DEDUCTION OF CHEMICAL COMPOSITION OF URINARY CALCULI BY RADIOLOGICAL MEANS

GEORGE COHEN, M.B., B.CH., D.M.R.D. (R.C.P. AND S.), *Department of Radiology, Johannesburg General Hospital*

The first X-ray diagnosis of urinary calculi was made by McIntyre[1] in 1896 and this diagnosis was confirmed at operation. Radiological reports refer to the presence of urinary calculi, but hardly ever attempt to deduce their chemical composition. Such deduction, can, however, often be made from an ordinary radiographic examination, and it may be of importance as pointing to the presence or absence of infection (for some stones develop only in infected urine) or as indicating that the stone will be easily crushed or crushed only with difficulty. It may even indicate the pH of the urine, e.g. in the renal calyces, where the pH may differ greatly from that of excreted or catheterized urine.

The chemical composition can be determined on the basis of the size, shape, situation, radiopacity or radiolucency, or number, of the calculi. Other important factors include the age of the patient, associated clinical signs and symptoms, and whether the calculi are uni- or bilateral.

Form and Structure

The external shape of all stones is influenced by that of the cavity in which they lie. The large 'stag-horn' calculi that form in the renal pelvis and calyces are most obvious examples of this. The nuclei of most stones are spherical, or nearly so, and it is probable that if the growth of a calculus were absolutely unrestricted it would remain a sphere.

Uric-acid calculi have round or oval nuclei, usually less than 5-7 mm. in diameter. The nucleus is devoid of lamination or radial striation and is radiologically homogeneous. It is surrounded by a series of concentric laminae, which usually have a regular or slightly wavy outline and are more or less of the same width in the same stone (though of different widths in different stones), unless the stone is oval shaped, in which case the laminae are thickest at the ends of the longest diameter. The surface is almost always smooth, but occasionally slightly mammillated.

Oxalate calculi are of 4 *types:*

(*a*) A small stone, which has the smoothest surface of all urinary calculi, is usually less than a pea in size, is always multiple, and is round in shape and rarely faceted.

(*b*) The 'mulberry' type, usually less than $1\frac{1}{2}$ inches in diameter. It is usually circular and the surface is often broken by mammillary processes, which are 4-5 mm. in height and 3-4 mm. in diameter at the bases and have nipple-shaped projections at the apices. These are the roughest and most irregular of all calculi. In the pelvis they are often triangular in shape and flattened from side to side owing to moulding. The mammillary processes may be entirely absent in portions close to the wall of the renal pelvis. A 'mulberry' or 'thorn-apple' stone in the bladder is to be diagnosed as an oxalate calculus.

(*c*) A rare type, which contains a few long thorny processes more than 1 cm. in length and less than 1-2 mm. in diameter. The thorny processes may be 1-8 in number. This is the 'Jack-stone' calculus of American uroradiologists. Stones of this type are smooth and are always in a dilated cavity (for example, a hydronephrotic cavity). With growth the spines increase in number and begin to become stunted in appearance, and the stone to resemble types *b* and *d*.

(*d*) The commonest type of uninfected calculus, often octahedral in shape with needle-like surfaces, but more often with flat plate-like surfaces. They are usually small, with the sharp points or edges projecting outwards from the body. If they impact in the upper ureter they may become smoother in appearance where they are in contact with the ureteric wall.

All oxalate calculi tend to change form with increase in size; the mulberry-like mammillated processes change to smoother forms. For example, one of the laminae may show well-marked mamillary processes but may be entirely covered by succeeding layers to assume a relatively smooth surface.

Phosphatic Calculi. 'Phosphatic' is a loose term for stones composed partially or wholly of phosphates. They may consist of either crystalline or amorphous calcium phosphate, of calcium magnesium ammonium phosphate, or of a mixture of these salts. There is usually a considerable mixture of calcium carbonate in 'triple phosphate' calculi and most phosphate calculi also contain calcium oxalate in small quantities, and other salts as well. The phosphate may be a deposit on the surface of a uric-acid or calcium-oxalate calculus.

(*a*) Crystalline stones of calcium phosphate are rare. They are smooth and dense, and have no distinct lamination but a definite radial striation.

(*b*) Amorphous phosphatic stones are commoner. They are usually mixed with triple phosphate. The outer parts show distinct inter-lamellar fractures. The surface is granular, and growth may be rapid to a degree where a cast of the cavity containing them is formed. A radial arrangement may occasionally be seen but is unusual.

(*c*) 'Triple phosphate' stones resemble type *b* but are smoother surfaced.

A 'stag-horn' stone in the renal pelvis of an adult may almost certainly be diagnosed as phosphatic.

Cystine calculi may be round or ellipsoid in the bladder but are usually 'stag-horn-like' in the kidney. A 'stag-horn' calculus in a child can be diagnosed as a cystine stone. They are smooth but occasionally have elevated mammillary processes which may make their outer border ill-defined. Irregular laminations and radial striations may be visible, the former sometimes being in the form of zig-zag streaks.

Density (i.e. relative radiopacity or radiolucency)

The density of calculi increases with increased atomic weight of the constituent elements; for example hydrogen (1), carbon (12), nitrogen (14), oxygen (16), sodium (23), magnesium (24), phosphorus (31), sulphur (32), potassium (39), calcium (40). For example, uric-acid stones ($C_5N_4H_4O_3$) are relatively translucent, whereas the common urinary calculi which are basically calcium phosphate containing a hydroxyl radicle[2] (having the mineralogic name of apatite) and of chemical formula $Ca_{10}(PO_4)_6(OH)_2$ are opaque. According to chemical composition the order of density

TABLE I

In decreasing order of density	*Order of incidence*	*Order of rate of growth*	*Age*	*Number*	*Shape*	*Size*	*Surface*	*Notes*
Calcium carbonate (O)	4	6	A	S/M				Septic. Alkaline urine.
Calcium oxalate (O)	1 (*a*)	7	<40 yrs.	S	'Mulberry' or thorn-apple', especially in bladder	Not large in kidney, but 'pigeon's egg' in bladder	Irregular if large, smooth if small	Pain and haemorrhage always severe.
Calcium phosphate (O)	2	1 (*b*)	A	M	'Stag-horn' or 'renal cast' and faceted	The largest of all types		Occasional fracture of stone.
Triple phosphate (O)							Smoother than calcium-phosph. stone.	Septic. Alkaline urine.
Cystine (O/T)	6	2	I/A	S/M	Oval or round 'stag-horn' in children	Small	Smooth—never found in ureter (slips down into bladder)	Familial cystinuria. Usually aseptic.
Urates (T)	3	5	I	M	Flattened ovoids or round	Small/moderate	Usually smooth. Occasionally rough and finely nodulated	Occasional fracture of stone.
Uric acid (T)	5	3	Y	M	Faceted	Small	Smooth—never found in ureter (slips down into bladder)	Spontaneous fracture common.
Xanthine (T)	7	4	A	S/M				Acid urine.

O=opaque. T=translucent. (*a*) Most frequent. (*b*) Quickest growing. I=Infant. Y=Youth. A=Adult. S=single stone. M=Multiple stones.

of the commoner urinary calculi is as follows:[3] calcium carbonate, calcium oxalate, calcium phosphate, calcium magnesium ammonium phosphate, cystine, urates, uric acid, xanthine.

The stones listed before cystine are always opaque, those listed after cystine translucent. There is some controversy whether cystine is denser than urates and uric acid,[3] but the 25%-sulphur-containing formula of cystine (COOH-CHNH$_2$-CH$_2$S) points to its being the denser.

Incidence

The order of frequency of urinary calculi is as follows: Calcium oxalate (pure or mixed), phosphates (calcium, magnesium, or calcium magnesium ammonium, i.e. triple phosphate), urates (sodium, ammonium, calcium, magnesium or potassium), calcium carbonate (rarely pure), uric acid, cystine, xanthine, indigo (pure or mixed with phosphates).

Other rare types including 'bacterial' stones,[3] fibrin stones,[3] cholesterol stones, stones of acetyl derivates of sulphapyridine, 'foreign body' stones (e.g. stones formed around a drainage tube), silicon stones, and urostealith stones. All these contain nuclei composed of desquamated epithelial cells, blood clot, foreign bodies, or urinary crystals.

In the bladder this order is a little changed, uric-acid and urate stones being commoner than phosphate, calcium-oxalate, cystine and calcium-carbonate stones. Xanthine and indigo stones may also occur in the bladder.

Other Factors

Age of Patient. It is only in the young that age is a factor helping in the determination of the composition of calculi. In infants the nucleus is usually of ammonium urate and in young adults of uric acid. The outer layers may be composed of any of the other possible constituents. Cystine stones are found usually in children, but occasionally they develop in adults.

Size. Cystine, urate and uric-acid stones are usually small or moderate in size and remain so. The calcium oxalate stone is of moderate size in the renal pelvis, being slow in its rate of growth, but may be the size of a pigeon's egg in the bladder. 'Foreign body' stones and phosphatic stones grow very rapidly and serial X-rays show continual and rapid increase in size. They are the largest stones and may reach considerable dimensions. Bacterial and non-crystalline stones are usually pin-head in size but may reach the size of a cherry or olive.

Site. Stones in the ureter are rarely composed of uric acid or cystine because stones of these substances are smooth and readily slip down into the bladder. A translucent stone in the ureter is therefore often composed of the rarer constituents such as xanthine and other radiolucent rare constituents.

Number of Stones. As stones which are found bilaterally, i.e. in both pelves or perhaps both ureters, usually occur only in the presence of infection, they are composed of phosphate or calcium carbonate. Cystine stones are an exception to this rule, but they are commoner in children, and less dense than the two septic stones. Calcium-oxalate stones are always single and unilateral, and uric-acid stones always multiple. Other stones cannot be differentiated on the bases of multiplicity or singularity.

Clinical signs and symptoms may give an indication of the chemical constitution of a stone. For example, extreme pain and continual haemorrhage are usually due to a very irregular stone such as a calcium-oxalate calculus of the bladder. Dilation of the ureter above the stone with or without hydronephrosis is rare in aseptic stones, and usually indicates that the stones are of septic origin, i.e. phosphatic or calcium-carbonate calculi. A stricture in the region of the stone, or below it, is usually also a result of a 'septic' stone of phosphate or calcium carbonate.

Rate of Growth. Phosphate stones grow at a faster rate than those of cystine, uric acid or xanthine (in that order). Calcium oxalate is the slowest-growing of all stones.

A spontaneous fracture through the stone almost certainly indicates that the stone is of uric acid or urate. A flake fracture may occur in phosphate stones, but fractures never occur in oxalate stones.

CONCLUSION AND SUMMARY

Table I is in the main a summary of the foregoing information.

Radiological reports have hitherto not attempted to diagnose the chemical composition of urinary calculi. From their appearance, from, structure, density, situation, size, shape and number, and from the age of the patient and his clinical signs and symptoms it is not difficult to make such a diagnosis and, with experience, the difficulties encountered become more and more easily resolved. The diagnosis of the chemical composition of the stones makes it possible to determine the presence or absence of infection, whether the stone can be easily crushed or crushed only with difficulty, and even the pH of the urine in parts of the renal tract far removed from the bladder (e.g. the renal calyces)

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