

The Varying Composition of the Nucleus and Peripheral Layers of Urinary Calculi

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Summary. The chemical composition of the different mineral phases in the nuclei and peripheral coatings of 200 urinary calculi was investigated by X-ray diffraction. The nuclei were found to contain 7 different substances. There was no relationship between the mineral composition of the nucleus and periphery. Scanning electron microscopy showed the absence of an organized aggregate structure in the mineral crystals in the nucleus. Since every mineral phase in the urolith can act as potential nucleus for new stone formation, this property must be taken into account in the prophylaxis of recurrent nephrolithiasis.

Key words: Urinary calculy - stone formation - core - shell - mineralphases.

Urinary calculi are not homogeneous in composition and contain concretions of many mineral substances. These are built up in layer formations visible to the naked eye. Prien and Frondel (3) found that calcium phosphate was present in the centre of almost all stones, with the exception of uric acid and cystine calculi. Lagergren (2) showed that nuclei composed of uric acid could be demonstrated in oxalate stones. Boyce (1) has postulated that complexes can be formed by the so-called calcium mucopolysaccharides and that crystallization may then occur in the presence of phosphate ions. The nucleus of the calculus grows in size by the deposition of activated mucoproteins in layers accompanied by precipitation of crystalline material. Boyce noted the similarity between this process and the systematic mineralization of bone.

The purpose of this study was to determine whether the composition of the nucleus and outer layers of urinary calculi varied both chemically and structurally, and to what extent the observations of Prien (3, 4, 5) and Lagergren (2) applied to the calculus material studied.

Materials and Methods

Two hundred different urinary calculi, which had been surgically removed, were investigated. The calculi were divided by a fine saw through the centre. Samples weighing about 20 mg were re-

moved with a thin needle from the central area enclosing the nucleus and also from the peripheral area. This operation was carried out under the microscope. The samples were carefully ground to a fine powder, transferred to glass slides, and examined by X-ray diffraction in order to determine their composition.

The principle of the method is based on the scattering of X-rays by crystalline structures. Crystal structure is determined by the specific spatial arrangement of the constituent ions according to precise physical laws and each crystal has its own individual lattice constants which can be measured by X-ray diffraction.

An unknown sample from a stone can therefore be identified by comparison with a set of standard values for known calculus constituents.

The use of scanning-beam electron microscopy has given the investigation of surfaces new impulses. This method makes possible illustrations of the relief structure enlarged up to 30 000 times. The illustrated impression has an almost 3-dimensional character. A beam of electrons, produced in a cathode, is focussed as a small point through electronic lenses on the area to be tested. This point feels the area, which has been coated with electrical conductive material, we used gold, scanning the surface horizontally or vertically. Electrons are reflected, caught, amplified, and projected on a screen.

Results

Seven different minerals were identified in the nuclei of the large urinary calculi investigated (the smaller stones were fully used for routine radiographic analysis). The minerals were:
3 phosphates: apatite, struvite and whitlockite
2 oxalates: whewellite and weddellite
as well as uric acid and cystine.

The composition of the peripheral layers is shown in the following 3 tables:

a) Phosphate nuclei (Tab. 1). 1) When the nucleus was composed of apatite, 11% of the stones investigated had a shell of apatite-struvite, 16% had a shell of apatite, whewellite and/or weddellite, while the shell was composed of apatite, whewellite and struvite in 1% of cases and of apatite, whewellite, weddellite and uric acid in a further 2%. 2) When a struvite nucleus was present, the following shells were found: in 17% of cases, struvite and apatite; in 3% struvite, apatite, whewellite and/or weddellite, while struvite was the sole shell in 1% of cases. 3) A peripheral shell of struvite and apatite was present in 1% of stones with a whitlockite nucleus.

b) Oxalate nuclei (Tab. 2) Nuclei consisting of the calcium oxalate monohydrate (whewellite) were about 5 times more frequently observed than nuclei composed of weddellite.

Table 1. Composition and frequency of Phosphate-Cores and their Shells

Core	Shell	Frequency	%
Apatite	+ Struvite	11	
	+ Whewellite and/or Weddellite	16	
	+ Whewellite and Struvite	1	30
	+ Whewellite and Weddellite and Uric Acid	2	
Struvite	+ Apatite	17	
	+ Apatite and/or Weddellite and Whewellite	3	21
	+ Struvite	1	
Whitlockite	+ Apatite	1	

Table 2. Composition and frequency of Oxalate-Cores and their Shells

Core	Shell	Frequency	%
Whewellite	+ Weddellite	19	
	+ Weddellite and Apatite	7	
	+ Weddellite and Uric Acid or Uric Acid-Dihydrate	3	32
	+ Struvite and Apatite	3	
Weddellite	+ Whewellite	4	
	+ Whewellite and Apatite	1	6
	+ Whewellite and Uric Acid	1	

1. When a whewellite nucleus was present, 19% of the calculi investigated had a shell of whewellite and weddellite while in 7% of cases there was present in addition. In 3% of cases the shell was of whewellite, weddellite while in 7% of cases there was apatite present in addition. In 3% of cases the shell was of whewellite, weddellite, uric acid or uric acid dihydrate, and in a further 3% of stones a shell composed of whewellite, struvite and apatite was present.

2. Three different types of shell were observed in stones with a weddellite nucleus. In 4% of cases this was of weddellite and whewellite, while apatite was present additionally in 1% of stones and uric acid also in a further 1%.

c) Uric acid nuclei (Tab. 3) In no case was the nucleus composed of uric acid dihydrate. Three different types of shell were again observed in stones with a uric acid nucleus:

In 2% of cases studied, the shell was uric acid, weddellite and/or whewellite. Uric acid and uric acid dihydrate was the shell in some cases and a mixture of all these 4 substances in some others.

d) Cystine nuclei. As expected these calculi had a cystine shell containing, in some cases, trace deposits of uric acid or urates.

The incidence of the different types of nuclei in the calculi studied is shown in Tab. 4. The frequency of occurrence of phosphate nuclei (52%) and, especially, apatite nuclei (30%) may be easily explained by the fact that the calculi used were all large unselected stones. As expected, phosphate

Table 3. Composition and frequency of Uric Acid- and Cystine-Cores and their Shells

Core	Shell	Frequency	%
Uric Acid	+ Weddellite and/ or Whewellite	2	6
	+ Uric Acid- Dihydrate	2	
	+ Uric Acid- Dihydrate and/or Whewellite	2	
Cystine	+ Cystine	4	

Table 4. Composition and frequency of urinary Calculi-Cores

Core	Frequency	(%)
Apatite	30	52
Struvite	21	
Whitlockite	1	
Whewellite	32	38
Weddellite	6	
Uric Acid	6	10
Cystine	4	

stones predominated in the specimens removed at operation while oxalate stones were frequently present among calculi which had been passed spontaneously.

Discussion

Unlike Prien (3) and Lagergren (2) we found, 7 different types of nuclear material and a wide variety of peripheral shells. The nucleus was generally composed of many small crystallites, i. e. an aggregate. Only rarely was the nucleus represented by a single crystallite.

A ground section of a largish elliptical stone is

shown in Fig. 1. The different concentric zones surrounding the centre of the stone can be differentiated clearly and it is recognizable that these zones have been formed from different phases. Even cursory examination shows that this stone has developed from a single nucleus. Such a nucleus represents an inoculum which facilitates the crystallization of identical or other components of calculi.

It is obvious from Fig. 2 that not only does the nucleus consist of many crystallites but also a single stone may have several nuclei. Close examination of the photograph shows that even a large nucleus may be the result of fusion of several smaller nuclei. Any of these small nuclei as well as the external small nuclei could have caused formation of a calculus. Both figures clearly show, on the basis of polarizing microscopical studies, that the formation of urinary calculi can be regarded as a regular process of aggregate formation (1).

The technique of polarization microscopy used to study uroliths has the disadvantage of poor resolution and of the necessity for preliminary grinding of the specimen, which causes mechanical destruction of the crystal aggregates. By contrast, the scanning electron microscope method requires no special preparation of the specimen other than the vacuum deposition of a layer of metal or carbon at least 100 Å thick.

A scanning electron microscopical (SEM) picture of a weddellite nucleus of a calculus is shown in Fig. 3. Whewellite crystals from the peripheral coat are present on the upper and lower borders; these crystals are randomly orientated to each other. A SEM picture of the centre of a phosphate nucleus shown in Fig. 4 likewise demonstrates the unorganized formation of mineral aggregates.

Unlike Boyce and Prien we are of the opinion that organized mineralization does not precede the formation of urinary calculi. Their results show the multiplicity of possible substances which can form nuclei. The calcium oxalate monohydrate (whewellite) was present 5 times more frequently than the dihydrated (weddellite). In no instance was uric acid dihydrate present as a nucleus.

The above observations lead to the conclusion that nuclei are formed in supersaturated solutions. The results show that there is no regular difference in the composition of the central and peripheral phases, with the exception of stones which have a secondarily formed shell of struvite, i. e. such as may occur in a patient suffering from urolithiasis associated with obstructive urinary tract infection. Otherwise most conceivable combinations of mineral phases can be observed in both the nuclear and peripheral areas.

Any of the mineral phases can act as a potential nucleus for new calculi. This is important in the management of urolithiasis where analysis of the constituents of the whole stone is an essential first step in the formulation of prophylactic measures to prevent recurrence of uroliths.

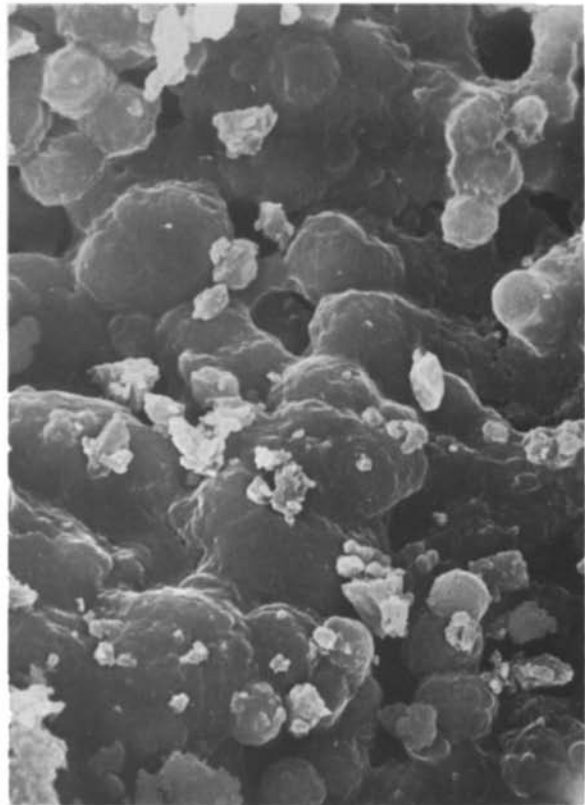
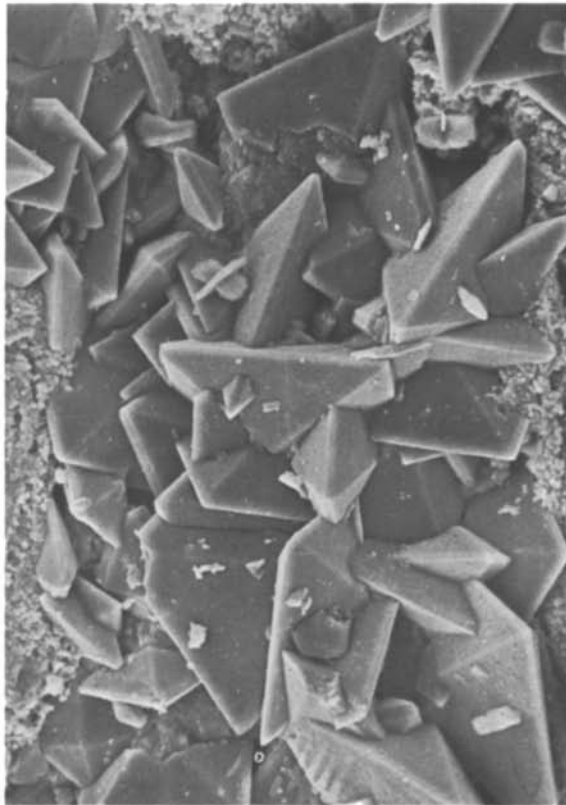
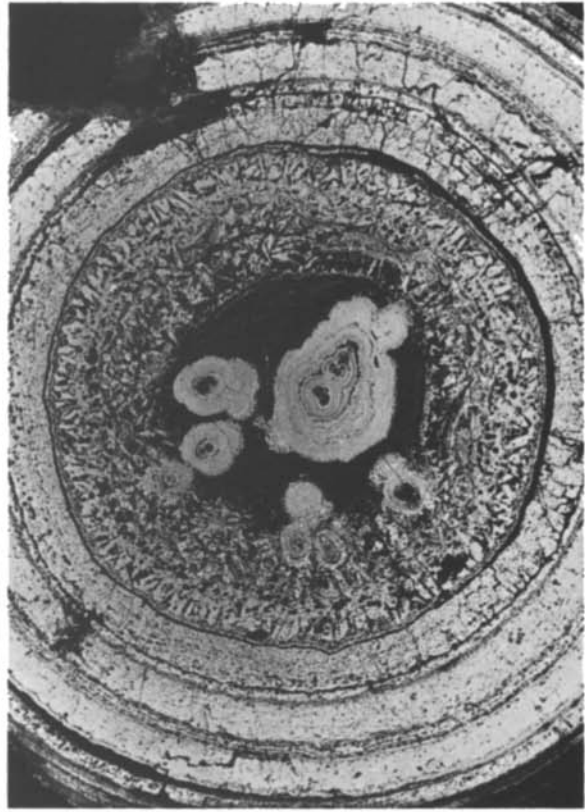
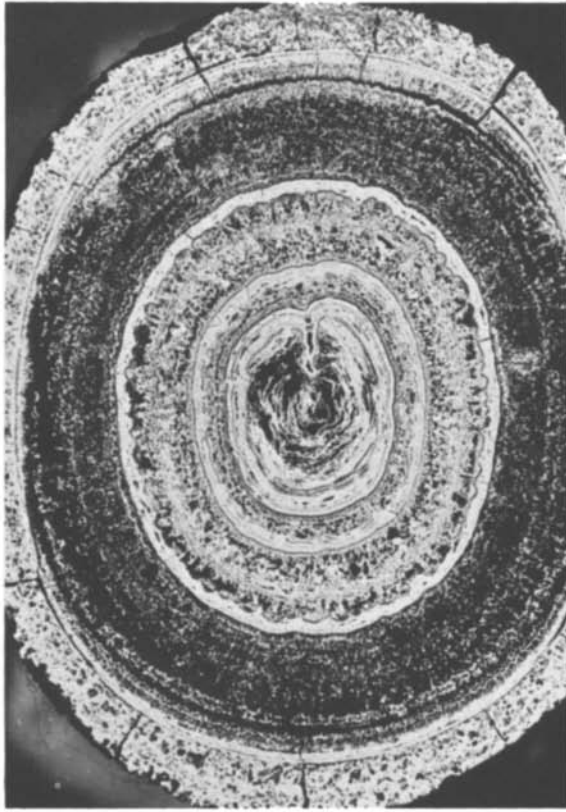


Fig. 1. A thin section of calculi with a single nucleus

Fig. 2. A thin section of calculi with several nuclei

Fig. 3. A scanning electron micrograph of a weddellite nucleus

Fig. 4. A scanning electron micrograph of a phosphate nucleus

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