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Morphology, microstructure and composition of two mixed kidney stones and their relation with pathogenesis

T. Topór (1) and E. Koszowska (2)

(1) Institute of Geological Sciences, Polish Academy of Sciences, Kraków, Poland (ndtopor@cyf-kr.edu.pl), (2) Institute of Geological Sciences, Jagiellonian University, Kraków, Poland (ewa.koszowska@uj.edu.pl)

Identification of the mixed stones components requires application of several analytical methods. Precise analysis of individual stone layers could be relevant for better understanding the pathogenesis of stone formation. Two mixed kidney stones (KS1, KS2), taken from patients who underwent surgery for kidney stone removal, were the objectives of the presented investigations. Observations of morphology and microstructure, identification of mineralogical phases, chemical composition and crystallographic features of KS1 and KS2 stones have been carried out using broad spectrum of analytical methods such as transmitted light microscopy, scanning electron microscopy (SEM with patterns obtained in SE and BSE beams) equipped with an energy dispersive spectrometer EDS, infrared spectroscopy (FTIR) and X-ray powder diffraction (PXRD). The shape of the KS1 stone indicated "staghorn" type of calculi, whereas the KS2 stone was classified as "non-staghorn" type. Both stones showed the layered structure macroscopically and under optical microscope. Three layers of the KS1 stone (KS1c-core, KS1e-external zone, KS1b-black coat) were composed of carbonate apatite with admixture of magnesium phosphate, whewellite (COM) with small amounts of apatite and organic matter, respectively. Two layers of the KS2 stone (KS2c-core, KS2e-external) consisted of whewellite with admixture of apatite and weddellite (COD), respectively. The observation in SEM under high magnification showed different forms of apatite: microcrystals, spherical nanoparticles and imprints of bacterial species. Moreover, structures resulting from dissolution of whewellite and weddellite crystals, pseudomorphs of whewellite after weddellite as well as the transformation of magnesium phosphate (struvite?) into another hydrated phase were noticed. The differences in chemical composition of carbonate apatite from the both stones were recognized. In the KS1 stone notable admixture of magnesium (up to 5 wt.% of MgO) in apatite was characteristic, whereas the chemical composition of KS2 stone was a typical bioapatite (up to 1 wt. % of MgO). Optical and electron microscopic identification of distinguished layers phases of KS1 and KS2 stones were confirmed by IR and PXRD methods. The precise analyses of these layers were applied to reconstruct the pathogenesis of the stones formation with emphasis on the successive steps of crystallization. Various mechanisms of the growth were demonstrated. Randall's plaque model and the free particle model were used to show initial crystallization of KS1 and KS2 stones, respectively. To reconstruct the successive steps of crystallization, changes of pH, supersaturation of Mg, Ca, PO, CaOx ions, Mg/Ca ratio, as well as the problem of infection and macromolecules in urine and some clinical aspects have been taken into consideration.

Keywords: nephrolithiasis, mixed stones analysis, optical microscope, SEM EDS, IR, PXRD, pathogenesis.