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The mineralogy of human urinary stones from Calgary, Quito and Honolulu

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Abstract

The mineralogy of 848 human urinary stones from Calgary (604), Quito (194) and Honolulu (50) were determined and the data studied in relation to the age, sex, race or ethnic origin of the stone formers, and also in terms of the size of the stones (< 7 mm or 7 mm and larger) and their location in the urinary tract. The results show that the Quito stone distribution strongly resembles that typically perceived to be characteristic of human stone disease in western industrialized countries (i.e., primarily the calcium stones whewellite, weddellite and apatite). An unusual aspect of Quito struvite stones (10% of the total) is that they are essentially restricted to males with chronic urinary infection. Filipinos and Chinese in Honolulu seem to produce stones at a rate equal to twice their proportion in the population whereas those of Hawaiian lineage produce half as many stones. Stones from Calgary fit into the broad ranges characteristic of western stone disease and are the source of the only pediatric stones encountered in this study.

Introduction

Certain minerals, such as whewellite ($CaC_2O_4 \cdot H_2O$), weddellite ($CaC_2O_4 \cdot 2H_2O$), struvite ($MgNH_4PO_4 \cdot 6H_2O$) and uricite ($C_5H_4N_4O_3$; commonly called uric acid) are rare in geological environments. These minerals, along with others such as apatite, brushite ($CaHPO_4 \cdot 2H_2O$) and whitlockite ($Ca_9MgH(PO_4)_7$), as well as a few phases not yet found as minerals (e.g., cystine, ammonium acid urate), are frequently found in human urinary stones (calculi) which are usually in the kidney but may occur anywhere in the urinary tract.

The classic paper on the mineralogy of human urinary stones (Prien and Frondel, 1947) focussed on the identification of mineral phases in urinary stones, and did not concern itself with variations in sex, age, race or ethnic origin of the stone formers in relation to the numerous mineral phases. Similarly, the few papers on human pathological mineralogy published in the mineralogical literature (Gibson, 1974; Mansfield and Griffith, 1976) are primarily concerned with the qualitative mineralogy of human stones. There are a few well-documented historical and geographical studies on the variations in the incidence of urinary calculi from various localities in Europe, the Near East, Thailand and the United States (e.g., Lonsdale, 1968; Sutor et al., 1974; Prasongwatana et al., 1983), but there are no studies from Canada, and the only one from Hawaii (Wurster et al., 1970) is almost exclusively concerned with uricite. There is one publishsed study of 100 patients with urinary stones from Ecuador (Paz y Miño et al., 1978), in which stone type, location in the urinary tract, patient occupation and certain medical data are discussed.

From the above survey, it is clear that there is a paucity of studies relating mineralogical stone type with sex, age, race or ethnic origin of the stone formers. To remedy this, we present a study of human urinary stones from three distinctly different localities in an attempt to interrelate the above variables.

Materials and methods

The mineralogy of the 848 stones was determined primarily by polarizing optical microscopy, augmented where necessary by X-ray diffraction and infrared spectroscopy.

The sources of the stones are as follows: 604 from Foothills Hospital, Calgary; 194 from Carlos Andrade Marín Hospital, Quito; 50 from Kaiser Medical Center, Honolulu. The stones from all localities were obtained during 1977–1982 and represent uninterrupted sequences (i.e., every stone received during the period was studied).

All 50 stones from Honolulu were removed surgically, whereas those from Calgary and Quito include both surgically removed and passed varieties. To make the discussion of the results between all localities comparable, those

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stones from Calgary and Quito 7 mm or greater in their maximum dimension were assumed to have been surgically removed; those less than 7 mm were assumed to have been passed. This division was used because it is one guideline used at Foothills Hospital to determine whether or not surgery is necessary. We have checked the available records of several hundred Calgary patients and many of the Quito patients and find that the 7 mm division is reliable in about 85% of the cases. Exceptions are principally due to breakage during or after surgery; occasionally, large stones are passed (e.g., one 60-year-old Quito female passed a 1-cm stone).

Data on age and sex of the patient, and the location of the stone (e.g., ureter) were collected for correlation with stone composition. In the case of the Honolulu patients, information on ancestry (e.g., Filipino) and the number of years the patient lived in Hawaii were also collected. Data on ancestry, either Caucasian or mixed Indian-Spanish, were obtained for the Quito patients. The distinction between the two groups is based solely on the physical appearance and personal data of the patients, and only minimal emphasis should thus be placed on this parameter; indeed, it is possible to suggest that almost all Ecuadorians, except some special groups which constitute no more than 15% of the population, are mixed to some degree. Data were also obtained on the occupations of most of the Quito patients.

All stones reported herein to be from Quito were carefully screened to ensure that they are from patients from Quito and/or the adjacent high mountainous area of Ecuador. Histories of the patients show that most are long-time residents of the region and travel very little. Due to the migratory nature of North Americans, we know that some stones produced by the Calgary and Honolulu patients must have been forming while the patients lived elsewhere. However, as it is impossible to quantify this variable, we assume that all stones from these two areas formed locally.

Results

The mineralogy of stones as a function of stone size and racial characteristics of the stone formers is given in Table 1. Table 2 lists the ratio of males to females, their average ages and, where known, the original location of the stones in the urinary tract, in relationship to racial characteristics and stone size. Figures 1–5 show various aspects of the distributions.

Honolulu

The ratio of males to females (Table 2) of 1.3 for the total population is the lowest in this study. For Caucasians, the ratio is 6.5 (13 males: 2 females); for the non-Caucasians, the ratio of 0.8 is remarkably low. Among Japanese stone patients (Fig. 1), females outnumber males 6 to 1, whereas for Filipinos and Hawaiians the comparable numbers are 7 to 5 and 5 to 3, respectively; males produced all four stones from those of Chinese origin. Whether or not such distributions are truly representative awaits the study of larger stone populations from this locality. The average age of Honolulu stone formers is 49 years; if information on passed stones had been available, the average would have been somewhat lower. Thus, stone disease in Honolulu is

Table 1. Summary of occurrences of urinary stones (number of stones)

Type of Stone	Calgary		Quito				Honolulu	
			Caucasian		Mixed		Caucasian	Non-Caucasian
	<7 mm	>7 mm	<7 mm	>7 mm	<7 mm	>7 mm	(all surgically removed)	
whewellite (pure)	66	6	11	1	18	3	-	2
weddellite (pure)	7	1	-	-	2	-	-	-
whewellite + weddellite	85	21	15	-	20	7	4	2
whewellite ± weddellite + apatite	195	86	26	14	23	25	6	17
apatite (pure)	19	10	-	-	2	-	-	2
struvite (pure)	2	2	-	-	-	-	-	-
struvite + apatite (±whewellite and/or weddellite)	8	14	1	1	6	9	2	9
struvite + uric acid + apatite	-	1	-	-	1	1	-	-
uric acid (pure) (= uricite)	24	5	1	-	1	-	1	2
uric acid + apatite	2	1	-	-	-	-	-	-
uric acid + whewellite	7	5	-	1	2	1	2	1
uric acid dihydrate	1	-	-	-	-	-	-	-
brushite + apatite (±whewellite and/or weddellite)	12	9	-	-	-	-	-	-
cystine (pure)	1	5	-	-	1	-	-	-
cystine + apatite or whewellite	4	-	-	-	-	-	-	-
whitlockite + apatite	-	1	-	-	-	-	-	-
ammonium acid urate	-	1	-	-	1	-	-	-
ammonium acid urate + uric acid	1	1	-	-	-	-	-	-
octacalcium phosphate	1	-	-	-	-	-	-	-
TOTAL	435	169	54	17	77	46	15	35

Not included in the above tabulation are 29 artifacts (materials shown to have originated outside the urinary tract) from Calgary and 5 from Quito.

Table 2. Selected statistics on urinary stones from Honolulu, Quito, and Calgary (M = male F = female)

Locality	Number of Stones	Ratio M/F			Number of Stones †,††				Average Age			
		Total	<7 mm	>7 mm	Upper Tract M	Upper Tract F	Lower Tract M	Lower Tract F	M<7 mm	M>7 mm	F<7 mm	F>7 mm
Honolulu*												
Total	50	-	-	1.3	28	22	0	0	-	49	-	49
Caucasian	15	-	-	6.5	13	2	0	0	-	53	-	43
Non-Caucasian**	35	-	-	0.8	15	20	0	0	-	45	-	50
Quito												
Total	194	2.5	2.7	2.0	83	45	24	2	40	46	35	36
Caucasian	71	2.0	2.2	1.4	31	18	2	1	40	40	34	37
Mixed	123	2.8	3.3	2.3	52	27	22	1	40	48	35	35
Calgary												
Total	604	2.5	2.5	2.6	375	150	49	8	47	50	41	45

* As all Honolulu stones were surgically removed, there are no data for stones <7 mm.
** For consistency with Fig. 2, the two Portuguese (1 male age 54 and 1 female age 77) living in Honolulu are classified as non-Caucasian.
† Upper tract includes stones from the kidney, ureter and pelvis; lower tract includes those from the bladder, urethra, prostate (4 from Calgary) and ileal conduit (1 from Calgary)
†† There are 40 stones from Quito and 22 from Calgary whose location (upper or lower tract) are not given on the medical records. Most of the stones that were passed are listed as kidney stones and are included in the statistics for the upper tract.

characteristic of middle life, especially so in the case of the uric acid stone formers (average age 58).

Struvite stones (11 out of 50) constitute 22% of all the surgically removed stones, whereas the calcium stones account for 66% of occurrences. Most (9 out of 11) struvites are from non-Caucasians, specifically from Hawaiians (3), Japanese (3), Filipinos (2) and Portuguese (1). Females produced 10 out of 11 of these stones and all came from the upper tract (9 from the kidney and 2 from the ureter). The relative abundance of the uric acid stones (12%) is low, because when such stones are diagnosed at Kaiser Medical Center, they are generally dissolved (by sodium bicarbonate, followed by Allopurinol treatment). All uric acid stones which were removed are from males (3 Caucasians, 2 Filipinos and 1 Hawaiian-Caucasian).

The ethnic distribution of those who formed stones which required surgical removal (Table 3) shows that the

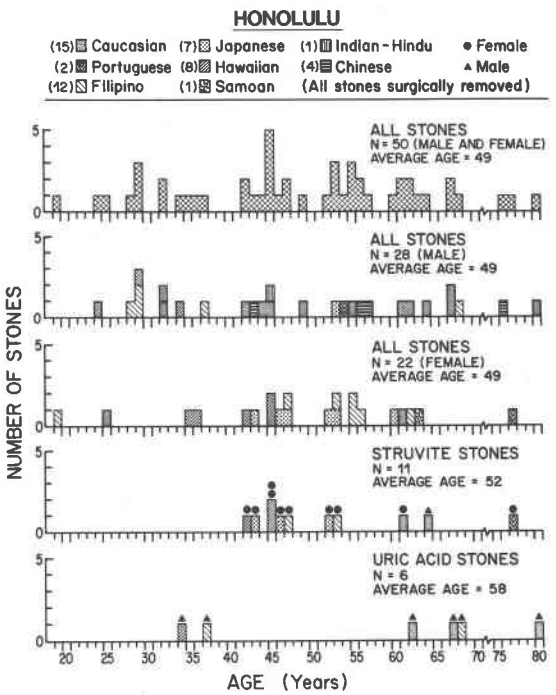

Fig. 1. Graphical presentation of urinary stone distributions at Kaiser Foundation Hospital, Honolulu, based on age, sex, and ethnic or racial origin. Numbers in parentheses e.g. (15) preceding Caucasian, indicate the number of stones for each ethnic or racial group (15 stones from Caucasians). Portuguese are considered separately from other Caucasians in this study.

Table 3. Urinary stone distribution in Hawaii by racial or ethnic origin

Ethnic Origin	Kaiser Foundation Hospital			State of Hawaii***	
	Health Plan Members (%)*	Stone Distribution (Number)	Stone Distribution (%)**	Population	Stone Distribution (%)†
Black	4.1	(0)	0	1.9	0
Caucasian	29.3	(15)	30†††	29.3	25.2
Chinese	3.9	(4)	8	6.2	10.7
Filipino	10.6	(12)	24+	14.3	27.2
Hawaiian††	28.2	(8)	16++	18.3	8.7
Japanese	11.2	(7)	14	24.9	26.1
Korean	2.1	(0)	0	1.8	0
Samoan	2.5	(1)	2	1.3	0.8
Other	8.1	-	-	2.0	1.3
Indian-Hindu		(1)	2		
Portuguese		(2)	4		
Total	100%	(50)	100%	100%	100%

* Data from 900 members of the Kaiser Health Plan using Kaiser Foundation Hospital, Honolulu.
** Stone distribution based on stones from Kaiser Foundation Hospital where all patients are members of the plan.
*** Data from State of Hawaii Health Survey (plus barracks and institution population).
† Stone distribution (%) for the State of Hawaii based on re-calculation from stone occurrences and ethnic origins of members using Kaiser Foundation Hospital.
†† Includes those who are part-Hawaiian.
††† Includes one Caucasian-Korean.
+ Includes two Filipino-Chinese.
++ Includes seven mixtures (2 Hawaiian-Filipinos; 2 Hawaiian-Caucasians; 1 Hawaiian-Japanese; 1 Hawaiian-Portuguese; 1 Hawaiian-Chinese).

Filipinos and Chinese seem to have the highest incidence of stone disease (about twice their percentage of the population). Those of Hawaiian (including part-Hawaiian) origin have lower than proportional stone incidence but, as indicated above, they have a high proportion of struvite stones (3 out of a total of 8 stones; Fig. 1).

Quito

For the population as a whole, male stone formers outnumber females by factors of 2.7 (for stones <7 mm) and 2.0 (for stones ≥ 7 mm) (Table 2). Among the mixed Indian-Spanish, males have a higher incidence of stone disease than do females, compared to the Caucasians. The average age of stone formers in Quito (males 40 and 46, females 35 and 36, depending on stone size) is the lowest among the three localities studied, and reflects the young age of the general population (Figs. 2 and 3).

There are 19 struvite stones out of 194, or 10% of the total. Among the ≥ 7 mm stones, struvites constitute 11 out of 63 stones, or 17%, and occur primarily among the mixed population. An interesting feature of the struvite distribution (Fig. 3) is the fact that of the total of 19 stones of this type, 18 were produced by males; usually struvite stones are much more abundant in females (e.g., Honolulu, Fig. 1). The one female who had a struvite stone was born in Germany and frequently travels abroad; consequently, the stone may not have formed in Quito. The fact that 17 of the 18 males are shown as being of mixed Indian-Spanish origin is not considered significant because of the method of classification indicated earlier and the medical histories of the patients discussed below.

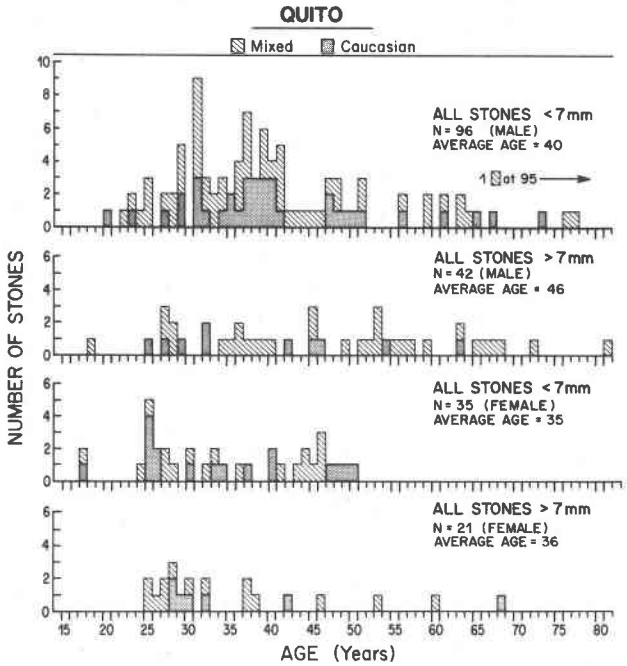

Fig. 2. Graphical presentation of the distribution of all stones from Quito based on age, sex, size and race (Caucasian or mixed Indian-Spanish).

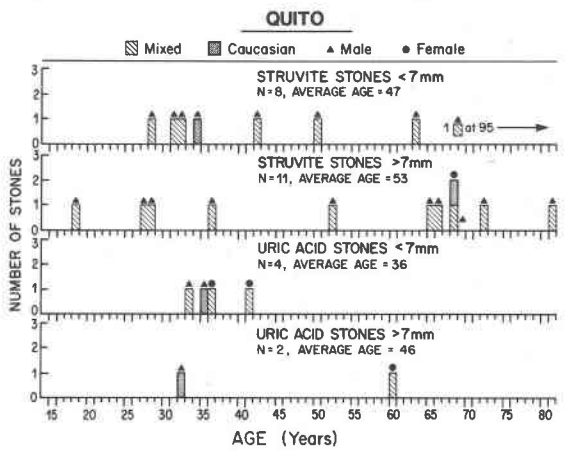

Fig. 3. Graphical presentation of the distribution of struvite and uric acid stones from Quito based on age, sex, size and race.

Occupations of the struvite patients vary from farm laborer to public accountant, and their ages range from 18–95 years. Most seem to have balanced, high carbohydrate diets and, except for one, they rarely travel from the Quito area. Although most were born and live in Quito, several live in outlying cities. A study of the medical histories available for 16 of the 18 males who had struvite stones shows: (a) eight are paraplegic; (b) most (13) of their stones occurred in the bladder; (c) three of the patients had prostate problems and two had brain damage; and (d) every one had a chronic urinary infection. With respect to the last observation, a higher percentage of urinary infection was also present in the calcium oxalate stone formers from Quito compared to these types of stone formers from other parts of the world (Paz y Miño et al., 1978).

Other stone types (six uric acid, one cystine and one ammonium acid urate) constitute only 4% of the Quito stones. Calcium stones account for 86% of the distribution. A large percentage of the stones from the mixed Indian-Spanish group are from the lower urinary tract (Table 2), which can be accounted for by the high incidence of struvite stones (13 examples) from the bladder.

Calgary

No statistics are available on the racial or ethnic mix of the Calgary stone formers. Figures available on the general population of Calgary show that most (at least 81.7%) are Caucasian whose ancestry (in 1981) can be traced to the United Kingdom (55.9%), Germany (9.5%), France (4.8%), the Ukraine (3.5%), Scandinavia (3.1%), Holland (2.7%) and Italy (2.2%). Chinese (3.0%), other Asiatics (4.4%), Native Peoples (0.9%) and all others (10.0%), including an undetermined number of Caucasians, constitute the remainder.

The ratio of male to female stone formers is 2.5 with essentially no difference between those whose stones are

<7 mm and $\geqq 7$ mm (Table 2, Fig. 4). The average ages of male stone formers (47 and 50 depending on size) are about 5 years older than those of comparable females (41 and 45). However, from Figure 4 it can be seen that the age distribution is bimodal; the younger group is about 20–35 years in age, whereas the older group starts at 45 years and decreases markedly at 65 years. The younger distribution can be explained by the fact that Calgary has a very young population (36% of the population is between 20 and 34 years of age and only 22% of the population is 45 years of age or older; 1981 data). Uric acid stone formers are considerably older (58 for males and 62 for females), as shown in Figure 5. On average, struvite stone formers seem to be younger than the general stone-forming population (based on only 27 stones).

The abundant calcium stones (whewellite, weddellite and apatite) constitute 85% of the <7 mm stones and 74% of the $\geqq 7$ mm stones. If the brushite stones are included with the more common calcium stones, the figures become 89% and 79%, respectively. Struvites account for 3% of the smaller stones and 10% of the larger stones (5% of the total); comparable figures for uric acid stones are 8% and 7%. The remaining stones account for 2% (<7 mm) and 5% ($\geqq 7$ mm), respectively, of the total stone occurrences, and are mostly cystine.

The Calgary struvite stone formers are predominantly female (6 out of 10 stones) for stones <7 mm, but males outnumber females 10 to 7 for stones $\geqq 7$ mm (Fig. 5). Only 5 struvite stones could be identified from the medical records as having come from the bladder and one was from an ileal conduit; the remainder were either from the kidney, ureter, or passed. Males produced 38 out of the total of 44 uric acid stones. Ten Calgary children (9 males and 1 female <17 years of age) produced urinary stones.

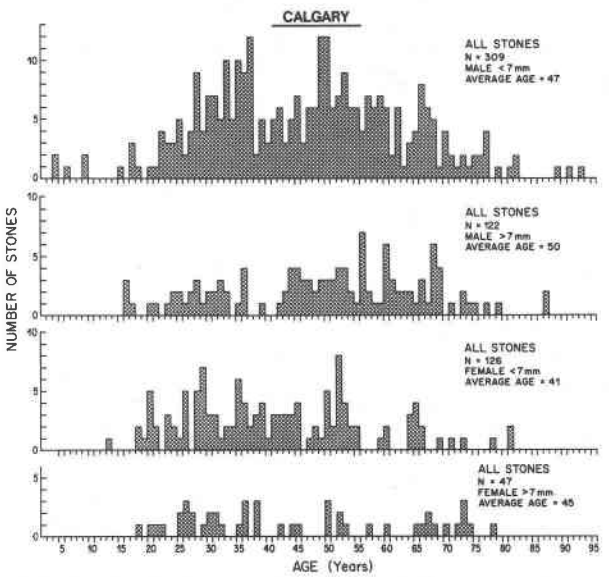

Fig. 4. Graphical presentation of the distribution of all stones from Calgary based on age, sex and size.

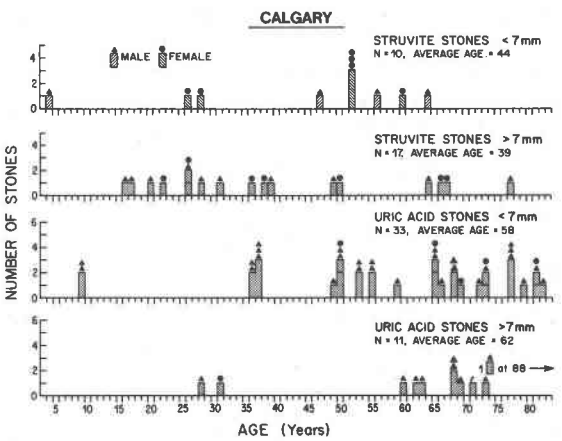

Fig. 5. Graphical presentation of the distribution of struvite and uric acid stones from Calgary based on age, sex and size.

Mixed calcium oxalates and/or apatite occurred in 3 cases, and there were two stones each of uric acid, struvite and cystine, and one of pure apatite; the 2 uric acid and the 2 struvite stones were each produced by different multiple stone formers. These results are in agreement with previous studies which showed that in most pediatric patients, contrary to prevailing opinions, most calculi are not of the struvite type (Sinno et al., 1979).

Discussion

The results from Calgary, Quito and Honolulu show certain significant differences in the occurrence of urinary stones with respect to several variables (e.g., age, race, sex, size) but they also show numerous similarities. With respect to the similarities, we might note that as far as the relative proportion of individual mineralogical stone types are concerned, the Quito stone distributions are remarkably similar to those of Calgary, e.g., in both places calcium stones account for about 85% of the total, the ratio of male to female formers is 2.5, small uric acid stones (<7 mm) are 2 to 3 times more common than large ones, and large struvite stones ($\geqq 7$ mm) are about 1.5 times more abundant than small ones. In fact, based on the Quito data alone one might reach the conclusion that the Quito stones indicate a very western, industrialized society (Lonsdale, 1968, discusses the characteristics of stone types in western industrialized societies). This conclusion would be reinforced by the absence of pediatric stone disease in Quito, and the normal occurrence of struvite stones (about 10% of the total). Furthermore, we have statistics on the occupations of the Quito stone formers (but not Calgary or Honolulu) and, as reported by Lonsdale (1968), those engaged in administrative work in western societies are many more times likely to develop urinary stones than are laborers or agricultural workers. The actual occupations of Quito stone formers (and the number of stones formed) are: professionals, including teachers and nurses (46), office workers (35), business people and merchants (27), laborers and industrial workers (21), housewives (12), farmers (7),

paraplegics (8), others, such as taxi drivers and students (5), and unknown (33).

There are several differences in the characteristics of the stone formers in the three localities, some less obvious than others. For example, the ratio of upper to lower urinary tract stones for Quito Caucasians (primarily of Spanish origin) is 16 to 1 compared to Calgary Caucasians (primarily of northern European origin), for whom the ratio is 9 to 1. Similar comparisons with Honolulu stone data are not possible, as at Kaiser Medical Center it is assumed that stones in the lower urinary tract will eventually pass, and hence they are not removed surgically. Also, there are apparently only 4 multiple (i.e. repetitive) stone formers in the Quito stone population (194 stones) and each produced 2 stones. Among the Calgary stone formers (604 stones), there were 38 people who produced 2 stones, 9 who produced 3 stones, 4 who produced 4 stones and one each who produced 5, 6, and 13 stones. The only previous study of stone disease in Hawaii (Wurster et al., 1970) showed: (a) the incidence of uric acid calculi in Oriental patients, particularly Chinese, Japanese and Filipinos, to be high; (b) that at least 27% of all stones produced by the indigenous population were uric acid stones; and (c) that approximately 50% of the cases with uric acid calculi required some form of surgical intervention. Our results, based only on large, surgically removed stones do not confirm the earlier results for reasons we cannot explain. Clearly, there is a need for more studies on stone disease from Hawaii in order to isolate the fundamental reasons for the observed distributions.

Acknowledgments

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