

## Sodium and potassium intakes in a representative population sample: estimation from 24 h urine collections known to be complete in a Cambridgeshire village

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1. A representative sample of eighty men aged 25–44 years from a Cambridgeshire village, each carried out one 24-h urine collection which was analysed for sodium, potassium, creatinine and urea content. The completeness of the collections was verified using oral doses of *p*-aminobenzoic acid (PABA; the PABA check test).
2. In the seventy-one collections shown to be complete, the average 24 h excretion of Na was 172 mmol and the average 24 h excretion of K was 74 mmol.
3. Fifty-one of these men's wives also made complete 24 h collections. The average content of these was 128 mmol Na and 61 mmol K.
4. Self reports and creatinine index would have identified as incomplete only 29 and 14% respectively of collections so judged by PABA.
5. Average excretion of 150 mmol Na/d was similar to estimated intakes of 140–167 mmol/d from the National Food Survey (Bull & Buss, 1980).

Despite considerable interest in the possible relation between dietary sodium and potassium and the aetiology of essential hypertension, comparatively little is known about intakes of these electrolytes in the population of the UK. It is known that estimation of Na intakes by conventional means using values derived from standard food tables are liable to gross errors (Paul & Southgate, 1978) but, in the steady state, 24 h urinary outputs of Na reflect input with acceptable accuracy (Schachter *et al.* 1980). However, few studies have, as yet, attempted to assess intake by this method in randomly selected British population samples. In addition, it is acknowledged to be difficult to assess the completeness of 24 h urine collections using the routine measurement of creatinine excretion (Edwards *et al.* 1969). The inclusion of incomplete results in a population estimate may result in systematic bias and an underestimate of excretion rates.

We have measured Na and K excretion in a randomly selected population of men using a sensitive marker of completeness of collection based on urine recovery of oral doses of *p*-aminobenzoic acid (PABA), the PABA check test (Bingham & Cummings, 1983). Similar estimations in the wives of these men served to give an indication of intakes in women.

### SUBJECTS AND METHODS

#### *Subject selection*

A one in four sample was selected from the 468 males aged 25–44 years on the age–sex register of a general practice based in a large village 10 km north of Cambridge. The 117

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men selected (twenty single and ninety-seven married) were all residents of this village and surrounding villages. Twelve were found to have moved out of the practice area and each of these was replaced with the next subject from the register.

#### *Recruitment of subjects and urine collections*

The initial approach to subjects was by means of a letter sent from the general practitioner giving a general explanation of the study and requesting the subjects' participation. This was followed by a home visit from one of us (D. R. R. W.) at which a fuller explanation was given and the method of 24 h urine collection explained. The wives of the married men were also asked to take part. Those who agreed to participate were allowed to choose the 24 h period over which they were to collect urine. They were also supplied with a set of written instructions, the PABA (in capsule form) and a bag containing two plastic 2-litre containers each primed with 0.45 g Thimerosal (T5125; Sigma Chemical Co., Poole, Dorset) as preservative, a plastic funnel and jug for the collection and a large safety pin for attachment to a suitable place on underclothing as a reminder. The subjects were requested to eat and drink normally during the period of collection and to follow their usual pattern of activity. The importance of collecting every drop of urine was clearly stressed, but to avoid the risk of subjects modifying their eating habits, at no time during the recruitment were the terms 'salt', 'sodium', 'blood pressure' or 'hypertension' mentioned.

#### *Completeness of collections*

Subjects were asked to take three 80 mg capsules of PABA, one capsule at the commencement of the 24 h urine collection, one with lunch on the same day and one with the evening meal. It was explained that PABA is present in small amounts in normal foods and that, though generally not considered to be essential for humans, it is sometimes classified as a B vitamin and included in some vitamin tablets. In order not to interfere with the analysis, therefore, subjects were asked not to take extra vitamin preparations and, in the latter part of the study, to avoid medication containing paracetamol which has a similar chemical composition to PABA. The PABA used in this study was obtained from BDH (Poole, Dorset), no. 27103, and was made up into capsules by the local hospital pharmacy.

#### *Collection of specimens*

The subjects were visited (by S.A.B.) on the evening of completing the collection when they were weighed (in indoor clothing without shoes) and their height measured (without shoes). All subjects were asked if they had lost any specimens of urine and if they had encountered any problems with the collection. They were also asked at what time the morning specimen had been discarded (the start of the collection period), the time the last specimen was added (the end of collection period) and the time the PABA capsules were taken. In addition, details of occupation and any current medication were noted and the subjects were asked if they would be prepared to make a further collection if necessary.

#### *Biochemical methods*

All collections were measured and diluted to 2 litres with distilled water. Na, K, urea and creatinine concentrations were measured by standard autoanalyser methods and urinary PABA as previously described (Bingham & Cummings, 1983) except that the following changes were made in order to shorten the method. Standards and 0.1 ml of the sample were pipetted into 25 ml glass-stoppered tubes. A few pellets of NaOH assisted in dissolving the PABA in standards of 80, 160 and 240 mg/l. From a solution of NaOH containing 40 g NaOH/l, 10 ml were added to samples and standards, and the analysis continued by a colorimetric method as previously described (Bingham & Cummings, 1983). Collections

Table 1. Details of subjects participating in the study

	Men	Women
Total no. of subjects collecting urine	80	55
Age (years)		
Mean	36.1	34.5
SD	5.61	5.5
Range	25.8-45.5	23.1-44.0
Social class*		
I+II	30	21
III	43	29
IV+V	6	5
Unclassified	1	0

\* By occupation (males) or husband's occupation.

Table 2. Constituents in twenty-one incomplete 24 h urine collections

(Mean values and standard deviations)

	PABA* (%)		Creatinine (mmol)		Na (mmol)		K (mmol)		Urea (mmol)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Men ( <i>n</i> 12)	68.9	9.1	13.7	2.8	131.0	31.0	66.2	14.7	281.4	64.3
Women ( <i>n</i> 9)	73.1	11.5	10.0	1.7	139.8	42.8	54.3	21.0	251.3	76.4

\* PABA (*p*-aminobenzoic acid), % recovery of oral dose.

containing less than 85% (205 mg) of the PABA marker were classified as incomplete (Bingham & Cummings, 1983) and an attempt was made to obtain a second collection from the subjects concerned.

## RESULTS

Three of the twelve replacements for subjects that had moved were also found to have moved. Three men had to be excluded from the study, two because of long-term absence from home, the third because of severe mental handicap, leaving 111 eligible subjects. No contact was established with seven (they were away from home on at least three occasions) and twenty-four subjects refused to participate (eight by telephone after receiving the first letter and sixteen after the first home visit). Participation was thus achieved from eighty men, 77% of those contacted or 72% of the eligible sample. In addition, fifty-five wives were studied, fourteen having been excluded because of pregnancy (eight subjects), breast feeding (five subjects) or current medication (one subject). Some characteristics of the subjects are shown in Table 1.

Compared with that expected in an East Anglian population (Office of Population Censuses and Surveys, 1973), the number of subjects in social class IV was less than expected (6 *v.* 16) and in social class II rather more (23 *v.* 15). However, the number in social

Table 3. *Constituents in complete 24 h urine collections*  
(Mean values and standard deviations)

	PABA* (%)		Sodium (mmol)		Potassium (mmol)		Urea (mmol)		Creatinine (mmol)		Time (h)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Collections complete first time												
Men (n 63)	94.8	5.6	173.8	52.3	75.1	23.7	381.9	106.3	16.0	2.9	23.3	2.7
Women (n 42)	94.4	3.9	124.8	38.4	59.8	15.6	290.2	82.5	11.0	2.0	23.6	1.2
Satisfactory second collections†												
Men (n 8)	94.4	7.8	160.6	47.5	68.6	21.4	369.3	94.6	16.0	3.1	23.3	1.4
Women (n 9)	91.0	6.2	147.8	33.6	69.0	20.0	324.5	69.6	12.3	1.5	24.2	1.4
Total complete collections												
Men (n 71)	94.7	5.8	172.4	51.6	74.3	23.4	380.5	104.5	16.0	2.9	23.3	2.6
Women (n 51)	93.8	4.5	128.1	38.4	61.5	16.6	296.4	80.8	11.2	1.9	23.7	1.3

\* PABA (*p*-aminobenzoic acid), % recovery of oral dose.

† Includes those in whom first collections contained paracetamol and those in whom first collections were incomplete.

*Intakes of sodium and potassium*

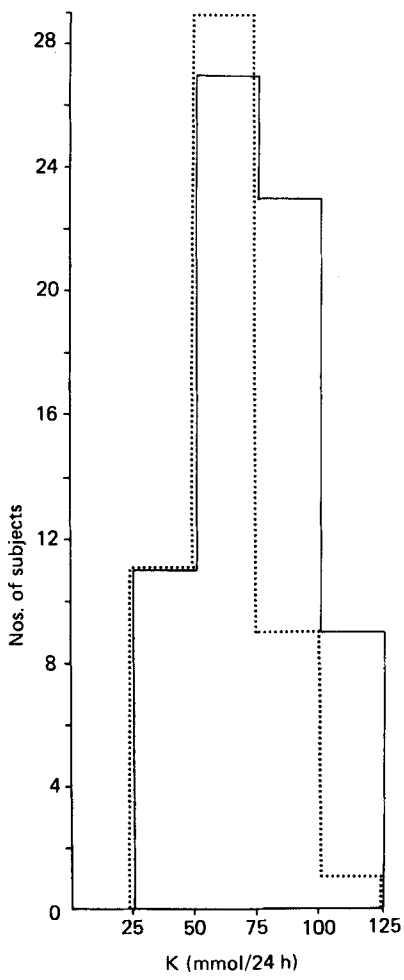
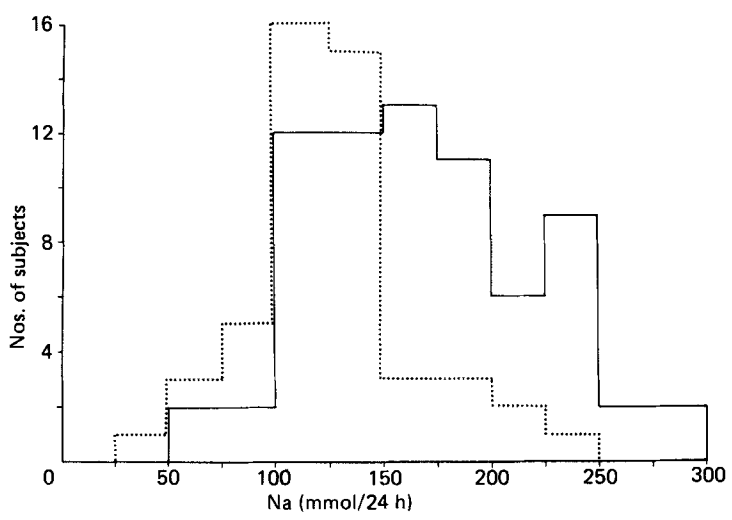


Fig. 1. Distribution of (a) sodium and (b) potassium in 122 collections of urine from men (—) and women (.....).

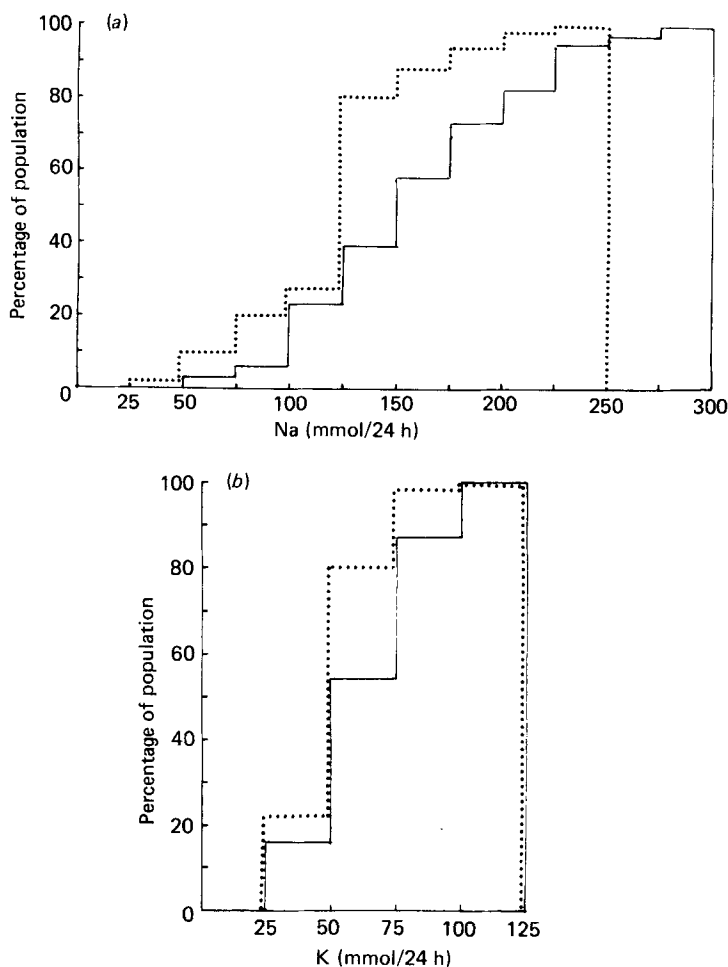


Fig. 2. Cumulative frequency distribution of (a) sodium and (b) potassium in 122 collections of urine from men (—) and women (.....).

class III non-manual was the same as, and the number of subjects in class III manual greater than, expected (36 v. 28).

Sixty-three men and forty-two women made urine collections judged to be complete (> 85% PABA recovery) on the first occasion. Samples from twelve men and nine women were judged to be incomplete (average PABA recovery 71%). All of these stated they had taken the capsules as directed. Of these twenty-one collections, only six were stated to be incomplete by the subject. Details of the twenty-one incomplete collections are shown in Table 2. Of these, three would have been judged incomplete by virtue of having creatinine outputs less than those regarded as 'normal', i.e. less than 9 mmol for women, 10 mmol for men, or by the creatinine index (Joossens & Geboers, 1983) which includes a correction factor for body-weight. Of the group which made complete collections, 38, 54 and 8% came from social classes I+II, III+IV, and V respectively and, of the group which made incomplete collections, 30, 65 and 5% came from social classes I+II, III+IV, and V respectively. There were no significant differences in body-weight or height between the two groups.

An attempt was made to obtain repeat collections from the twenty-one individuals who made incomplete collections, and ten agreed to do so. Two of these ten individuals were unable to make a complete collection at the second attempt. They were not asked to try again. For the remaining eight subjects, average urea, creatinine and PABA were significantly higher (Student's *t* test) in the repeat collections than in the initial collection by 46% ( $P < 0.02$ ), 23% ( $P < 0.05$ ) and 24% ( $P < 0.01$ ) respectively. Na and K were also higher (by 14% and 9%) but these differences were not significant.

Nine individuals (five men and four women) took paracetamol in the earlier part of the study. This caused a markedly high 'recovery' of PABA. These subjects were asked to repeat the collections and all of them did so. In the repeat collections, Na was 9% higher ( $P < 0.05$ ) compared with the paracetamol-containing collection but there were no significant differences in creatinine, K and urea excretions.

Results for collections completed first time, satisfactory at the second attempt and for all complete collections are shown in Table 3. Average time of total complete collections ( $n$  122) was 23.5 h. Average 24 h Na excretion for men was 172.4 mmol (equivalent to 10.1 g NaCl) and for women 128.1 mmol (7.5 g NaCl). The average excretion of K for men was 74.3 mmol and for women 61.5 mmol. Mean Na:K for men was 2.5 and for women 2.1. The distributions of these electrolyte excretions are shown in Figs. 1 and 2. Na output was significantly correlated with body-weight in men ( $r$  0.386,  $P < 0.05$ ) and in women ( $r$  0.451,  $P < 0.01$ ). When the constituents of the twenty-one incomplete collections were compared with the 122 complete samples, the content of all constituents was lower, and significantly so in men except for K (for Na,  $t = -6.08$ ; K,  $t = -1.64$ ; urea,  $t = -4.41$ ; creatinine,  $t = -2.62$ ).

Sixty-five (55%) of the complete collections were commenced either on a Saturday or Sunday, but there were no significant differences between mean Na and K excretion rates on weekdays and on weekend days. The collections (referred to in Table 3) were all carried out between the last week in May and the second week in October.

Mean Na output in men of the non-manual social classes (I, II and III non-manual) was lower than for men of social class III manual, IV and V (165.8 (SE 8.0) mmol v. 178.9 (SE 9.6) mmol) though this difference was not statistically significant. Mean K excretion rates in these two groups were similar (76.9 (SE 3.4) mmol/24 h and 70.7 (SE 4.8) mmol/24 h respectively). In women, there was little difference between Na outputs in the non-manual group and the manual group (women classified on the basis of their husbands' social class). Mean Na outputs in these two groups were 128.6 (SE 7.5) mmol/24 h and 129.1 (SE 8.0) mmol/24 h respectively.

#### DISCUSSION

Some estimates have been made of Na intakes in the UK population. Bull & Buss (1980) calculated an average intake of 113 mmol Na/d on the basis of data derived from the National Food Survey (NFS) (Ministry of Agriculture, Fisheries and Food, 1980) and a further 54 mmol/d purchased as table salt. They also reported analyses of representative quantities of food prepared for eating, salted 'as appropriate' but excluding salt added at the table. These suggested an average intake of 140 mmol/d. Beevers *et al.* (1980) collected 24 h urine samples from hypertensive and normotensive individuals, aged 45–64 years and living in Renfrew, Scotland. Urinary Na excretions ranged from 144.4 (SE 59.4) mmol in hypertensive women to 196.1 (SE 62.0) mmol in normotensive men. Earlier, Dauncy & Widdowson (1972) had reported much higher intakes in men living in one of five towns and cities in the UK. The highest intakes they found were in Plymouth (mean 241.1 (SE 83.3) mmol/d). These were estimated, not by 24 h urine collection but from single urine

specimens using a value of 25 mg creatinine excretion/kg per 24 h for the calculation of daily output. A British food industry estimate (Druce, 1983) gave a range of 185–209 mmol Na/d. Clearly, estimates of Na consumption vary markedly, partly because of methodological problems, and this makes any recommendations to reduce Na intake (National Advisory Committee on Nutrition Education, 1983) difficult to formulate.

The present study is the first to measure the urinary Na and K outputs in a random sample of the male population using the PABA check as a means of assessing the completeness of urine samples and to give the results only for those subjects known to have provided complete samples. PABA was originally chosen for a verification of the completeness of 24 h urine collections because it is a harmless but well absorbed (Arvanitakis *et al.* 1978) precursor of *p*-amino hippuric acid (PAHA) which is quickly and quantitatively excreted by the kidney via filtration and active tubular secretion (Tune *et al.* 1969). Marker tablets are now commercially available (PABA-Check Tablets, Laboratories for Applied Biology Ltd, London) and the method of analysis is simple and readily modified for autoanalysis (Weinfeld & Lee, 1979). Adequate preservative is necessary during the collection; 5 g boric acid added to each 2-litre bottle seems to be an acceptable alternative to Thimerosal (S. A. Bingham, unpublished results). If 24 h urine collections are complete, a single collection should contain  $93 \pm 4\%$  (Bingham & Cummings, 1983) and a continuous series  $99 \pm 3\%$  recovery (Bingham & Cummings, 1984) of three oral 80 mg tablets or capsules of PABA given with meals.

In the present study, when collections containing  $< 85\%$  recovery were excluded, the coefficient of variation between individuals in PABA recovery was only 6%, compared with 18% in creatinine excretion. This range in creatinine excretion is less than that of 25% usually quoted (Jackson, 1966) for free-living individuals. However, in no previous study has it been possible to verify the completeness of collections made by free-living individuals, and in the present study 17% of samples collected were incomplete despite careful instructions in the technique of urine collection and adequate equipment for doing so. Only 14% of these would have been detected by the use of creatinine and only 29% from self reports. The greater sensitivity of the PABA check in detecting incomplete collections is therefore highlighted by this randomly selected population sample.

It has been suggested that the inclusion of incomplete samples within a population average will be cancelled out by over collection (Joossens & Goeboers, 1983) (which PABA cannot detect) but this study does not support this suggestion. In none of the complete collections was the creatinine index in excess of the upper limit of normal and the average time from the start of the collection (when the first specimen was discarded) and the last one being added was 23.5 h. The PABA check test is reliant on subject motivation in that the three capsules or tablets need to be taken during the 24 h period as directed. However, low PABA recovery, although it can result either from an incomplete collection or failure to take one or more capsules, clearly signifies an unsatisfactory observation which can be repeated or at least excluded from analysis. We were surprised by the extent to which paracetamol is consumed by healthy individuals and instructions for PABA check tablets take account of this.

Initially, it was hoped to obtain repeat collections to replace those found to be incomplete. However, this was successful in only eight individuals and although the excretion of the least variable constituents (PABA, urea and creatinine) was significantly higher in the repeat collections, the difference was not statistically significant for Na and K. However, highly significant differences were found when a comparison of large numbers of samples was made between all incomplete collections in men and those which were complete, with *t* values ranging from 2.62 to 6.08. These results suggest that the inclusion of incomplete 24 h



collections in a large population sample would lead to systematic underestimation of Na and K excretion rates.

The average intake of Na in this sample of men was 172 mmol. The sample of women was not random though it served to give an indication of an average intake in married women in this age group of 128 mmol/24 h. These intakes are lower than might be expected from other estimates (Dauncey & Widdowson, 1972; Beevers *et al.* 1980; Druce, 1983). At no time were the subjects aware that Na and K were the objects of the study and systematic error could not have arisen from this source. However, the method assumes no losses of Na from other excretory routes, such as faeces and skin, which may not always be true in Britain where climatic conditions are unpredictable. When the average excretion is adjusted to equal numbers of men and women, the average excretion is 150 mmol, similar to that of 140–167 mmol estimated from the NFS (Bull & Buss, 1980). A recent study (Sanchez-Castillo *et al.* 1984) in which total excretion of Na in a sample of men and women was also 150 mmol, suggested that 70–90% of Na in the diet is derived from food, with only 5% added in cooking and 6% added at the table. If Na intakes are to be reduced then this reduction would have to come from salt in processed food which supplies a large proportion of the total (Bull & Buss, 1980).

Both ischaemic heart disease and cerebrovascular disease mortality vary by social class and by geographical region in the UK. Hypertension is an important risk factor for both and, if intakes of dietary Na or K, or both, are major aetiological factors, then social class and geographical differences in intakes may be expected. This study has not demonstrated differences in Na or K excretion rates between non-manual and manual social classes, though the numbers of subjects may be insufficient for this purpose. Clearly, larger social class and geographical studies are needed in which precautions are taken to ensure the completeness of 24 h urine collections. The present study has shown the feasibility of epidemiological investigations using the PABA check test to verify the completeness of collections.

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