Box 5.1 Benefits of calcium and magnesium precipitation for water absorption by the intestine of marine teleost fish

Approximately 85 per cent of the volume of seawater that passes through the gastrointestinal tract of marine teleosts is absorbed from the intestine. Hence, for every litre of seawater imbibed, 850 mL are absorbed and 150 mL of fluid passes out of the gut. Based on these values, we can calculate the concentrations of Ca^{2+} and Mg^{2+} that would theoretically occur in the fluid voided from the rectum as few of these ions are absorbed from the imbibed seawater. Figure A(i) shows the calculated values.

- At the starting concentration for Ca^{2+} in seawater of 10 mmol L^{-1} (assuming no Ca^{2+} absorption from the intestine) the Ca^{2+} concentration in excreted fluid would equal 67 mmol L^{-1} (10 (mmol L^{-1}) × 1000/150 (mL/mL)).
- At a starting concentration of Mg^{2+} in seawater of 44 mmol L^{-1} (assuming no Mg^{2+} absorption from the intestine) the Mg^{2+} concentration in excreted fluid would equal 293 mmol L^{-1} (44 (mmol L^{-1}) × 1000/150 (mL/mL)).
- The sum total of Ca^{2+} and Mg^{2+} concentrations equals 360 mmol L^{-1}. This high concentration of divalent cations would restrict water absorption from the intestinal lumen as osmolality reaches a balance with the extracellular fluids.

Compared to these theoretical quantities, Figure A(ii) shows the benefits of bicarbonate secretion by the intestine of teleosts living in seawater, based on measured concentrations:

- Measured concentrations of HCO_3^- and CO_3^{2-} for rainbow trout acclimated to seawater indicate a total excretion of 115 mmol L^{-1}.
- The measured Ca^{2+} concentration of 2 mmol L^{-1} in excreted rectal fluid, compared to the theoretical value of 67 mmol L^{-1}, indicates that 97 per cent (((67-2)/67) × 100) of dissolved Ca^{2+} has been removed from solution.
- The measured Mg^{2+} concentration of 170 mmol L^{-1} in excreted rectal fluid indicates that 42 per cent (((293-170)/293) × 100) of the dissolved Mg^{2+} has been removed from solution.
- Carbonate precipitation as complexes with calcium and magnesium results in an overall difference in the measured total concentration of dissolved ions of 73 mmol L^{-1} (360-287)[1]. The reduction in ion concentrations reduces the osmolality of the intestinal fluids by approximately 70 mOsm kg^{-1} (assuming 1 mole equals 1 Osmole[2]). Given a plasma osmolality of about 350 mOsm kg^{-1}, carbonate precipitation effectively creates about a 20 per cent difference in the osmotic concentration between the intestinal fluid and extracellular fluid, which enhances water absorption from the intestine, by osmosis.

[1] Interactions between ions can reduce their effective concentrations (ion activities), as we discuss in Box 4.1, so ion activities may differ slightly from the measured concentrations.

[2] Section 4.1.1 discusses the relationships between osmolality (Osm kg^{-1}), osmolarity (Osm L^{-1}) and molarity (mol L^{-1}); a 1 molar ideal solution has an osmolarity of 1 Osmolar (1000 mOsm L^{-1}).

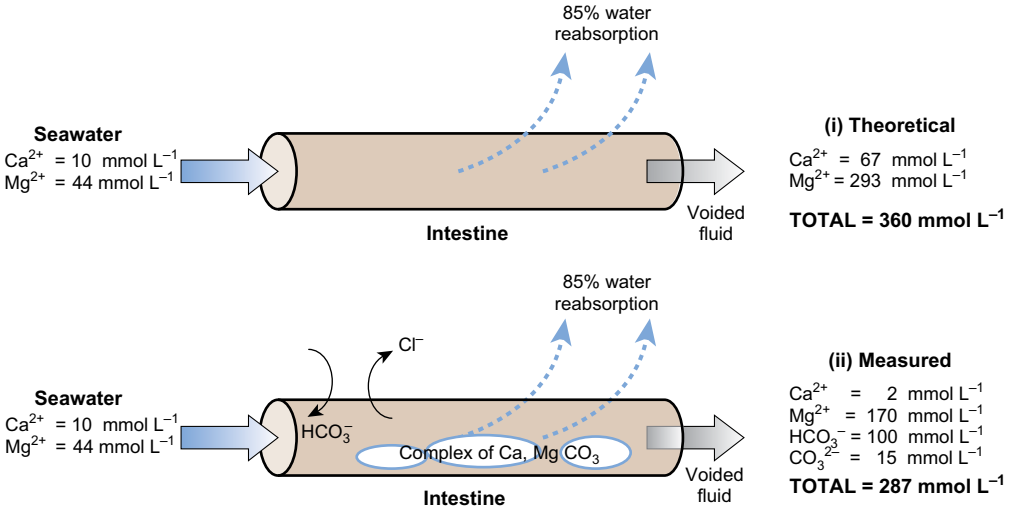

Figure A Effect of bicarbonate secretion by the intestine of rainbow trout (*Onchorynchus mykiss*) acclimated to seawater on ion concentrations in rectal fluid

The intestine is represented as a tube along which seawater flows after drinking. The concentrations of Ca^{2+} and Mg^{2+} in the seawater are shown on the left side of the diagram.

(i) Theoretical concentrations of Ca^{2+} and Mg^{2+} in the rectal fluid if normal amounts of water are reabsorbed (85 per cent of the volume imbibed), assuming no Ca^{2+} or Mg^{2+} are reabsorbed.

(ii) Measured concentrations of ions. The precipitation of calcium and magnesium as carbonate complexes in the intestine reduces the total concentration of dissolved ions.

Source: adapted from Wilson RW et al (2002). Review. Intestinal bicarbonate secretion by marine teleost fish - why and how? Biochimica et Biophysica Acta 1566: 182–193.