

## IONIC ASSOCIATIONS WITHIN 460 NON-INFECTION URINARY STONES

### *A Quantitative Chemical Analytical Study Applying a New Classification*

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**Abstract.** In addition to standard quantitative wet chemical and inductively coupled plasma atomic-emission spectrometric stone analytic techniques, elemental analysis for the determination of nitrogen, carbon and hydrogen was utilized in this study of 460 category I (non-infection) urinary stone samples from western Saudi Arabia. They were classified according to the percentage composition of detected ions, including trace or minimum amounts. The incidence of uric acid stones (24%) is higher than that reported from western countries but similar to those reported from eastern Europe and other parts of the middle east and most are in the group with the highest uric acid content (Ur14). Oxalate stones are the most common type (61%) and phosphate stones (15%) the least common. The results confirm the reliability of elemental microanalysis and support its use for the quick identification of stones especially those that weigh <1 mg and are too small for wet chemical analysis. Within the various stone types, however, the ionic associations shown by wet chemical analysis denoted the presence of mutual indirect associations between the characterising ion oxalate and both uric acid and phosphate ions, but no association between the characterizing ion uric acid and phosphate ions. Factors that affect these ionic correlations may influence the processes of stone initiation and type of stone formed.

**Key words:** urinary stones, non-infection stones, stone analysis, elemental microanalysis, percent ionic composition, classification, inter-ionic associations, stone formation, type of stone, geographical variations, Saudi Arabia.

Quantitative chemical analysis of the urinary stones has been preferred by many investigators (12, 14, 16, 17, 18, 23, 33, 34) and particularly important are the microanalytic techniques that can be used for stones that weigh less than 5 mg (22, 44).

Almost all these investigators apply calculations, based on certain assumptions, to the findings of their chemical analysis to arrive at estimates of the composition for compounds. Accordingly, several classifications of urinary stones have been suggested (14, 40, 41, 42, 43, 45), but it is difficult to compare them as the chemical analysis results are presented differently (28).

We have proposed a different scheme for the classification of urinary stones (4), which is based only on the percentage composition of detected ions without the need for such cumbersome calculations which introduce an element of uncertainty (28). In addition, our classification includes specification and consideration of both the trace and minimum amounts of ions present.

We report the application of our classification system to 460 urinary stone samples from patients in the western region of Saudi Arabia.

## MATERIAL AND METHODS

### *Analytical methods*

A total of 540 stone samples were coded and prepared. Those that weighed more than 60 mg ( $n=451$ ) were subjected to wet chemical analysis to measure the oxalate (46) and phosphate (6) in a sulphuric acid digest and urates and xanthine in a lithium carbonate digest (12).

In all 540 samples we performed elemental microanalysis to measure total concentrations of carbon, nitrogen and hydrogen, using tungsten trioxide to help combustion, in addition to standard methods (5, 8, 9, 47). Calcium and magnesium were measured by inductively coupled plasma atomic-emission spectrometry.

Table I. Identification of the three urinary stone types by the percentage of their characterising ions and further classification into groups by the percentage of particular ions

Type of stone	Characterising ion and its percentage composition	Stone group	Indicating ion and its percentage composition
Uric acid stones (Ur)	Uric acid $\geq 20$	Ur11	Oxalate <40- > 33
		Ur12	Oxalate 33-> 21
		Ur13	Oxalate 21-10
		Ur14	Oxalate < 10
Oxalate stones (Ox)	Oxalate $\geq 40$	Ox11	Uric acid < 20
		Ox12	Phosphate < 20
		Ox13	Uric acid & phosphate < 20 each
Phosphate stones (Ph)	Phosphate $\geq 10$ & Uric acid < 20 & Oxalate < 40	Ph11	Oxalate < 40-10
		Ph12	Oxalate < 10

*Details of the classification scheme*

The three types of urinary calculi were identified by the percentage composition of their characterising ions (Table I). The stone was designated a uric acid stone, therefore, when the uric acid radical was 20% or more. Though a stone was designated an oxalate stone when the oxalate radical was 40% or more the amount of phosphate radical required to designate a stone as phosphate stone was 10% or more with uric acid or oxalate being less than 20% or less than 40%, respectively.

The two main categories of stones; non-infection stones (Category I) and infection stones (Category II), were differentiated by the percentage of magnesium (Table II). Unlike category I stones, category II contain 3% of magnesium or more.

In category I stones, the characterising ion of one type, at a different percentage, was the indicating ion for the subgrouping of another type (Table I). Accordingly, category I uric acid stones, which always contained trace amounts of phosphate radical (less than 2%) and variable amounts of oxalate (up to 39%), were further divided into four groups (Ur11, Ur12, Ur13, Ur14) according to the percentage of oxalate radical that was present (Table I).

Category I oxalate stones always contained other radicals in addition to oxalate (uric acid or phosphate or both). So we further divided oxalate stones into three groups (Table I) according to whether they contained uric acid (Ox11) or phosphate (Ox12), or both (Ox13). The amount of uric acid or phosphate was always less than 20% in all three groups.

Category I phosphate stones contained up to a minimum amount (2-10%) of uric acid and variable amounts of oxalate radical so the phosphate stones were divided into two groups (Ph11 and Ph12) according to the percentage of oxalate radical that was present (Table I).

Quick identification of the three types of urinary

calculi could also be made from measurements of the percentages of total organic nitrogen, carbon and hydrogen in the stones. The percentage of nitrogen differentiates the uric acid stones from both the oxalate and phosphate stones (Table III). Furthermore, the percentage of carbon differentiates the oxalate from the phosphate stones. Meanwhile, in the oxalate stones, the percentage of hydrogen may differentiate oxalate monohydrate stones from the dihydrate or mixed mono and dihydrate oxalate stones (Table III).

Samples were labelled according to this classification, using an abbreviation to refer to their type (Ur for uric acid, Ox for oxalate or Ph for phosphate), followed by a Roman numeral to indicate their category (I, the non-infection or II, the infection stone) and then an Arabic numeral to indicate the group (four groups in the uric acid, three in the oxalate and two in phosphate types). For example, Ur11 denotes a group I uric acid stone sample of the non-infection category (category I).

**RESULTS**

In this series we are presenting only the results for the 460 category I stone samples. The identi-

Table II. Differentiation of category I (the non-infection stones) from category II (the infection stones) by the percentage of magnesium

Category	Definition	Percentage of magnesium
1. Category I	Non-infection stones	< 3
2. Category II	Infection stones	$\geq 3$

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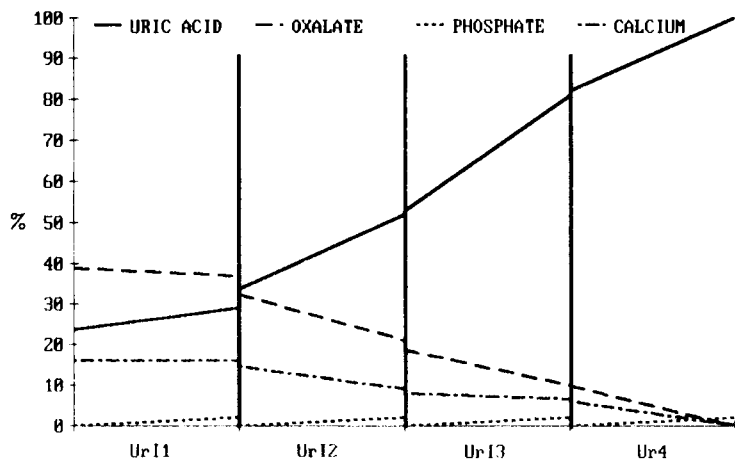


Fig. 1. Percentage composition of uric acid, oxalate, phosphate and calcium ions in the four urate stone groups (Ur11, Ur12, Ur13 and Ur14).

fication of the various types or groups was both easy and precise. Correlations with current observations about stone composition were possible and some ionic association within the various types were obvious.

*The uric acid stones*

One hundred and eight of the samples (24%) were uric acid stones (Table IV). Their classification into four groups by both the wet chemical and elemental micro-analytical studies is shown in Table V.

The results of the wet chemical analysis in the four groups of uric acid stones showed that the

amount of oxalate directly associated with the amount of calcium and indirectly with the amount of uric acid (Fig. 1). The uric acid content is indirectly associated with either the oxalate or calcium content but not with the phosphate content (Fig. 1).

The results of elemental microanalysis of category I uric acid stones (Table V) confirms their classification into four groups by the wet chemical analysis. Each group had a definite range of percentages of total organic carbon or nitrogen, and the results showed a direct association between the uric acid content and the total carbon or nitrogen content (Fig. 2).

*The Oxalate stones*

Oxalate stones were the most common (61% of the total, Table IV) and their chemical compo-

Table III. Identification of the three types of urinary stone by the percentage of nitrogen and carbon, and differentiation, in the oxalate stones, between the monohydrated and dihydrated forms by hydrogen content

Type of stone	Nitrogen	Carbon	Hydrogen
Uric acid stones (Ur)	≥ 8	≥ 22	< 3
Oxalate stones (Ox)	< 8	17- < 26	< 2 (monohydrate) ≥ 2 (dihydrate & mixture of both forms)
Phosphate stones (Ph)	< 8	< 12.8	< 3

Table IV. Relative percentage incidence of category I stone types and groups in 460 stone samples

Type of stone	Incidence No. (%)	Group	Incidence No. (%)
Uric acid stones	108 (24)	Ur11	5 (5)
		Ur12	14 (13)
		Ur13	17 (16)
		Ur14	72 (67)
Oxalate stones	281 (61)	Ox11	22 (8)
		Ox12	24 (9)
		Ox13	235 (84)
Phosphate stones	71 (15)	Ph11	47 (66)
		Ph12	24 (34)

Table V. Percentage of ions in 108 category I uric acid stone samples

Constituents	UrI1	UrI2	UrI3	UrI4
Oxalate	38.8–36.8	32.4–21.0	18.7–10.0	9.9–0
Uric acid	23.7–29.1	33.6–51.8	52.6–80.8	81.9–100
Phosphate	0–2.0	0–2.0	0–2.0	0–2.0
Calcium	16.0	14.5–9.1	7.8–6.5	5.9–0.1
Magnesium	0–0.5	0–0.5	0–0.5	0–0.5
Nitrogen	0.2–10.7	14.3–21.5	21.7–27.2	28.5–33.3
Carbon	22.3–22.5	23.7–27.3	28.1–30.9	31.2–35.8
Hydrogen	2.0–2.3	2.2–2.9	2.3–2.9	2.3–2.9

sition and subclassification is shown in Table VI.

Wet chemical analysis in the oxalate stones showed that the oxalate radical is indirectly associated with the uric acid or phosphate radicals present. Meanwhile, its direct association with the calcium radical (described in the uric acid stones), was best confirmed in group 1 oxalate stones (OxI1).

The results of elemental microanalysis showed that the highest ranges for the percentage of nitrogen (more than 1%) or carbon (more than 19%), were in groups 1 and 3 of the oxalate stones (OxI1, OxI3) which contained variable amounts (less than 20%) of uric acid (Fig. 3), confirming the previously mentioned direct association between uric acid and both nitrogen and carbon.

#### The phosphate stones

Phosphate stones were the least common (15%, Tables IV and VII). Wet chemical analysis showed a higher percentage of phosphate in group PhI2 than group PhI1, confirming the indirect association between phosphate and ox-

alate radicals (Fig. 4). The calcium content in the two groups (PhI1 and PhI2) was within the same range indicating its direct association with both ions (Fig. 4).

Elemental microanalysis showed that high percentages of carbon (more than 9%) were present in group PhI1 phosphate, which also contained a higher percentage of oxalate indicating a direct association between the oxalate and carbon content (Fig. 5). This was not obvious in either the uric acid or the oxalate (OxI1, OxI3) stones, because of the presence of uric acid, as its content of carbon is much higher than that of the oxalate.

## DISCUSSION

The percentage incidence of uric acid stones is much higher than that (2–12%) reported from western countries (7, 11, 14, 15, 26, 33, 34, 35, 36, 37, 43) but is similar to previous reports about urolithiasis in Saudi Arabia (1, 2, 17, 25), Kuwait, Central Europe and Israel (39), Turkey (38), Jordan (10), Sudan (19) and Iraq (3). The percentage incidence of group UrI1 (the highest

Table VI. Percentage of ions in 281 category I oxalate stone samples

Constituents	OxI1	OxI2	OxI3
Oxalate	45.6–55.42	42.37–52.5	40.87–60.54
Uric acid	0.05–10.92	0	0.01–17.23
Phosphate	0	3.6–10.9	0.10–16.20
Calcium	19.2–26.48	22.85–26.78	16.54–29.85
Magnesium	0.01–0.92	0.01–0.92	0.01–0.92
Nitrogen	0.22–5.11	0.21–0.56	0.22–7.68
Carbon	15.3–21.48	13.2–16.06	12.8–25.54
Hydrogen	1.67–2.35	1.56–2.2	1.34–2.88

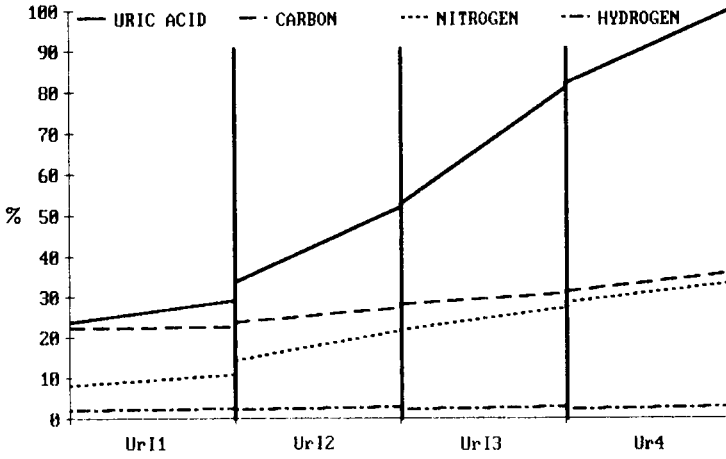


Fig. 2. Percentage composition of carbon, nitrogen, hydrogen and uric acid ions in the four uric acid stone groups.

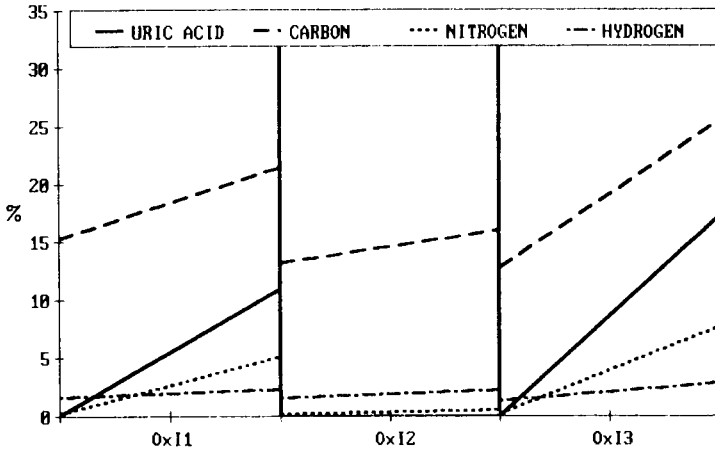


Fig. 3. Percentage composition of carbon, nitrogen, hydrogen and uric acid ions in the three oxalate stone groups (Ox11, Ox12 and Ox13).

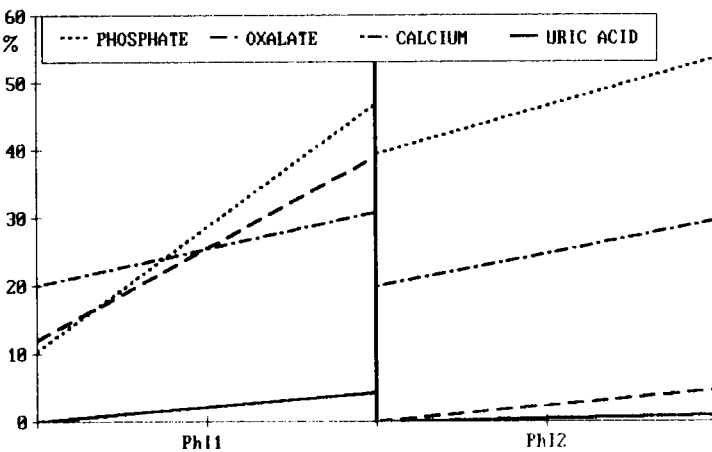


Fig. 4. Percentage composition of uric acid, oxalate, phosphate and calcium ions in the two phosphate stone groups (Ph11 and Ph12).

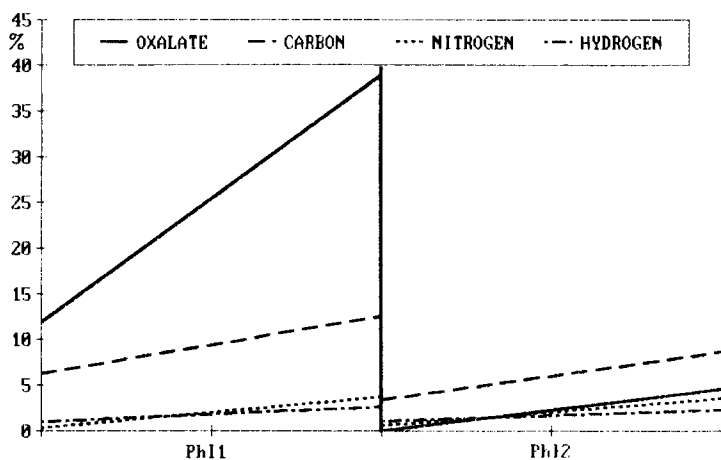


Fig. 5. Percentage composition of carbon, nitrogen, hydrogen and oxalate ions in the two phosphate stone groups.

oxalate content) is close to that reported by Fuss et al. (14), while group Ur14 (the purest form of uric acid stones as they contained trace or no oxalate or phosphate) is the most common in Saudi Arabia (Table IV).

Oxalate stones seem to be the most common type which is in agreement with western reports (14, 24, 26, 32, 38–42) as well as that in Sudan (20, 21) and with reports from Saudi Arabia (2, 25, 27).

The presence of some uric acid in the oxalate stones has previously been described (7, 14) and the amount of less than 20% is in agreement with the report of Prasongwatana et al. (29). The presence of a phosphate radical points to the calcium phosphate compound often described in calcium oxalate stones (11, 14, 19, 21, 31, 38–42).

In the present study, the oxalate stone with trace amount of uric acid (in group Ox11), phosphate (in group Ox12), or both (in group Ox13) was considered to be the purest form of oxalate stones.

The phosphate stones represent the least common type of category I (non-infection) stones. This is in agreement with previous reports from Saudi Arabia (2, 25, 27). Its relative percentage incidence (15.4) is less than that reported by Schmucki & Asper (36) and Esho (11) and this supports the findings of Westbury (45).

The relative percentage incidence of the phosphate stones group Ph11, which contains variable amounts of oxalate (less than 40%) is nearly double that of group Ph12 (Table IV):

this is in agreement with the findings of Sutor & Wooley (38, 39) in industrialised countries.

Only Fuss et al. (14) reported the presence of some uric acid in the calcium phosphate stones. As there is no pure calcium phosphate stone (21) in the present study, we designated group Ph12 as the purest form of the non-infection phosphate stones, because it contained a trace of uric acid and a minimum amount of oxalate ions.

The various correlations shown by the results of elemental microanalysis (Fig. 6) confirm its reliability and support its use for quick identification of stones particularly those that weigh less than 1 mg, which are too small for wet chemical analysis.

Within the various stone types, the ionic relations shown by wet chemical analysis denote the presence of mutual indirect associations between the characterising ion oxalate, and the

Table VII. Percentage of ions in 71 category I phosphate stone samples

Constituents	Ph11	Ph12
Oxalate	11.9–38.89	0–4.60
Uric acid	0–0.26	0–0.77
Phosphate	10.26–46.75	39.40–53.50
Calcium	19.90–30.65	19.82–29.40
Magnesium	0.01–2.95	0.01–2.95
Nitrogen	0.33–3.76	0.54–3.51
Carbon	6.3–12.60	3.37–8.67
Hydrogen	0.99–2.63	1.03–2.20

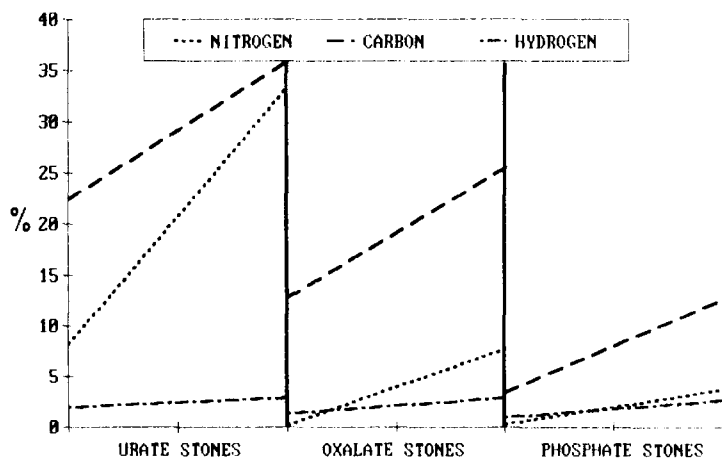


Fig. 6. Percentage composition of carbon, nitrogen and hydrogen ions in the three stone types.

uric acid and phosphate ions; there was, however, no association between the characterising ion uric acid and phosphate ions (Fig. 1). This suggests that the process of stone formation may be initiated by an association between the uric acid and oxalate rather than phosphate ions or between the oxalate and phosphate ions. Hence, the presence of up to 39% oxalate ions in group 1 uric acid stones, and presence of group 2 in the oxalate stones. To influence the type of stone that is formed, this association may be acted on by more than one external factor as denoted by the indirect relations between those ions within the stone.

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