Types of Intravenous Fluids

See online here

Intravenous fluids are most commonly administered in acute and severe hypovolemic conditions. In the therapeutics, two classes of i.v. fluids are most commonly utilized: crystalloids and colloids; both have their own advantages and disadvantages. The effect of various clinical conditions on the volume of ICF and ECG can be best studied by Darrow-Yannet diagrams.

Definitions of Intravenous Fluids

Osmosis

The spontaneous movement of water across a semipermeable membrane from a region of **low solute concentration** to a region of **high solute concentration**, which tends to equalize the solute concentrations on either side of the membrane.

Osmotic pressure

The hydrostatic pressure is necessary to counteract the process of **osmosis**.

Osmolality

It is the osmolar concentration of a solution when it is expressed as **osmoles/Kg of water**.

Osmolarity

It is the osmolar concentration of a solution when it is expressed as **osmoles/L of water**. About 80% of total osmolarity of the interstitial fluid and plasma is due to sodium and chloride ions, while half of the total osmolarity of the intracellular fluid is due to potassium ions and the remainder is due to other intracellular substances.

Osmotic gradient

The difference in the osmolarity of two solutions on either side of a semipermeable membrane.

Distribution of Fluids Within the Body

The human body comprises approximately 60 % of water; out of which $2/3^{rds}$ of total body water (TBW) is present inside the cells, i.e. **intracellular fluid compartment** (ICF) and $1/3^{rd}$ of TBW is present outside the cells, i.e. **extracellular compartment** (ECF).

The ECF is further sub-divided into **plasma**, which comprises $¼^{th}$ of ECF or $1/12^{th}$ of TBW and **interstitial fluid** which comprises about 3/4 of ECF or 3/12 of TBW.

TBW = ICF ($2/3^{rd}$) + ECF ($1/3^{rd}$)
ECF = Plasma ($1/4^{th}$) + Interstitial Fluid ($3/4^{th}$)
The interstitial fluid comprises of electrolytes, amino acids, glucose, hormones, and various other products of **metabolism**. It is essential for the maintenance of the membrane potential of cells and also necessary for the moving of substances back and forth between cells and blood vessels.

Intracellular fluid and interstitial fluid are separated by a relatively impermeable cell membrane, which does not allow substances to spontaneously move across the membrane, except the water. The interstitial space and plasma are separated by a **capillary membrane**, which is relatively permeable, allowing the molecules to easily move across the membrane.

An exception to this is intravascular protein albumin, which does not move easily along the capillary membrane, thus exerting osmotic pressure to keep the fluid within the blood vessels, protecting from being drawn into the interstitial space. If this would happen, it would result in low blood pressure and extravascular fluid accumulation, which is **edema** if it is localized and **anasarca** if it is systemic throughout the body. The osmotic pressure exerted by proteins, such as albumin, is called as **oncotic pressure**.

Tonicity: A measure of the **effective osmotic gradient** between two fluids separated by a semipermeable membrane. It is influenced only by the solutes which cannot cross the membrane.

Based on the tonicity, fluids are divided into three types:

Hypertonic solution

The solution with a **higher concentration of solutes** outside the cell than inside the cell. When a cell is immersed into a hypertonic solution, the tendency for water is to flow out of the cell in order to balance the concentration of the solutes causing the cell to **shrink in size**.

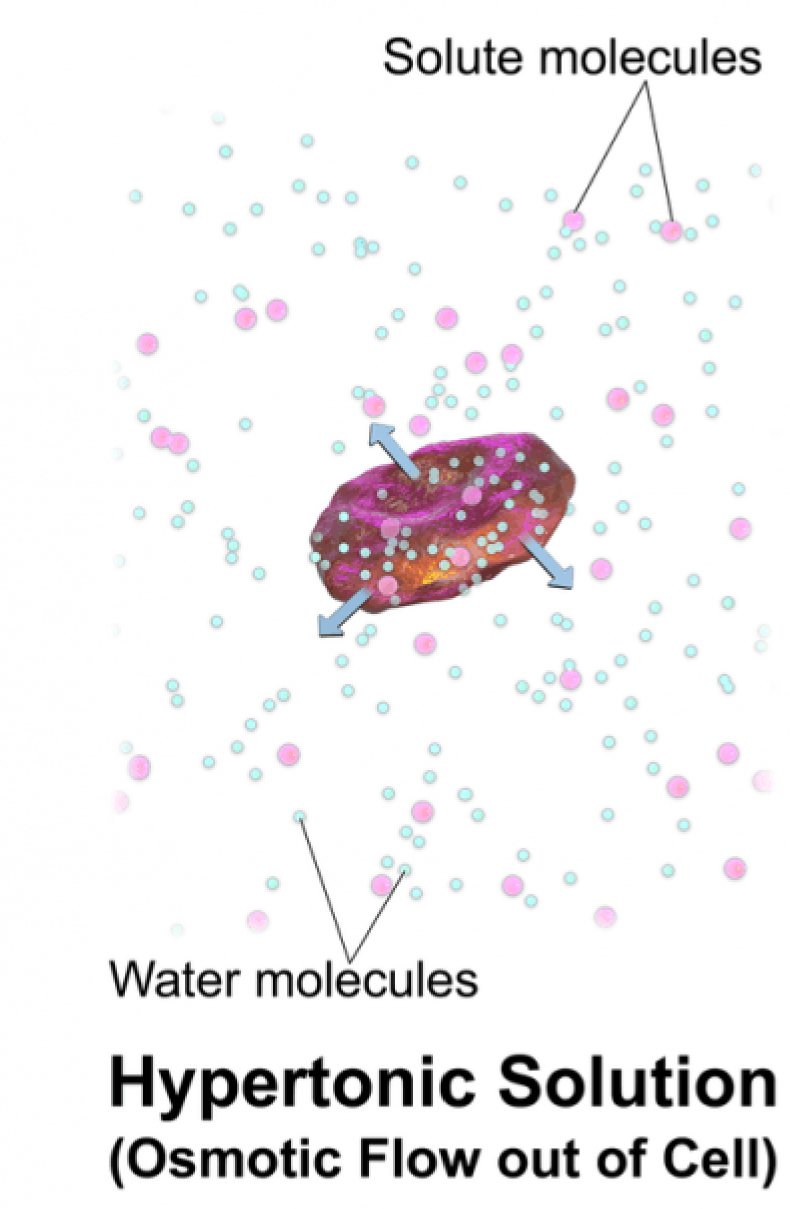


Image: "A red blood cell in a hypertonic solution, causing water to move out of the cell." by BruceBlaus. License: CC-BY 3.0

Hypotonic solution

The solution with a lower concentration of solutes outside the cell than inside the cell. When a cell is immersed into a hypotonic solution, in an attempt to balance the concentrations of solutes inside and outside the cell, water will rush into the cell causing it to expand in size and thus **bursting**.

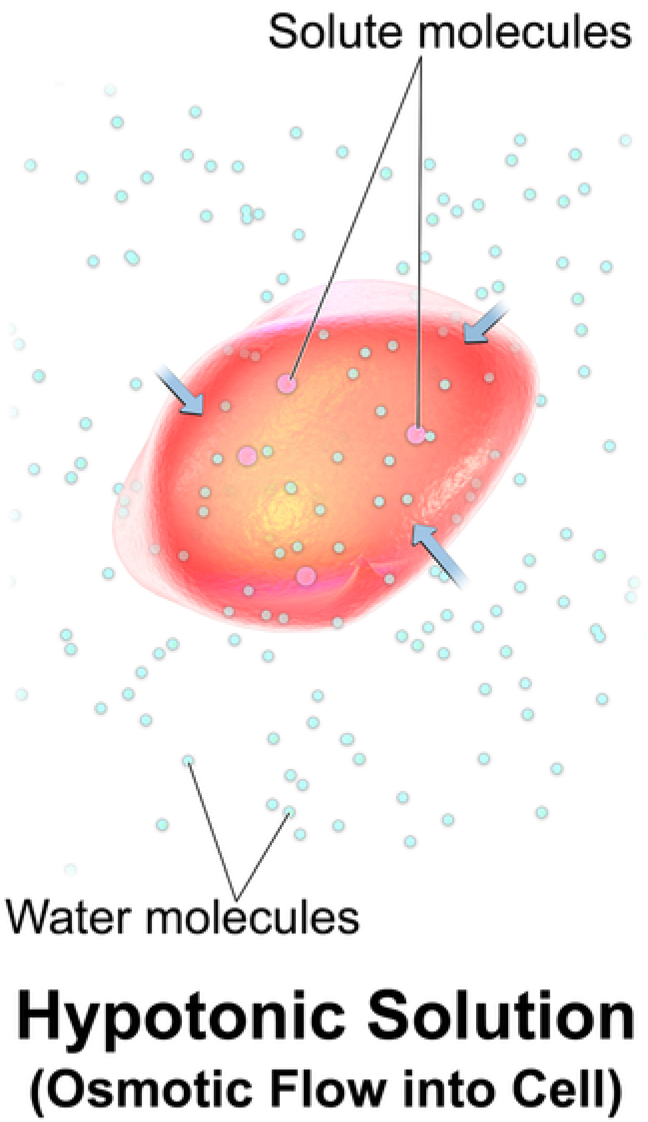


Image: "A red blood cell in a hypotonic solution, causing water to move into the cell." by BruceBlaus. License: CC-BY 3.0

Isotonic

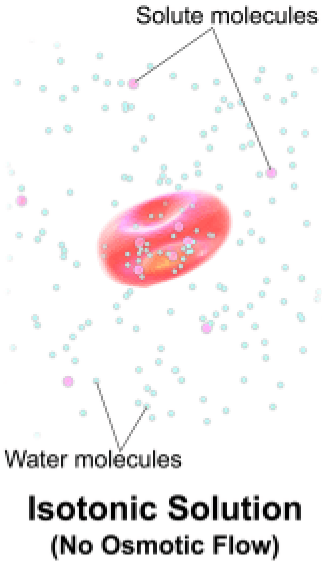


Image: "Depiction of a red blood cell in an isotonic solution." by BruceBlaus. License: CC-BY 3.0

A solution having the effective osmolar concentration; its solute concentration is not the same like the one of the cell. In this case, the **cell neither swells nor shrinks** because there is no concentration gradient for water across the cell membrane.

Osmolarity of **water is zero**; infusion of water will result in an immediate decrease in plasma osmolarity, making the blood hypotonic relative to the interior of the RBC. There will be a flow of water into the RBC until the concentration gradient is the same. This results in the **swelling of the RBC and eventual lysis**.

Osmolality, intracellular volume, and extracellular volume are represented by the **Darrow-Yannet diagram** (this will be discussed in a later section).

Types of IV Fluids

Crystalloids

Crystalloids contain **organic or inorganic** salts dissolved in **sterile water**. Most commonly used solutes in crystalloids are **glucose and sodium** chloride. Crystalloids are the electrolyte solutions, which have a relatively low tendency to cross plasma membranes.

- Most commonly used crystalloids are **normal saline (NS)** and **lactated Ringer's (LR)**. Normal saline contain 0.9 % sodium chloride and lactated Ringer's contain sodium chloride (6 g/L), sodium lactate (3.1 g/L), potassium chloride (0.3 g/L) and calcium chloride (0.2 g/L).
- **Half-normal saline** (1/2 NS) has half the concentration of NaCl i.e. 0.45 % NaCl.
- **D5W** composed of 5 % dextrose in water. D5W is isotonic to the serum. It contains glucose, which is instantaneously metabolized when D5W enters the circulation.

Properties of crystalloids

- **Do not readily cross plasma membranes**, but do readily cross capillaries.

- They remain in ECF.
- Distributed evenly within ECF, readily diffusing across capillary walls to equilibrate between intravascular (plasma, ECV) and interstitial volume.
- They are indicated in the **loss of plasma (hypovolemia)** caused by trauma, burns and post-operative patients.
- Crystalloids, when compared to colloids, have **low plasma expansion efficacy**. Colloids are rapid plasma expanders.
- Both crystalloids and colloids show **same efficacy**. Many studies reported equal survival rate of patients treated for fluid resuscitation, both with colloids or crystalloids.
- **Examples** of crystalloids are **normal saline, ½ normal saline, D5W and ringer lactate**.
- Crystalloids are **fluid of choice** due to its **low cost, as compared to colloids**.

Table: Composition of common crystalloid solutions

Fluid	Na^+ meq/l	Cl^- meq/l	K^+ meq/l	Ca^{2+} meq/l	Glucose g/l	Buffer meq/l	Osmolarity Mosm/l	Tonicity	Indication
Normal Plasma	140	100	4	2.4	0.85	HCO_3 24	290	n/a	n/a
0.9% saline	154	154	0	0	0	0	308	Isotonic	Resuscitation
0.45% saline	77	77	0	0	0	0	154	Hypotonic	Maintenance
Ringer lactate (Hartmann's solution)	130	109	4	3	0	Lactate 28	273	Isotonic	Resuscitation
D5W	0	0	0	0	50	0	252	Hypotonic	Hypernatremia Hyperglycemia

Crystalloids, when administered in **large volumes**, can cause **tissue edema (gastrointestinal)**. Infusion of large volumes of normal saline, even after correction of intravascular volume, can lead to a **normal anion gap metabolic acidosis**.

Ringer lactate is **contraindicated** in:

- **Hyperkalemia**: due to presence of K^+
- **Concurrent blood transfusion**: due to binding of Ca with citrate in blood products.
- With drugs such as **amphotericin, ampicillin, and thiopental** (can bind with these drugs)

D5W can cause **pediatric death** due to **hyponatremia** caused by the **excess administration of dextrose solution**.

Colloids

These are the electrolyte solutions, which have a relatively high tendency to stay intravascular. They **contain large proteins** that generally **do not cross capillary walls**.

Colloids are used as **plasma expanders** indicated in conditions such as burns, hypovolemic shock, trauma and tissue damage. Colloids **do not have the oxygen carrying capacity**.

Examples of colloids

Natural: Albumin, fresh frozen plasma

Synthetic: Dextran, hydroxyl ethyl starch (HES), gelatin.

Properties of colloids

- Colloids are **expensive**; however, they **exhibit fast plasma expansion**. They also have a **longer duration of action**.
- Volume expansion due to colloid is determined by its molecular weight and concentration.
- Colloids are typically **used for resuscitation** in **severe hypovolemia**. **Major side effects** of synthetic colloids include **allergic reactions (anaphylaxis), coagulation abnormalities, renal failure**.
- Most commonly used colloids are **HES and gelatin**. HES are **natural polysaccharides**. It is **least allergic** among the colloids.
- The recommendation to use colloids was **restricted** in October 2013 due to studies that showed an increase in renal failure and a decrease in the overall survival rate. However, in September 2014, methodical flaws and contradictions in those studies could be shown. The use of colloids and their side effects is still the **subject of research** and, if possible, a treatment with crystalloids should be preferred until further studies may bring clarification.
- Colloids interfere with the **coagulation factor VII**; thus cause coagulation abnormalities.
- Gelatins are obtained from the degradation of animal collagen. Gelatin shows a short duration of action.
- **Albumin and dextran** (use is abandoned due to adverse effects) are **rarely used**. **Dextran** is a **linear polysaccharide**. It is available as **dextran-40** (molecular weight 40.000) and **dextran-70** (molecular weight 70.000).

Distribution of IVFs

1. Infusion of 1 L of normal saline (NS)

- Entire liter will remain in ECF
- Will distribute within ECF, equilibrating between intravascular and interstitial spaces:
    - 250cc (1/4) will remain in **intravascular space (plasma)**
    - 750cc (3/4) will enter interstitial space

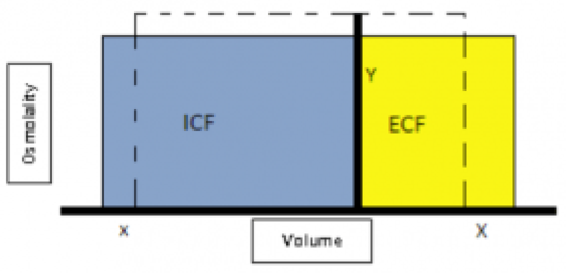
2. 1 L of ½ NS: Equivalent to 500cc of free water + 500cc of NS

- 500cc free water will distribute within TBW: Equilibrating between ECF and ICF,167cc (1/3) will remain in ECF,333cc (2/3) will enter ICF
- 500cc equivalent to NS: will distribute within ECF, 667cc total will remain within ECF and will equilibrate **between intravascular and interstitial volumes**, 167cc (1/4) will remain in intravascular space. 500cc (3/4) will enter the interstitial space.

3. 1 L of D5W: Equivalent to 1 L of pure water

Will completely equilibrate between ECF and ICF, 333cc (1/3) will remain in ECF, 667cc (2/3) will enter ICF. 333cc in ECF will equilibrate between intravascular and interstitial volumes. 83cc (1/4) will remain in intravascular space, 250cc (3/4) will enter interstitial space.

Darrow-Yannet Diagrams

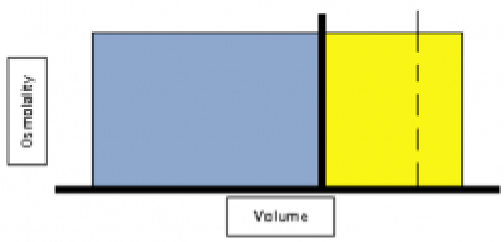


A Darrow-Yannet diagram: Osmolality on Y-axis and volume on X-axis. Source: Medceron/Lecturio

- A **Darrow-Yannet diagram** is used to study the **effect** of various clinical conditions, such as dehydration, shock, vomiting, and diarrhea on **osmolality and volume** of **extracellular and intracellular fluid**.
- **Osmolality (on the Y-axis)** is represented by **mOsm/kg H_2O,** while **volume (on the X-axis)** is represented in **liters**.
- In Darrow-Yannet diagram, a **solid line signifies normal values** and **dashed lines** signify a **change in the volume and osmolality** (concentration of solutes in ICF and ECF).

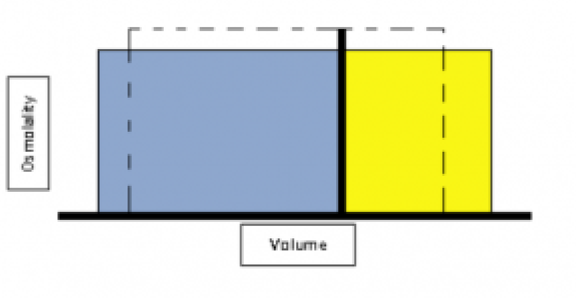
Changes in fluid compartments in various clinical scenarios

- In acute fluid loss conditions like **hemorrhage, diarrhea, and vomiting**, there is a decrease in ECF Volume and no change in body **osmolality and ICF Volume**. The Darrow-Yannet diagram for such conditions is depicted here:



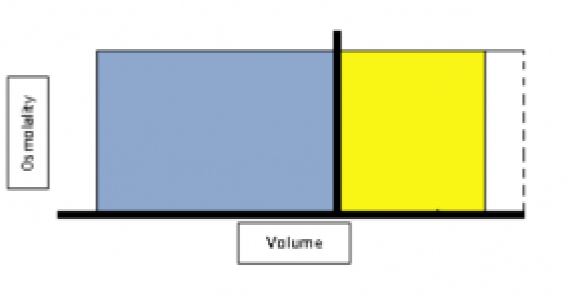
Source: Medceron/Lecturio

- In the loss of hypotonic fluid in conditions like **dehydration, diabetes insipidus, and alcoholism**, there is a decrease in ECF volume and ICF volume, but an increase in body osmolality. The Darrow-Yannet for such conditions is depicted here:



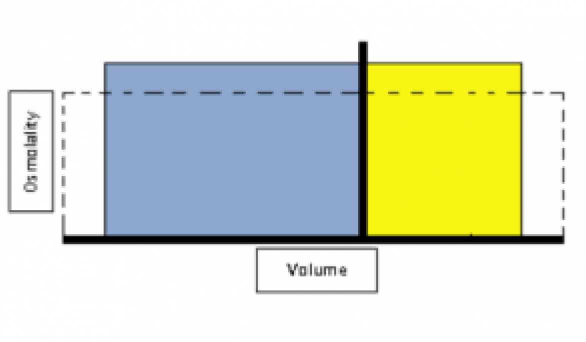
Source: Medceron/Lecturio

- In conditions with a gain of isotonic saline, there is an increase in ECF volume, but no change in osmolality and ICF volume. The Darrow-Yannet diagram for such conditions is depicted here:



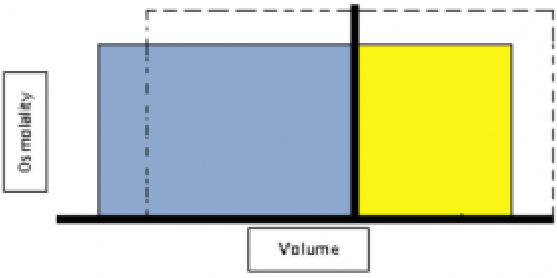
Source: Medceron/Lecturio

- In conditions with a gain of hypotonic fluid as in infusion of hypotonic saline or water intoxication, there is an increase in ECF and ICF volume, but a decrease in body osmolality. The Darrow-Yannet diagram for such conditions is depicted here:



Source: Medceron/Lecturio

- In conditions with a gain of hypertonic saline as in infusion of hypertonic saline or **hypertonic mannitol**, there is an increase in ECF volume and body osmolality, but a decrease in ICF volume. The Darrow-Yannet diagram for such conditions is depicted here:



Source: Medceron/Lecturio

IVFs Summary

Component	Clinical effect
Packed RBCs	Increase Hb and O_2 carrying capacity in conditions such as acute blood loss, severe anemia
Platelets	Stop significant bleeding in quantitative and qualitative platelet dysfunction condition
Fresh Frozen Plasma (FFP)	Increase levels of coagulation factors in coagulation consuming conditions such as DIC, cirrhosis, and to manage immediate warfarin reversal
Cryoprecipitate	Contains fibrinogen, fibronectin, factor VIII, vWF, and factor XIII used to treat factor VIII dysfunction diseases including hemophilia A, vWD
Blood transfusion risks include transfusion reactions (TACO, TRALI), hemochromatosis, citrate chelation of Ca^{++}, hyperkalemia from lysing of RBCs from old blood units	

Review Questions

The answers are below the references.

1. A Darrow-Yannet diagram is used to study the effect of various clinical conditions on the volume of ICF and ECF. Which of the following parameter is present on the Y-axis of the curve?

A. Osmolality
B. Osmolarity
C. Volume
D. Oncotic pressure
E. Osmotic pressure

2. What effect will there be on a cell when immersed in a hypotonic solution?

A. Bursting
B. Shrinking
C. No-effect
D. Chemical modifications
E. Morphological modifications

3. The composition of D5W is?

A. 0.9% NaCl
B. 5% dextrose
C. 5% dextran
D. 10% KCl
E. 5% CaCl2

References

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Correct answers: 1A, 2A, 3B

Notes