ringer's lactate: 147 mmol/L sodium, 156 mmol/L chloride, 4 mmol/L potassium and 2.2 mmol/L calcium.
- Hartmann's solution: 131 mmol/L sodium, 111 mmol/L chloride, 5 mmol/L potassium, 2 mmol/L calcium and 29 mmol/L bicarbonate (lactate).
- Glucose 4%/NaCl 0.18%: 30 mmol/L sodium, 30 mmo/L potassium and 40 g/L glucose (164 kcal/L).
- Glucose 5%: 50 g/L glucose (205 kcal/L).

One significantly different fluid in this category is glucose 10% (100 g/L glucose (410 kcal/L)) which is considered *hypertonic*. Here, the solution on one side of the cell membrane has a solute concentration greater than on the opposite side. Care

should therefore be taken with glucose (dextrose) solutions as the glucose is metabolised, leaving water. This quickly balances through the ECF and ICF spaces and can cause hyponatraemia and cellular oedema.

Normal saline can cause hypernatraemia and hyperchloraemic acidosis if given in excess (Gutteridge 2004).

Synthetic colloids

Synthetic colloids are used solely to expand the plasma volume as they have no oxygen capacity or clotting functions. They may be divided into three groups.

Hydroxyethyl starch (HES)

HES solutions are derived from a modified vegetable starch dissolved in 0.9% normal saline. This is similar to the glycogen found in liver and muscle, resulting in a reduced potential for immunological reactions. The different ratios of hydroxyethyl groups to glucose molecules within the starch will dictate how long the HES is maintained in the circulatory system. Available as 6% and 10% solutions, the former will expand the plasma volume by 500 ml with a 500 ml infusion, whereas the 10% solution acts similarly to 20% albumin in that 500 ml will cause an expansion of 750 ml volume. The difference in types available reflects the 'degree of substitution' of the hydroxyethyl groups to glucose molecules and their subsequent duration, with HES remaining up to four times longer in the system.

The molecular weight also covers a wide range (10–2000 kDa) compared to albumin (69 kDa). The amount of leakage through the capillaries is therefore much reduced, thus allowing HES solutions to remain longer in the vascular compartment. HES is eliminated via the kidney with molecules > 70 kDa being broken down by serum amylase. Again, the higher amount of HES groups present, the longer it takes for degradation to occur and hence there is a longer duration of effect.

Gelatins

This group of colloids derive from bovine proteins made soluble in 0.9% normal saline. Whilst molecular size varies, it tends to be approximately 30 kDa. Due to this relatively small size, gelatin molecules are not readily retained in the vasculature, leaking both into the interstitium and through the renal capillary system into the urine. As such, gelatines do not maintain their expansion properties for more than 3 hours. They are therefore useful for short-term expansion (e.g. to counteract the hypotension caused by spinal anaesthesia) but require long-term infusion for conditions such as sepsis. This sustained treatment may lead to a sodium buildup in women who have renal or hepatic impairment.

Dextrans

Dextrans are naturally occurring glucose polymers made by leucosoic bacteria. Simpler in structure than the hydroxyethyl groups, the molecular size is varied, so regulating its duration within the vasculature. Dissolved in 0.9% normal saline or 5% dextrose, dextrans are available in two molecular weights. Dextran 40

(low molecular weight) expands the blood by 150% of the infused volume in a similar manner to 10% HES, but will only remain active for 6–8 hours. The higher molecular weight dextran 70 expands the blood by only 100% of the infused volume, but has approximately 18 hours effective duration. A recognised chemical effect of dextran is the increased plasma viscosity seen during infusion. Whilst this definitely interferes with blood clotting functions, it is used occasionally during surgery to reduce the incidence of deep vein thrombosis. There is also an acknowledged incidence of anaphylaxis with the higher molecular weight dextrans.

Blood and blood products

In cases of significant haemorrhage, whole blood is an ideal choice due to it having the capacity to carry oxygen and the presence of clotting factors. Fresh blood is preferable to stored blood as, in time, stored blood breaks down, decreasing the concentrations of platelets and clotting factors. As a result of this breakdown, a rise in potassium, ammonium and cell debris is to be seen.

A cross-match and typing between the recipient and donor unit must be undertaken prior to transfusion. An initial infusion rate of 4 ml/kg/h should be used, unless a severe deficit is present, in which case the blood should be given as rapidly as possible. In cases where renal/cardiac disease or an acknowledged fluid overload is present, the infusion rate should be slowed to 1 ml/kg/h. One unit of packed red cells can be expected to raise the haematocrit level by approximately 3%. Targets for infusion should be set to reach a required haematocrit level without exceeding it. Except in extreme emergency, blood should be infused through both an infusion-warming device and a blood filtration system. The blood should not exceed 42°C and any units should be infused within a 4-hour period to prevent bacterial buildup. The woman should be carefully monitored for signs of transfusion reaction and/or fluid overload. If fresh frozen plasma is required, to correct coagulation deficiencies, it should be pre-thawed at room temperature or using a controlled method over 30 minutes.

Albumin

Albumin is naturally found in the body evenly divided with one-third found in the skin, one-third in the vasculature and one-third in the body tissues. Approximately 5% of the blood albumin transfers through the capillary per hour to the tissues (transcapillary escape rate). This acts as a buffer to the blood's oncotic pressure, so regulating its ability to attract water. The resulting effect is an even hydration of blood and tissues.

Albumin can be considered for use for the following conditions: hypoalbuminaemia, resuscitation in acute hypovolaemia and hypovolaemia occurring after the acute phase of critical illness. Available as 4.5% or 20%, the albumin is dissolved in saline and acts by drawing water from the interstitium back into the vasculature. Of the two concentrations, 100 ml of the 20% solution has the equivalent effect of 300 ml of the 4.5% solution, expanding to three times its volume in infusion. The molecular size of albumin is 69 kDa. This plays an important role in

women suffering from oedema or sodium elimination conditions, as albumin levels affect the colloid oncotic pressure and thus the transfer of water to and from the interstitium with its dissolved gasses and metabolites. In cases of capillary leakage, the amount of colloid and water in the interstitium increases the distance between the capillary and the cells, thus causing reduced oxygen transfer between the two structures and resulting in hypoxia. In cases where the oedema is caused by sepsis, it is vital to address the cause in order to prevent the return of fluids from the interstitium and the subsequent restoration of normal gas exchange becoming a temporary state (Allison & Lobo 2000).

Diuretic usage

As denoted by the phrase 'fluid balance', there is a necessary correlation between administered or present fluids and those eliminated from the body. Concerns regarding fluid overload, and resulting pulmonary oedema, and pre-renal oliguria often result in the use of diuretic drugs to increase urine formation and output. The use of loop diuretics such as frusemide (furosemide) can promote diuresis by reducing the intravascular water and increasing the colloid oncotic pressure. This encourages water to be drawn from the interstitial space, back into the vasculature. In oliguria, it is important that the patient is fluid loaded (and still oliguric) prior to the administration of diuretics. Sodium reabsorbtion is inhibited in the loop of Henle in the medulla, enhancing the renal tubular oxygen balance, and diuresis often occurs despite renal impairment. Mechanically, this can help flush the renal tubules of any necrotic debris.

In cases of pulmonary oedema that result in adult respiratory distress syndrome, fluid restriction and diuretic administration are an advocated course of action. However, for critically ill pregnant women who become potentially oliguric, it is important that the cause (such as hypovolaemia) is treated or excluded prior to the use of diuretic drugs.

Summary

- Normal values in physiological measurements must be established as appropriate to the woman's condition.
- A normal balance should be sought, that takes into account both the previous events and the current condition of the woman, and pre-empts foreseeable occurrences.
- Fluids and treatments should be carefully administered with clearly defined end objectives. These should be determined by a multispeciality approach and laid out in policy.
- Fluids have individual properties and are not simply crystalloid or colloid. Choose with an aim in mind.
- Constant reassessment of the woman's condition must be undertaken to avoid potential harm.
- Expert help should be sought prior to implementing any stage of treatment.

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