Deacon's Challenge No. 31 Answer

The normal pH of plasma is 7.40: the minimum pH of urine is 4.5. Assuming an average urine volume of 1.5L/24h, estimate the limit of titratable acidity of the urine, indicating what assumptions you make.

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Acid in urine exists as free hydrogen ions and hydrogen ions bound to salts (i.e. buffered). The two principal buffers in urine are phosphate and ammonia:

$$H^+ + HPO4^{2-} \rightarrow H_2PO_4^- \qquad pK_a = 6.8$$
$$H^+ + NH_3 \rightarrow NH_4^+ \qquad pK_a = 9.8$$

By convention, titratable acidity of urine is defined as the amount of acid consumed when urine is titrated with alkali to the pH of the glomerular filtrate (the same as plasma pH i.e. 7.40).

Since the pK_a of the ammonium ion is at least 2 pH units above the plasma pH, it exists almost entirely as NH_4^+ and there is virtually no free ammonia available for buffering secreted acid. Therefore, ammonium ions do not contribute significantly to titratable acidity. Similarly, at pH 4.5 bicarbonate (pKa 6.1) is virtually completely consumed. By contrast, the pK_a of phosphate is close to blood pH and is present in sufficient amount to act as the primary urinary buffer.

The amount of phosphate available for buffering, i.e. the amount of HPO_4^{2-}, can be calculated from the Henderson Hasselbach equation, the plasma pH and the urinary total phosphate:

$$pH = pK_a + \log_{10} \frac{[HPO_4^{2-}]}{[H_2PO_4^-]}$$

$$7.40 = 6.8 + \log_{10} \frac{[HPO_4^{2-}]}{[H_2PO_4^-]}$$

$$\frac{[HPO_4^{2-}]}{[H_2PO_4^-]} = \text{antilog}_{10}(7.4 - 6.8) = \text{antilog}_{10}\,0.6 = 3.98$$

If the total amount of urinary phosphate is known, then the amount of each species of phosphate can be calculated:

$$[\text{Total phosphate}] = [HPO_4^{2-}] + [H_2PO_4^-]$$
$$[H_2PO_4^-] = [\text{Total phosphate}] - [HPO_4^{2-}]$$

$$\frac{[HPO_4^{2-}]}{[\text{Total phosphate}] - [HPO_4^{2-}]} = 3.98$$

Rearranging and solving for $[HPO_4^{2-}]$:

$$[HPO_4^{2-}] = 3.98\,[\text{Total phosphate}] - 3.98\,[HPO_4^{2-}]$$
$$[HPO_4^{2-}] + 3.98\,[HPO_4^{2-}] = 3.98\,[\text{total phosphate}]$$
$$4.98\,[HPO_4^{2-}] = 3.98\,[\text{Total phosphate}]$$
$$[HPO_4^{2-}] = \frac{3.98\,[\text{Total phosphate}]}{4.98} = 0.80\,[\text{Total phosphate}]$$

The total phosphate concentration is not given. The daily excretion of phosphate is extremely variable and reflects dietary intake. One quoted range is 16-48 mmol/24 h. Therefore it would be reasonable to assume a value of 50 mmol/24 h as an estimate of the maximum daily excretion likely to be encountered. Therefore:

$$\text{Amount of } HPO_4^{2-} \text{ in 24 h urine} = 0.80 \times 50 = 40 \text{ mmol}$$

N.B. no use is made of the 24 h urinary volume.

At a urine pH of 4.5, (at least 2 pH units below the pKa of phosphate), essentially all HPO_4^{2-} is consumed by buffering H^+, and the component of titratable acidity due to phosphate is therefore approximately 40 mmol.

At a pH of 4.5 the free hydrogen ion concentration can be calculated as follows:

$$pH = \log_{10} \frac{1}{[H^+]} \quad \text{and} \quad [H^+] = \frac{1}{\text{antilog}_{10}\,pH}$$

$$[H^+] = \frac{1}{\text{antilog}_{10}\,4.5} = \frac{1}{31623} = 0.000032 \text{ mol/L} = 0.032 \text{ mmol/L}$$

which is small enough to be ignored.

Therefore the limit of titratable acidity can be estimated as approximately **40 mmol/24 h** if the following assumptions are made:

1. Free hydrogen and bicarbonate ions and ammonia do not contribute significantly.
2. Phosphate is the major urinary buffer.
3. Other forms of phosphate (H_3PO_4 and PO_4^{3-}) are insignificant.
4. The maximum likely phosphate excretion is 50 mmol/24 h.

Question No. 32

A laboratory performs sweat tests by collecting sweat for 20 min using 5.5 cm filter paper disks. In order to comply with the proposed Sweat Test Guidelines that the sweat secretion rate should exceed 1 g/m²/min what is the mimimum weight of sweat that should be collected?