Chapter 12  Phosphate Minerals in Human Tissues

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Introduction

The mineralized or calcified tissues in biological systems are composed of two phases: organic and inorganic or mineral phases. In the invertebrates (e.g., echinoderms, mollusks, arthropods, etc.), the inorganic phase is usually calcium carbonate, CaCO₃, predominantly in the form of either calcite or aragonite or both. In the invertebrates, the inorganic phase consists of one or more types of phosphate minerals (predominantly calcium phosphates) depending on the nature of calcification, i.e., normal (e.g., bones and teeth) or abnormal or pathological (e.g., dental calculi, salivary and urinary stones, soft tissue calcifications, etc.). In several pathologically calcified tissues, the mineral is non-phosphatic, such as calcium oxalates (whewellite and weddellite), sodium urates, uric acid, cysteine.

The main purpose of this chapter is to review the occurrences and types of phosphate minerals in human tissues. Considered in this review are: (a) factors influencing the formation of the phosphate minerals in vivo and in vitro; (b) the co-existence of one type of phosphate mineral with another phosphate or non-phosphate mineral(s); and (c) their in vivo and in vitro transformations from one type of phosphate mineral to another. The background material was obtained from earlier reviews (21, 22, 40, 46, 83, 84, 95, 100–103, 105, 107, 108, 113, 117). Much of the illustrated experimental data are from past and current work of the authors (47–78, 116).

Occurrences of Phosphate Minerals in Human Tissues

Being the main inorganic constituent of bones and teeth, the most abundant mineral in human tissues is a basic calcium phosphate idealized as calcium hydroxyapatite, Ca₁₀(PO₄)₆(OH)₂. Other calcium phosphates [brushite or DCPD, CaHPO₄·2H₂O; octacalcium phosphate, Ca₈H₂(PO₄)₆·5H₂O; whitlockite or tricalcium phosphate, β-TCP, β-Ca₃(PO₄)₂; calcium pyrophosphate dihydrate (mono- and tri-clinic forms), CPPD, Ca₂P₂O₇; amorphous calcium phosphates, ACP]; and magnesium phosphates [struvite, MgNH₄PO₄·6H₂O; newberyite, MgHPO₄·3H₂O; amorphous calcium magnesium pyrophosphate, or calcium magnesium phosphate, ACMP] have been identified with or without association with apatite,
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A.

B.

C.

D.

Fig. 1. X-ray diffraction patterns of some phosphate minerals in human tissues. A Tooth enamel; B dentine; C amorphous calcium phosphate (ACP) containing Mg\(^{2+}\) plus CO\(_3\)\(^{-}\); D ACP containing Mg\(^{2+}\) plus P\(_2\)O\(_5\)\(^{-}\). A and B are from normal calcifications, C and D, from pathological soft tissue calcifications. The X-ray diffraction pattern of bone is similar to that of dentine, B.

as constituents of pathological calcifications (1, 13, 14, 16, 22, 24, 30, 78, 91–99, 105).

Apatites in normal calcified tissues of teeth and bone have been postulated to form either directly or indirectly by way of precursor calcium phosphates such as ACP, DCPD, OCP or TCP (1, 13, 14, 30, 39, 93, 99, 105). The presence of any of the possible precursors has not been detected in the X-ray diffraction patterns of tooth (enamel, dentine) or of bone (Figs. 1A, B). In contrast, several types of phosphate minerals co-exist in some pathological tissue calcifications (e.g., DCPD, OCP, \(\beta\)-TCP, and apatite in dental calculi, urinary and salivary stones) as shown in Figs. 2B, C, and 3C). In some cases of pathological tissue calcifications, the phosphate minerals co-exist with non-phosphate minerals (e.g., calcium and magnesium phosphates with calcium oxalates in urinary stones; calcium phosphate dihydrate, CPPD, with sodium urates in pseudodepositions). “Apatitic” and amorphous calcium phosphate deposits have been observed in articular, tumoral (Figs. 3A, B) and non-visceral calcifications in uremic patients (17, 59), in aortic valves (43) and pulmonary, ectopic and other extra-osseous calcifications (1, 12, 38, 106, 112).