

## Fluid management

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# The use of intravenous therapy

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## Aims and intended learning outcomes

The aim of this article is to increase your understanding of fluid and electrolyte homeostasis, and provide the rationale for the care and management of patients undergoing intravenous fluid therapy. After reading this article, you should be able to:

- Describe different body fluid compartments.
- Define the principles of osmosis, diffusion and filtration in relation to the movement of water and solutes between compartments.
- Differentiate between hypotonic, isotonic and hypertonic solutions.
- Understand the role of electrolytes in fluid balance.
- Identify the signs and symptoms of fluid and electrolyte imbalance.
- Explain the different reasons for commencing intravenous fluid therapy.
- State the different types of intravenous fluid and give a rationale for their use.
- Analyse the nurse's role in observing and supporting the patient undergoing intravenous fluid therapy.

## Introduction

Knowledge of different parenteral fluids and their method of action is essential to the safe delivery of infusion therapy. Nurses have a professional and legal responsibility to understand the rationale for the use of specific prescribed fluids and the desired and untoward effects of administration. Safe administration demands an understanding of the role of electrolytes and water and of the mechanisms of movement

between different body compartments, as well as knowledge of the actions of the various solutions available.

## Body fluid compartments

The total amount of water in a male weighing 70kg is around 40L. Almost two thirds by volume (25L) is contained in the intracellular fluid (ICF) compartment, which consists of trillions of cells. The remaining one-third (15L) is found in the extracellular fluid (ECF) compartment (outside the cells). The ECF compartment is divided into two sub-compartments: the plasma (3L), the fluid portion of blood in the blood vessels, and the interstitial fluid (12L) which bathes the body cells.

There are numerous other examples of ECF that are distinct from blood plasma and interstitial fluid (ISF), such as cerebrospinal fluid, synovial fluid, lymph, serous fluid and secretions from the gastrointestinal (GI) tract.

The fluid compartments are separated from one another by semi-permeable membranes. Water and small molecules pass through the membrane, whereas larger colloid substances and proteins are confined to the intravascular space. The composition of each compartment is maintained by the selectivity of its membrane. The intravascular fluid (IVF) is separated from the ISF by the capillary membrane, and between the ISF and the ICF is the cell membrane. The controlled movement of fluids and solutes between these spaces ensures that vital nutrients can pass from the IVF to the cells, and that waste products can move out of the cells and into the IVF. The body fluid compartments are maintained at

## In brief

### Author

Helen Hand BSc(Hons), MA(Ed), RGN, is Lecturer, School of Nursing and Midwifery, University of Sheffield. Email: h.e.hand@sheffield.ac.uk

### Summary

Nurses have a professional and legal responsibility to understand the rationale for the use of prescribed fluids. Safe administration requires an understanding of the role of electrolytes and water and of the mechanisms of movement between different body compartments.

### Key words

- Intravenous therapy
- Nursing: care

These key words are based on subject headings from the British Nursing Index. This article has been subject to double-blind review.

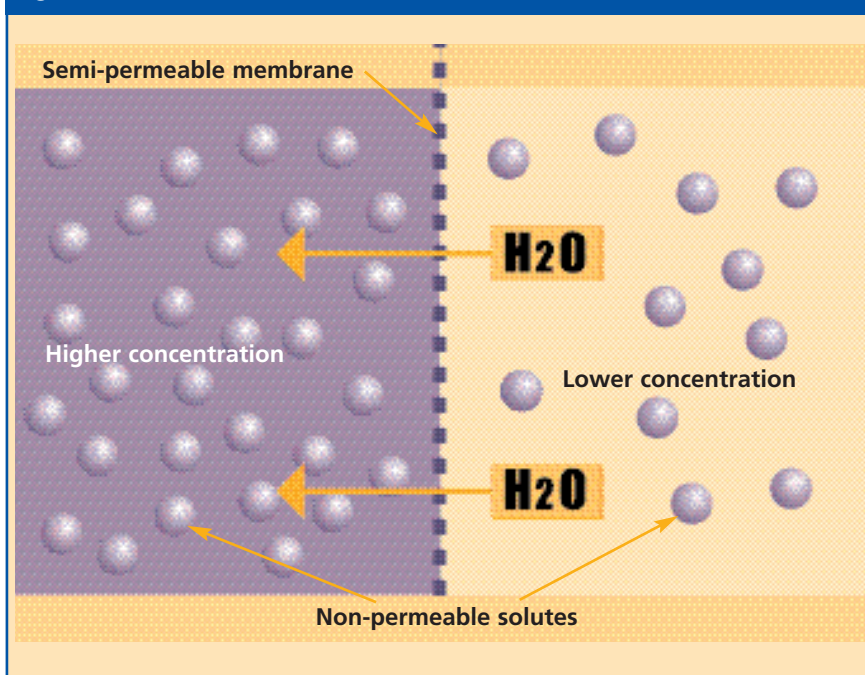
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# Fluid management



Fig 1. Osmosis



## Box 1. Homeostatic mechanisms

- Osmosis
- Diffusion
- Facilitated diffusion
- Filtration
- Active transport

a constant level by the homeostatic mechanisms listed in Box 1.

**Osmosis** This is the movement of water through a selectively permeable membrane, that is, one that allows only certain substances to cross (Fig. 1). Pores in the membrane allow the movement of water molecules, from an area of low solute concentration to an area of high solute concentration. For example, if a glucose solution is separated from pure water by a membrane that is permeable to water, but not permeable to large glucose molecules, water will diffuse from the area of high water concentration (pure water) to the area of low concentration (the glucose solution), to equalise the concentration of the two solutions.

**Diffusion** Diffusion is the movement of substances from an area of high concentration to an area of low concentration. This is called a diffusion gradient. Because of the random movement of molecules and the collisions that result from this movement, molecules of a given type will eventually be evenly distributed throughout a system. This process can be seen, for example, when ink is dropped into a glass of water or when perfume is sprayed into a room. The ink spreads evenly throughout the water and the perfume spreads evenly throughout the air in the room. The net movement of ink molecules and perfume molecules is from a region of high concentration to one of low concentration – in other words they move down a concentration gradient.

Diffusion is a passive process, it does not require

energy. In the body, the diffusion of substances takes place across a selectively permeable plasma membrane and will only occur if the molecules are small enough to pass through.

**Facilitated diffusion** This makes use of highly selective 'carrier molecules' situated in the cell membrane. This is used by large lipid insoluble molecules, such as glucose, to gain rapid entry into cells. If the carriers became saturated, diffusion will be reduced even though a diffusion gradient still exists.

## TIME OUT 1

Using an anatomy and physiology text, list at least five substances that move across the cell membrane by diffusion.



**Filtration** This is a passive process; there is a gradient on either side of the membrane, but this time it is pressure rather than solute concentration.

Hydrostatic pressure forces water and small dissolved molecules out of the plasma into the ISF. This movement occurs at blood capillary level, fluids and small molecules leaving the blood to supply nutrients and raw materials to the cells for use in metabolic processes. Filtration is also important in urine formation. The hydrostatic pressure at the nephron causes water and other molecules to pass through the tubule in the first stage of urine production.

If fluid is forced out of the capillary by hydrostatic pressure, it will be drawn back into the blood supply at some point to maintain overall blood volume. This is achieved by the presence of plasma proteins in the blood which attract water by osmosis. Plasma proteins, such as albumin, are unable to leave the capillary, which means that the blood is more concentrated in terms of plasma proteins and has a low water concentration compared to ISF, which has a high water (and low plasma protein) concentration. Water, therefore, moves by osmosis from the area of high water concentration (ISF) to the area of low water concentration (blood) to equalise the two compartments.

Water is driven out of the arteriolar end of the capillary because hydrostatic pressure is greater than the plasma oncotic pressure, generated by the plasma proteins. As water is forced out, however, the hydrostatic pressure decreases and is eventually exceeded by the plasma oncotic pressure. This pressure difference favours the drawing back of water to the capillary from the interstitial space. In this way, essential nutrition



is supplied and waste products are removed from cells and brought into the bloodstream for excretion, and the overall blood volume is maintained. Any fluid that is not returned directly to the bloodstream is returned by the lymphatic system, which drains the interstitial space.

Plasma protein concentration is, therefore, an important factor in the maintenance and distribution of fluid extracellular compartments.

**Active transport** Where no electrical or concentration gradient exists, substances are unable to move by simple diffusion and, therefore, have to be 'actively transported'. This requires the use of energy in the form of adenosine triphosphate (ATP), to move substances against a pressure or concentration gradient. The sodium-potassium pump on the cell membrane that is responsible for maintaining intracellular fluid volume best illustrates this concept. Sodium is actively pumped out of the cell, against a concentration gradient, while potassium is allowed in (Dougherty and Lamb 1999).

### Tonicity

Understanding tonicity is vital to comprehend the mechanisms involved in fluid and electrolyte imbalance and their management with intravenous fluid and electrolyte therapy.

Many intracellular molecules, particularly proteins and selected ions, are prevented by their size from diffusing through the plasma membrane. Consequently, any change in their concentration produces changes in water concentration on either side of the membrane and results in net loss or gain of water by the cell. This osmotic movement of water in and out of cells is influenced by the tonicity of the solutions to which they are exposed. Tonicity is: '... the ability of a solution to change the tone or shape of cells, by altering their internal water volume' (Marieb 1998).

A solution with the same concentration of non-penetrating solutes (unable to cross the membrane) as body cells is isotonic, or the same tonicity. If a cell is placed into an isotonic solution (such as 0.9% saline or 5% glucose), the cell will not change its shape or tone.

Solutions that have a higher concentration of non-penetrating solutes than the cell are called hypertonic solutions. Cells immersed in hypertonic solutions will lose water by osmosis, which will cause them to shrink (crenate). Solutions that are more diluted and, therefore, contain less non-penetrating substances than cells are called hypotonic solutions. Cells placed in hypotonic solutions rapidly gain water by osmosis. Distilled

water represents the most extreme example of hypotonicity as it contains no solutes at all. If a cell were placed into a solution of distilled water, it would continue to gain water until it eventually burst.

### TIME OUT 2

Make a list of the intravenous infusion solutions commonly used in your clinical area. Decide whether they are isotonic, hypertonic or hypotonic and state what effect they would have on cells placed in them.



### Electrolytes

It is important when nursing patients with fluid and electrolyte imbalance and those receiving infusions, to understand the role of electrolytes in body fluids, the reason why and how their levels are maintained within homeostatic limits, and the problems that can arise as a result of the imbalance. Because the electrolyte content of ECF differs from that of ICF, it is customary to measure the electrolytes in ECF, chiefly plasma. Plasma electrolyte concentrations can be used to assess and manage patients with a diversity of electrolyte imbalances. Although some tests are performed on serum, the terms 'serum' and 'plasma' are used interchangeably.

**Sodium** Sodium plays a vital role in maintaining the concentration and volume of ECF. It is the main cation (positively charged ion) of ECF and, therefore, the major determinant of the osmotic pressure of ECF. The normal concentration of sodium is 135-145mEq/L.

Sodium is also important in maintaining irritability and conduction of nerve and muscle tissue, and assists with the regulation of acid-base balance. Average daily intake of sodium far exceeds the body's normal requirement. The kidneys excrete excess sodium and are capable of conserving sodium in times of extreme sodium restriction. Sodium concentration is maintained via regulation of water intake and excretion. If serum sodium falls below 135mEq/L (hyponatraemia), the kidneys excrete water. Causes of hyponatraemia are illustrated in Box 2.

Conversely, if serum sodium levels rise above 145mEq/L (hypernatraemia), the osmotic pressure of serum increases stimulating the thirst centre and causing the release of antidiuretic hormone (ADH) by the posterior pituitary gland. ADH acts on the kidney to conserve water, thus diluting the sodium.

### Box 2. Causes of hyponatraemia

- Prolonged diuretic use
- Excessive diaphoresis (sweating)
- Prolonged vomiting/diarrhoea
- Extensive burns
- Renal disease
- Over infusion of dextrose 5%
- Anorexia, fasting, alcoholism
- Syndrome of inappropriate antidiuretic hormone (ADH)
- Adrenal impairment
- Cirrhosis
- Congestive cardiac failure
- Drugs, such as intravenous cyclophosphamide, carbamazepine, amitriptyline, ecstasy
- Addison's disease

(Malster 1999)



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## Box 3. Causes of hypernatraemia

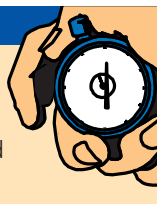
- Inadequate water intake
- Watery diarrhoea
- Severe insensible loss
- Burns
- Osmotic diuretic therapy
- Hyperglycaemia
- Diabetes insipidus
- Near drowning in salt water
- Hypertonic IV saline
- Hyperaldosteronism (Conn's syndrome)

(Malster 1999)

Aldosterone released from the adrenal cortex also regulates serum sodium by causing the kidney to conserve sodium and water, thereby increasing ECF volume. Possible causes of hypernatraemia include water deprivation/loss, excessive infusion of saline and diabetes mellitus. Because sodium is the major determinant of the osmotic pressure of ECF, hypernatraemia always causes a shift of water out of the cells, which leads to cellular dehydration. Possible causes of hypernatraemia are presented in Box 3.

### TIME OUT 3

Using an appropriate textbook, find the signs and symptoms that might accompany hypernatraemia and hyponatraemia.



**Potassium** Potassium is the main cation of ICF, which contains more than 98 per cent of the body's total potassium. The 2 per cent found in ECF is kept in a narrow range of 3.5-5.0mEq/L. Because the ratio of ICF to ECF helps determine the resting membrane potential of nerve and muscle cells, an alteration in the plasma potassium level might adversely affect neuromuscular and cardiac function. Excess or deficit in ICF or ECF can, therefore, cause serious, (potentially fatal) impairment of body function.

The body gains potassium from food (primarily meat, fruit and vegetables) and medication. In addition, ECF gains potassium any time there is a breakdown of cells (tissue catabolism) or movement of potassium out of the cells. However, elevated serum potassium does not occur unless there is a concomitant reduction in renal function (Horne and Swearingen 1991). Potassium is lost from the body through the kidneys, GI tract and skin, but the kidneys are the primary regulators. They do this by adjusting the amount of potassium excreted in the urine. The presence of aldosterone also increases the excretion of potassium. Conditions that increase aldosterone secretion might, therefore, increase urinary excretion of potassium.

High serum potassium levels (hyperkalaemia) have an adverse effect on heart muscle and can cause cardiac arrhythmias. Hyperkalaemia is, therefore, a life-threatening emergency requiring prompt recognition of ECG changes and treatment. If the potassium level rises above 5.5 mEq/L, an infusion of dextrose with insulin might be commenced to assist the movement of potassium back into the cells. Other signs and symptoms of hyperkalaemia include tingling and

numbness in the extremities, a potassium level below 3.5 mEq/L and a slow heart rate.

Signs of hypokalaemia include malaise, skeletal and smooth muscle atony, muscular cramps and postural hypotension.

### TIME OUT 4

Using your textbook, list the possible causes of hyperkalaemia and hypokalaemia.



**Other electrolytes** Calcium is one of the body's most abundant ions. It combines with phosphorus to form the mineral salts of the bones and teeth. Calcium exerts a sedative effect on nerve cells and has important intracellular functions, including development of the cardiac action potential and contraction of muscles. Less than 1 per cent of the body's calcium is found in ECF.

Magnesium has an important role in enzyme activity, contributing to the metabolism of carbohydrates and proteins. Serum levels should be 1.3-2.1mEq/L. A magnesium imbalance is common in critically ill patients, although deficits can occur in less ill patients, such as those experiencing withdrawal from alcohol and those receiving parenteral or enteral nutrition after a period of starvation. Magnesium is excreted by the kidneys, therefore, diminished renal function results in abnormal renal magnesium retention.

Chloride is the chief anion (negatively charged ion) of ECF, with a plasma concentration of 97-110mEq/L. Chloride deficiency leads to a deficiency of potassium and vice versa. There is also a loss of chloride with a loss of sodium. Phosphate is the chief anion of ICF, with a normal plasma level of 1.7-2.3mEq/L.

### TIME OUT 5

Before moving on, find out what the normal plasma levels of the following substances should be: sodium, potassium, urea, creatinine, bicarbonate, calcium, magnesium, glucose and phosphate.



## Fluid and electrolyte replacement

Knowledge of the different parenteral fluids and their method of action is essential to the delivery of infusion therapy. Infusions can be separated into those that influence cellular fluids, and



those that expand the intravascular volume.

#### **Infusions that influence cellular fluids**

Sodium chloride in water is primarily a source of fluid and electrolyte, with different percentages available to reflect changes in the patient's sodium balance. Sodium 0.9% is isotonic to normal body fluid, and will not, therefore, alter the osmotic movement of water across cell membranes (unless ICF is more or less concentrated than normal). Isotonic crystalloid solutions are rapidly dispersed into ECF, so large volumes need to be infused to substitute for intravascular losses (Waschke and Frietsch 1999). Sodium 9% is generally used to sustain ECF volume by compensating for losses due to dehydration, urinary excretion of sodium, or fluid drains following surgery. It is also indicated at the initiation and termination of blood transfusions so that haemolysis of red blood cells that occurs with dextrose in water is avoided.

Hypertonic saline (3% and 5%) is also available. This is used to expand intravascular volume by moving endothelial and intracellular water into the intravascular space. It is also used in severe sodium depletion when rapid restoration of electrolyte balance is important. It is often used in conjunction with colloids to prolong the intravascular volume effect. Hypertonic solutions contain higher concentrations of particles when compared to plasma. This causes fluid to leave the cells and enter the plasma, and has the potential, therefore, to cause fluid overload. Hypertonic solutions also have the potential to irritate peripheral veins and administration should be slow and carefully monitored.

Hypotonic saline (0.45%) is used as an electrolyte replenisher and maintenance solution, preferred over isotonic saline where there is a question over the amount required. The complications of saline administration include overhydration, sodium overload and potassium deficit.

Dextrose 5% in water is isotonic but, unlike normal saline, glucose will penetrate cells and be metabolised, in effect leaving behind the infused water. It is, therefore, a useful means of replacing or maintaining fluid volume without altering electrolytes. It also provides calories, 1L of 5% dextrose provides the patient with 170 calories. Hypertonic solutions such as 10% glucose will yield 340 calories and are useful for providing calories for patients unable to tolerate large quantities of water (for example, those with renal insufficiency). Concentrations higher than 5 per cent can irritate veins and rapid infusion can cause dehydration by promoting osmotic diuresis, again highlighting the need for careful patient observation.

Various combinations of dextrose and saline exist. The saline component aids maintenance or expansion of ECF volume, whereas glucose aids cellular hydration as it is metabolised, and provides a small amount of energy. Glucose 4% with sodium chloride 0.18% is commonly used to supply calories, water and moderate amounts of sodium and chloride, while glucose 5% with sodium chloride 0.9% supplies fluid, nutrients and electrolyte replenishment. Hypotonic solutions such as dextrose 2.5% with saline 0.45% drive fluid from the plasma into the interstitial space and are, therefore, used to rehydrate body cells.

The third most commonly infused electrolyte is potassium. Ideally potassium should be replenished slowly by diet, however, patients with severe hypokalaemia might require an infusion. Potassium solutions administered intravenously have value as a source of water and electrolytes, and those with glucose are also a valuable source of nutrients. Infusion is, therefore, indicated when dietary measures are not feasible and when replenishment of fluids and electrolytes is required.

Conditions that might result in potassium deficiency include vomiting, diarrhoea, use of potent diuretics, malnutrition, some forms of renal disease and metabolic acidosis. Excess potassium can lead to cardiac arrhythmias and even death. Therefore, potassium levels need to be checked regularly and carefully controlled.

If potassium is added to an infusion manually, it should be carefully checked and the bag agitated to ensure thorough mixing. Failure to do this might result in a bolus of potassium being administered accidentally. The most frequently used method of potassium administration, according to Malster (1999), is potassium chloride in an isotonic solution. Careful consideration should be given to the infusion rate as rapid infusion can lead to irritation of the veins. Surrounding tissues are also at risk if the solution extravasates and central lines are, therefore, the preferred method of administration. Over correction must also be avoided because of the consequences of hyperkalemia.

Other infusion fluids used include Ringer's solution and Hartmann's solution. Ringer's solution contains the primary electrolytes found in plasma (with the exception of magnesium and chloride) and is, therefore, a source of electrolyte and fluid replacement. Hartmann's solution is similar to plasma, with the exception of magnesium. It is modified by the addition of sodium lactate, which is metabolised by the liver to bicarbonate. This is useful in certain conditions, such as metabolic acidosis.

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## Infusions that expand intravascular volume

There are a variety of infusions used to expand vascular volume and blood cell count. The choice lies between crystalloids, blood and its blood derivatives and artificial colloids.

**Blood and its derivatives** Infusion of whole blood and plasma is undertaken to replace volume lost by haemorrhage caused by injury or surgery where blood loss exceeds 20 per cent of total blood volume (Clark *et al* 1997). Whole blood contains cells (red, white and platelets), plasma and electrolytes. Whole blood, therefore, replaces fluids, electrolytes and oxygen-carrying capacity.

Packed cells are the result of the removal of platelet-rich plasma from whole blood. One unit of packed red blood cells contains the same amount of oxygen carrying red blood cells as a unit of whole blood. The danger of circulatory failure is lessened because of the reduced volume. It is, therefore, appropriate for patients with heart failure or renal failure.

Plasma is the liquid content remaining after the red cells have been removed. It contains water, electrolytes, proteins, globulin and coagulation factors. Fresh frozen plasma contains all the normal components of blood plasma, including clotting factors and fibrinogen. It is beneficial to patients with clotting deficiencies or bleeding disorders. It is an isotonic volume expander, therefore, patients receiving multiple units must be observed for signs of fluid overload. It should not be used for volume expansion – this is better done with crystalloid or colloid solutions.

Albumin comprises 40 per cent of the plasma protein and can be purified from raw plasma. It is naturally synthesised in the liver and is responsible for maintaining plasma oncotic pressure. Albumin is available for infusion as 4.5% and 20%. The 4.5% albumin is isotonic and can be used in the treatment of low serum albumin levels and hypovolaemia to expand the plasma volume. Albumin 25% is hypertonic and depends on additional fluids either drawn out of the tissues, or administered separately for its maximum osmotic effect. It must be administered with caution as rapid infusion can cause an increase in intravascular oncotic pressure, resulting in circulatory overload. Albumin is mainly indicated to treat shock in cases of burns, haemorrhage, surgical losses and trauma (Josephson 1999).

There does not appear to be any convincing evidence that albumin is better than synthetic colloids for volume replacement. Several studies have failed to show that treatment with albumin improves


outcome and, according to findings by the Cochrane Institute of Albumin Reviewers (1998), it might actually increase mortality by increasing interstitial oedema, especially in the lung.

**Artificial colloids** These include dextrans, hydroxyethyl starch (HES) and gelatin derivatives. Dextrans are polydispersed solutions available as dextran 40, 70 (low molecular weight dextrans) and 110 (high molecular weight dextran). Dextran 40 acts as a hypertonic solution expanding rapidly on infusion, whereas dextran 70 acts isotonicity. Interference with blood clotting, allergic reaction and cross-matching difficulties are problems associated with dextrans (Collis 1984, Josephson 1999, Waschke and Frietsch 1999).

Gelatins are complex carbohydrate molecules too large to pass out of the capillaries or vascular walls, so are restricted to the vascular space. They generate osmotic forces that cause water to enter blood vessels, thereby expanding the plasma volume. This is the main reason why they are used in preference to crystalloids. Because the electrolytes present in the solution contain calcium, blood and gelatin cannot be mixed or infused down the same line, as the calcium will initiate clotting.

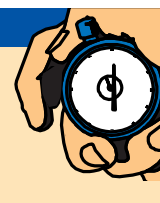
HES is available as high molecular weight and medium molecular weight starch. HES solutions are primarily eliminated from the body by filtration through the kidney. Research has shown that treatment with HES in patients with burns (Waxman *et al* 1989), and following cardiac surgery (Boldt *et al* 1991), led to more favourable outcomes compared to treatment with albumin 5%. HES was also found to produce less allergic reactions than dextrans.

## Conclusion

By working through this article, you should be aware of the importance of undertaking observations on patients undergoing infusion therapy and able to provide a rationale for the choice of fluid, based on your knowledge of fluid movement and the function of electrolytes .

## TIME OUT 6

Now that you have completed the article, you might like to think about writing a practice profile. Guidelines to help you are on page 55.



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