Mineral Metabolism on Rice Diets

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(*Received* 30 *December* 1949)

Over half the population of the world eats a diet in which rice predominates and such a diet usually has a low mineral content. This is certainly true for the diets consumed by most of the people of Ceylon (Nicholls, 1936; Nicholls & Nimalasuriya, 1939; Bibile, Cullumbine, Watson & Wickramanayake, 1949; Cullumbine, 1949*a*), and it is difficult to understand how these people can grow and maintain health on such low mineral intakes. The problem is further complicated by the fact that these diets, which are rich in cereals (50–60 % at least of the total calories may be obtained from rice), have a relatively high content of phosphorus, and presumably of phytate phosphorus too. McCance & Widdowson (1942–3*a*) have shown that the phytic acid of bread interferes with the absorption from the gut of calcium and magnesium. Their results indicate that the greater the phytic-acid content of a diet rich in bread, that is, the higher the extraction rate of the flour from which the bread is made, the less is the absorption of these minerals from the intestine. Walker, Fox & Irving (1948) have confirmed these findings and they made the further interesting observation that subjects can adapt themselves to a lowered absorption of calcium or magnesium. This recalls the suggestion of Nicholls & Nimalasuriya (1939) who, when discussing the low dietary intake of calcium by the average Ceylonese, concluded that only a process of racial adaptation could explain the growth of Ceylonese without the occurrence of bony abnormalities.

Unpolished rice has a higher phytic-acid content than polished rice (McCance & Widdowson, 1935), and both types of rice are consumed in Ceylon. It seemed desirable, therefore, to determine whether there was any difference in the calcium and magnesium metabolism of subjects when eating diets first high in unpolished rice and then in polished rice. Further, it seemed necessary to see whether the suggestion of the occurrence of a process of adaptation has any experimental basis.

METHODS

Subjects. The subjects were twelve male medical students who lived in a nearby medical students' hostel. One of us (T. W. W.) was Resident Warden at this hostel during the period of the experiments and this facilitated the control of the diet and the collection of specimens. T. W. W. supervised the preparation of all meals, the issuing of food and the consumption of food throughout the experiments. Arrangements were also made to collect specimens during the day at the Physiology Department, where all the students were working. The subjects were under observation for a continuous period of at least 12 weeks. Three of the subjects were maintained on the particular diets for 31 weeks; it was not thought advisable to study the rest of the subjects for the prolonged period since this would have extended their experiment into an examination term. Five of the subjects were Ceylon Tamils and seven were Sinhalese. They were all normally active and healthy and within the age range 21–25 years. Their heights and weights are given in Table 1.

Table 1. *Heights and weights of the subjects*

Subject no.	Height (cm.)	Weight (kg.)
1	158·5	55·0
2	160·5	55·0
3	163·0	72·5
4	162·0	56·5
5	180·0	61·5
6	165·0	51·5
7	158·5	50·0
8	157·0	46·5
9	158·5	53·0
10	154·5	58·5
11	163·0	64·0
12	160·0	64·5

Diets. The diet was adjusted so that each subject ate daily the equivalent of 9 oz. raw rice. Our dietary surveys have indicated that this is the average consumption of rice among the Ceylonese (Cullumbine, 1949*b*). This quantity of raw rice is equivalent to at least 27 oz. cooked rice, and this formed the main bulk of the diet. The rest of the diet was typically Ceylonese in character. On the average the daily diet was composed of: rice 9 oz., potatoes 1·5 oz., sugar 1 oz., dhal 3 oz., green vegetables 2 oz., vegetable fruits (bread-fruit, jack-fruit, ladies' fingers, brinjals) 2·5 oz., fresh fruit 4·5 oz., white bread 3·5 oz., beef 4 oz., fresh fish 1 oz., butter 0·5 oz. It was not supplemented with vitamin D or any other vitamin. It was varied from day to day but was repeated from week to week. On different sampling weeks the actual foodstuffs eaten by the subjects through each 7-day period were weighed. This allowed us to check the constancy of consumption by each individual and also enabled us to calculate the chemical composition of each subject's diet. The diet had, it was found, the following average calculated (see p. 110) daily composition:

Calories	2005	Iron	16·5 mg.
Protein: total	84·0 g.	Vitamin A*	9750 i.u.
animal	41·0 g.	Aneurin: polished rice	1·70 mg.
Fat	39·5 g.	unpolished rice	2·20 mg.
Carbohydrate	351 g.	Riboflavin	4·74 mg.
Calcium	575 mg.	Nicotinic acid	20·2 mg.
Phosphorus	1485 mg.	Ascorbic acid	101·6 mg.

* Derived from preformed vitamin A and carotene, in the approximate proportions 1:2. The intake has been assessed using a conversion factor of 2 i.u. carotene as equivalent to 1 i.u. vitamin A.

The subjects took the different varieties of rice as follows.

Weeks 1–4 inclusive: 'normal' diet, i.e. a mixture of polished (Europe no. 2) and unpolished (Ceylon Country) rice in the proportions of 6:4 and a total of 9 oz. rice a day.

Weeks 5–7 inclusive: unpolished rice diet, i.e. 9 oz. unpolished (Ceylon Country) rice a day.

Weeks 8–10 inclusive: polished rice diet A, i.e. 9 oz. polished (Europe no. 2) rice a day.

Weeks 11–12 inclusive: polished rice diet B, i.e. 9 oz. polished (Small Mills Specials) a day.

Two types of polished rice diet were used because several varieties of rice are consumed in Ceylon, and analyses showed that these differed in mineral content (Table 2). The rice was prepared by boiling in water, after a preliminary washing, the water being drained off and discarded after the washing. This is the usual method of preparing rice in Ceylon. About one-third of Ceylon's rice is grown locally (Country rice, unpolished and parboiled), and the rest is imported from various countries, including Burma, Egypt and Brazil. Most of the imports come from Burma as Milchard no. 2, which is a moderately highly milled parboiled rice, or as Small Mills Specials which is lightly milled and polished. Europe no. 2 is well milled and polished and Europe no. 1 very highly milled and polished. The rices used in the diets were Ceylon Country rice in the unpolished rice diet, Europe no. 2 in the polished rice diet A and Rangoon Small Mills Specials in the polished rice diet B. (It is, of course, more correct to speak of lightly milled and highly milled rices than of unpolished and polished rices, but the latter terms are in more general use.) It will be seen, therefore, from Table 2 that the unpolished rice diet should be intermediate in calcium content and highest in phytate-phosphorus content; polished rice diet A should be low in calcium and low in phytate-phosphorus content; and polished rice diet B should be high in calcium content and intermediate in phytate-phosphorus content. The average Ceylonese eats a mixture of country rice and polished rice and such a mixture formed our so-called normal diet.

Table 2. *Mineral composition of different varieties of rice*

Variety of rice	Extraction rate (%)	Calcium (mg./100 g.)	Magnesium (mg./100 g.)	Total phosphorus (mg./100 g.)	Phytate phosphorus (mg./100 g.)
Ceylon Country (unpolished and parboiled)	Not known	21·8	77·12	350	225
Milchard no. 2 (polished and parboiled)	71	21·1	9·07	244	170
Europe no. 1 (polished and raw)	40	12·7	7·74	169	81
Europe no. 2 (polished and raw)	47	14·1	6·98	179	81
Small Mills Specials (polished and raw)	62	29·2	9·80	193	134

The rice always supplied 40–50 % (varying with individuals) of the total estimated calories.

Experimental and analytical procedure. The general experimental procedure and the analytical methods closely followed those described by McCance & Widdowson

(1942–3*a*). The foods, faeces and urines were analysed for calcium, magnesium, total phosphorus, phytate phosphorus, and iron. Duplicate samples were taken in parallel and the determination was repeated if good agreement was not obtained. The only difficulty found was in obtaining good duplicate determinations for iron in food. McCance & Widdowson (1942–3*a*) reported a similar inconsistency.

Sampling was done for 7 consecutive days, during each of weeks 2, 4, 7, 10 and 12. The first 2 weeks (2 and 4) of sampling enabled us to determine that each subject was in a maintained mineral balance, that the diet was satisfying and that the subjects understood the co-operative nature of their task. The subsequent sampling weeks were spaced so as to ensure that the subjects had time to adjust themselves to the new dietary conditions.

Following this 12-week period, three subjects were maintained on the unpolished rice diet for a further period of 18 consecutive weeks. Samples were collected for the 7 consecutive days of each 3rd week of this period. From this more prolonged experiment it was hoped to obtain evidence as to the reality of the process of adaptation.

RESULTS

The figures obtained for the two preliminary sampling periods, when the subjects were eating the normal diet, were so consistent that, for the sake of brevity, only the results for week 4 are given for this period.

Calcium metabolism. McCance & Widdowson (1942–3*a*) discussed their results on the basis of the estimated amount of calcium absorbed, the assumption being made that all the faecal calcium was obtained from unabsorbed food calcium. Steggerda & Mitchell (1946*b*) have shown that this assumption may not be true, so that we have here considered the calcium balance (total intake less total excretion) rather than the absorption (Table 3).

All twelve subjects showed a positive calcium balance during the 4 preliminary weeks that they were eating a normal diet. In every instance substitution of unpolished, country rice for the normal mixture of rice resulted in a substantial decrease in this metabolic balance and, in six subjects, the balance actually became negative. This occurred despite the fact that the intake of calcium on the unpolished rice diet was in many subjects higher than on the normal, mixed-rice diet. The decrease in the calcium balance was due to the increased excretion of calcium in the faeces, the faecal calcium being greater in all subjects when they were eating the unpolished rice diet.

Consumption of polished rice instead of the unpolished rice altered the balance again. In all subjects the balance became more positive or changed from a negative to a positive one, although the actual intake of calcium was uniformly less on this diet of polished rice than when unpolished rice was consumed. This change in the calcium metabolism was due to the lessened excretion of calcium in faeces. The urinary excretion of calcium was, in nine subjects, greater on the polished rice diet.

Increasing the calcium intake, by the substitution of polished rice diet B for diet A, still further increased the calcium balance. The increase in amount of calcium retained in the body was roughly proportional, but not equal, to the increase in intake, and both the faecal and urinary calcium excretions also were increased.

Table 3. *Daily intake, excretion and retention of calcium, magnesium, total phosphorus and iron from diets containing unpolished and polished rice*

(Measurements in mg./day)

Subject no.	Diet	Calcium Intake	Calcium Excretion Faeces	Calcium Excretion Urine	Calcium Excretion Total	Calcium Balance	Magnesium Intake	Magnesium Excretion Faeces	Magnesium Excretion Urine	Magnesium Excretion Total	Magnesium Balance	Total phosphorus Intake	Total phosphorus Excretion Faeces	Total phosphorus Excretion Urine	Total phosphorus Excretion Total	Total phosphorus Balance	Iron Intake	Iron Excretion Faeces	Iron Excretion Urine	Iron Excretion Total	Iron Balance
1	Normal	575	401	115	516	+59	351	194	147	341	+10	1504	502	935	1437	+67	15·5	11·1	2·1	13·2	+2·3
	Unpolished rice	618	505	107	612	+6	383	230	159	389	−6	1703	693	896	1539	+164	15·5	10·3	1·4	11·7	+3·8
	Polished rice A	568	203	185	388	+180	368	202	149	351	+17	1022	281	726	1007	+15	14·7	10·4	1·1	11·5	+3·2
	Polished rice B	740	231	278	509	+231	452	246	132	378	+74	1064	275	763	1038	+26	14·9	10·2	1·2	11·4	+3·5
2	Normal	630	498	115	613	+17	434	324	102	426	+8	1435	561	830	1391	+44	15·2	11·6	2·1	13·7	+1·5
	Unpolished rice	632	526	109	635	−3	434	362	112	474	−40	1783	702	1020	1722	+61	14·9	12·1	1·0	13·1	+1·8
	Polished rice A	551	334	127	461	+90	369	282	62	344	+25	1070	338	694	1032	+38	14·6	11·9	1·4	13·3	+1·3
	Polished rice B	790	492	148	640	+150	394	222	81	303	+91	998	306	657	963	+35	15·0	11·6	2·5	14·1	+0·9
3	Normal	585	303	126	529	+156	430	260	25	285	+145	1161	457	641	1098	+63	15·7	12·8	2·4	15·2	+0·5
	Unpolished rice	619	378	132	510	+109	453	289	45	334	+119	1489	735	636	1371	+118	16·1	13·4	2·4	15·8	+0·3
	Polished rice A	551	219	142	361	+190	390	166	86	252	+138	938	294	615	909	+29	14·4	11·9	1·9	13·8	+0·6
	Polished rice B	806	343	163	506	+300	521	281	96	377	+144	1050	306	711	1017	+33	15·2	12·5	1·8	14·3	+0·9
4	Normal	742	506	161	667	+75	641	469	119	588	+53	1352	419	877	1296	+56	21·8	18·4	1·5	19·9	+1·9
	Unpolished rice	826	641	156	797	+29	615	480	134	614	+1	1720	504	1146	1650	+70	21·1	16·6	1·9	18·5	+2·6
	Polished rice A	609	297	199	496	+113	540	308	126	434	+106	1221	324	862	1186	+35	22·3	17·8	2·1	19·9	+2·4
	Polished rice B	1181	632	231	863	+318	837	475	145	620	+217	1716	408	1147	1555	+161	23·0	18·4	2·0	20·4	+2·6
5	Normal	502	352	68	420	+82	407	210	116	326	+81	1450	406	1008	1414	+36	17·2	12·3	3·8	16·1	+1·1
	Unpolished rice	504	441	90	531	−27	439	234	122	356	+83	1637	480	1056	1536	+101	16·7	12·0	4·1	16·1	+0·6
	Polished rice A	479	174	89	263	+216	401	123	120	243	+158	1112	237	877	1084	+28	17·2	12·4	5·2	17·6	−0·4
	Polished rice B	671	255	111	366	+305	455	149	132	281	+174	1216	254	916	1170	+46	17·3	12·3	4·3	16·7	+0·6
6	Normal	472	267	55	322	+150	403	249	78	327	+76	1239	405	792	1197	+42	18·6	16·2	1·0	17·2	+1·4
	Unpolished rice	465	310	46	356	+109	419	290	85	375	+44	1463	573	807	1380	+83	16·9	14·9	1·7	16·6	+0·3
	Polished rice A	440	235	53	288	+152	374	141	80	221	+153	1041	246	760	1006	+35	16·9	14·2	1·3	15·5	+1·4
	Polished rice B	556	270	83	353	+203	504	183	97	280	+224	1017	223	760	983	+34	17·9	15·6	1·8	17·4	+0·5
7	Normal	625	492	78	570	+55	426	289	45	334	+92	1376	347	976	1323	+53	21·7	18·6	0·9	19·5	+2·2
	Unpolished rice	648	535	83	618	+30	447	379	74	453	−6	1664	482	1089	1571	+93	20·7	18·6	1·1	19·7	+1·0
	Polished rice A	566	376	92	468	+98	398	162	35	197	+201	1175	215	924	1139	+36	20·4	17·7	1·2	18·9	+1·5
	Polished rice B	844	521	140	661	+183	536	230	49	279	+257	1563	306	1151	1457	+106	20·8	17·4	2·1	19·5	+1·3
8	Normal	480	253	141	394	+86	339	232	84	316	+23	1345	481	824	1305	+40	12·4	11·1	1·1	12·2	+0·2
	Unpolished rice	471	276	134	410	+61	349	280	76	356	−7	1467	503	911	1414	+53	11·8	10·7	0·4	11·1	+0·7
	Polished rice A	409	163	156	319	+90	318	174	66	240	+78	1241	216	986	1202	+39	12·9	10·6	1·3	11·9	+1·0
	Polished rice B	634	264	162	426	+208	454	226	89	315	+139	1279	278	956	1234	+45	13·4	11·1	1·2	12·3	+1·1
9	Normal	792	503	246	749	+43	481	362	118	480	+1	1702	674	936	1610	+92	19·8	15·9	1·5	17·4	+2·4
	Unpolished rice	883	668	225	893	−10	501	384	128	512	−11	1826	802	907	1709	+117	17·3	13·9	1·3	15·2	+2·1
	Polished rice A	867	486	283	769	+98	456	263	117	380	+76	1522	341	1103	1444	+78	21·6	16·9	1·4	18·3	+3·3
	Polished rice B	929	505	301	806	+123	618	348	129	477	+141	1683	406	1176	1582	+101	20·4	16·6	1·1	17·7	+2·7
10	Normal	525	396	104	500	+25	424	316	62	378	+46	1098	416	657	1073	+25	11·9	8·7	1·8	10·5	+1·4
	Unpolished rice	552	448	135	583	−31	442	374	56	430	+12	1103	480	584	1064	+39	12·8	9·9	2·1	12·0	+0·8
	Polished rice A	438	209	154	363	+75	378	186	63	249	+129	941	263	675	938	+3	11·7	9·0	2·2	11·2	+0·5
	Polished rice B	540	271	162	433	+107	437	203	83	286	+151	915	285	645	930	+15		—	—	—	
11	Normal	418	284	92	376	+42	362	265	71	336	+26	981	303	662	965	+16	11·4	9·9	1·4	11·3	+0·1
	Unpolished rice	445	361	107	468	−23	379	287	82	369	+10	979	360	598	958	+21	11·7	10·2	1·1	11·3	+0·4
	Polished rice A	410	261	64	325	+85	353	197	67	264	+89	945	185	737	922	+23	10·9	9·3	0·8	10·1	+0·8
	Polished rice B	751	394	89	483	+268	539	286	64	350	+189	972	206	743	949	+23	13·3	11·0	1·1	12·1	+1·2
12	Normal	512	403	90	493	+19	399	185	87	272	+127	870	351	511	862	+8	18·8	15·6	1·2	16·8	+2·0
	Unpolished rice	505	436	129	565	−60	400	222	93	315	+85	862	371	474	845	+17	19·7	16·8	0·6	17·4	+2·3
	Polished rice A	497	333	97	430	+67	381	161	99	260	+121	673	239	440	679	−6	16·6	13·2	1·3	14·5	+2·1
	Polished rice B	671	452	116	568	+103	549	208	95	303	+246	671	217	446	663	+8	21·0	17·5	1·4	18·9	+2·1

It is obvious, therefore, that the greater calcium retentions were obtained on the polished rice diet B. With unpolished rice the calcium balance tended to become negative. This obviously suggests that, from the point of view of calcium metabolism, polished rice is to be preferred. The less highly milled rice, Small Mills Specials, had a higher calcium content than the highly milled Europe no. 2 rice and our results suggest that the former, 62 % extraction rice, is the rice of choice for inducing calcium retention.

Magnesium metabolism. Very similar conclusions are obtained from a study of the magnesium balance on the various types of diet (Table 3).

The results are not so consistent as with calcium, but the same general tendency is to be noted.

Total phosphorus metabolism (Table 3). The intake of total phosphorus was greater on the unpolished rice diet but so was the excretion of phosphorus in the faeces. There was, however, a definite tendency for the retention of phosphorus to be greater on the diet of unpolished rice. McCance & Widdowson (1942–3*a*) reported the same phosphorus balance with diets containing bread made from high and low extraction flours. Walker *et al.* (1948) found the retention of phosphorus to be somewhat greater on a white bread diet than on a brown bread diet. Our figures suggest that the phosphorus retention is proportional to the amount absorbed. Increased absorption is accompanied by increased urinary excretion, but it is also accompanied by increased utilization or storage. Therefore, because of the greater phosphorus content, a diet containing unpolished rice will be more likely to provide a positive phosphorus balance than a diet of polished rice. On all types of diet, however, positive balances were obtained and all the diets were probably adequate from the standpoint of the phosphorus metabolism.

Iron metabolism. The consumption of unpolished rice did not affect the amount of iron retained by each subject (Table 3). Walker *et al.* (1948) similarly found that the iron balance did not vary as their subjects changed from white to brown bread diets, although Widdowson & McCance (1942) found a greater iron absorption from white bread diets than from brown bread diets. Our experimental periods may have been too short to reveal significant differences with such small metabolic balances.

Phytic-acid phosphorus. Unpolished rice contains more phytic acid than polished rice and, in conformity with this, we found the phytic-acid phosphorus contents of the unpolished rice diets higher than those of the polished rice diets. The differences, however, were not as great as would be expected from our analytical figures for raw rice. If each subject consumed daily an average of about 9 oz. of rice we should expect the diets with unpolished rice to contain 270–430 mg. more phytic-acid phosphorus than the polished rice diets; the average estimated difference was only 117 mg./day (Table 4). A probable explanation of this is that the phytic-acid phosphorus of rice cooked by Ceylonese methods is less than that of raw rice. Some preliminary estimations that we have made on various Ceylonese rice dishes suggest that about two-thirds of the phytate may be hydrolysed or broken down during the process of cooking.

The difference in phytic-acid phosphorus content does not explain the marked differences in the total phosphorus content of the two types of diet. Unpolished rice contains more of other types of phosphorus too. Presumably our results on the

Table 4. *Daily intake, excretion and retention of phytate phosphorus on unpolished and polished rice diets*

Subject no.	Diet	Intake (mg.)	Excretion in faeces (mg.)	Phytate hydrolysed (percentage of intake)
1	Unpolished rice	346	39	89
	Polished rice A	260	32	88
2	Unpolished rice	367	62	83
	Polished rice A	321	42	87
3	Unpolished rice	399	44	89
	Polished rice A	308	35	89
4	Unpolished rice	315	70	78
	Polished rice A	197	56	72
5	Unpolished rice	455	84	82
	Polished rice A	241	27	89
6	Unpolished rice	628	75	88
	Polished rice A	487	40	92
7	Unpolished rice	415	67	84
	Polished rice A	246	33	87
8	Unpolished rice	321	83	74
	Polished rice A	148	29	80
10	Unpolished rice	252	61	76
	Polished rice A	161	26	84
11	Unpolished rice	332	55	83
	Polished rice A	300	44	85
12	Unpolished rice	380	48	87
	Polished rice A	247	42	83

influence of various types of rice on mineral metabolism can be explained on the basis of the greater phytic-acid content of unpolished rice, though whether there is sufficient phytic acid present quantitatively to account for the noted differences in calcium and magnesium balances we cannot say. We may assume that inorganic phosphorus does not interfere with calcium absorption, since McCance & Widdowson (1942–3*a*) have shown that fortification of bread with calcium phosphate improves the absorption of calcium.

The proportion of phytate hydrolysed did not vary with the type of diet consumed (Table 4).

Adaptation. Walker *et al.* (1948) thought that their results indicated that subjects could gradually adjust their metabolism so as to obtain positive calcium balances on diets poor in calcium, but rich in phytate phosphorus, and that the smaller the difference between the experimental calcium intake and the normal calcium intake the quicker this adjustment occurred. McCance & Widdowson (1942–3*a*) could find no evidence for such an adjustment in their subjects, but their periods of observation (at least for calcium) were probably too short for this to become evident.

The calcium intakes on our experimental unpolished rice diet were very similar to, and indeed slightly greater than, the subjects' normal intakes. We should expect, therefore, that if an adjustment were to occur it would occur quickly. Different subjects may vary in their response and it may be argued that those subjects whom we found to have a positive calcium balance during the 3rd week of the unpolished rice period had already adjusted themselves to the new dietary conditions.

To obtain further evidence on this important aspect, three subjects consumed the experimental unpolished rice diet continuously for 18 weeks. Two of these subjects (nos. 2 and 9) had previously had negative calcium and magnesium balances on this diet; the third (no. 1) was almost in equilibrium for both calcium and magnesium (Tables 2 and 3). Analyses done on the samples for every 3rd week of this period gave the results shown in Table 5.

It is evident that the calcium and magnesium balances improved for each subject so that, for example, originally negative balances in time became positive. This is definite evidence of an adaptation on the part of the organism to adverse dietary conditions. That this adaptation may not be entirely sufficient is suggested by the figures for the 19th week of the experiment, when polished rice diet A (lower calcium and phytic-acid contents) was consumed. This change in diet was accompanied by an immediate increase in the amounts of calcium and magnesium retained.

It is not possible to say what is the essential nature of this process of adaptation. It is achieved, apparently, by decreasing the quantities of calcium and magnesium in the faeces. This may be due to an alteration in the intestinal flora producing increased breakdown of phytate, or to altered rates of absorption. The urinary excretion, it will be noted, tended to increase and all our figures suggest, as McCance & Widdowson (1942–3*b*) have shown, that the urinary calcium, at least, tends to follow the absorption.

DISCUSSION

Calcium requirements. Most of the dietary requirements are still disputed. The optimum requirements are usually defined as those necessary to produce normal growth and full health but there is considerable confusion over the standards of growth and health at which to aim. The Ceylonese are, on the average, smaller than Europeans. This may be due to multiple deficiencies in the diet, but it must also be remembered that even the upper classes are still relatively small in stature (Cullumbine, 1949*c*). Therefore, it seems reasonable to assume that each race has its own growth standards and, therefore, possibly its own dietary requirements.

The minimum daily requirement of calcium is usually taken as the amount that will just maintain a positive metabolic balance and, on this basis, it seems that about 10 mg./kg. body-weight is this requirement for western people (Steggerda & Mitchell, 1939, 1941, 1946*a*; Leitch, 1937; Holmes, 1945). The results reported in this paper suggest that the calcium requirement varies also with the type of cereal in the diet, and that the process of adaptation may enable subjects to maintain a positive balance even on low intakes of available calcium. For these reasons it is difficult to make a dogmatic statement about the minimum requirements for adult Ceylonese. All that we can usefully say, at present, is that 10 mg./kg./day would seem to be an ample allowance of calcium for these subjects. The average weight of our group was 60·2 kg.; the average weight of adult male Ceylonese is 50 kg. There are, however, considerable individual variations in the metabolism of calcium. Thus, on the unpolished rice diet subject no. 6

Table 5. *Daily intake, excretion and retention of calcium and magnesium on a diet of unpolished rice*

		Calcium					Magnesium				
			Excretion					Excretion			
Subject no.	Week	Intake (mg./day)	Faeces (mg./day)	Urine (mg./day)	Total (mg./day)	Balance (mg./day)	Intake (mg./day)	Faeces (mg./day)	Urine (mg./day)	Total (mg./day)	Balance (mg./day)
1	3	606	512	109	621	−15	392	242	162	404	−12
	6	612	506	109	615	−3	387	238	158	396	−9
	9	624	483	121	604	+20	389	206	171	377	+12
	12	603	467	118	585	+18	376	198	169	367	+9
	15	610	444	131	575	+35	395	199	174	373	+22
	18	609	448	128	576	+33	398	197	173	370	+28
	19*	573	195	179	374	+199	354	135	173	308	+46
2	3	641	532	119	651	−10	427	341	111	452	−25
	6	646	517	123	640	+6	400	311	109	420	−20
	9	626	465	138	603	+23	375	260	121	381	−6
	12	638	467	141	608	+30	405	265	115	380	+25
	15	651	472	137	609	+42	415	248	137	385	+30
	18	643	444	152	596	+47	406	242	146	388	+18
	19*	569	302	161	463	+106	375	264	72	336	+39
9	3	865	679	208	887	−22	514	402	118	520	−6
	6	831	648	195	843	−12	529	405	115	520	+9
	9	820	606	212	818	+2	527	388	121	509	+18
	12	863	657	209	866	−3	508	354	133	487	+21
	15	851	585	225	810	+41	518	356	132	488	+30
	18	872	606	228	834	+38	523	349	141	490	+33
	19*	847	529	243	772	+75	465	278	123	401	+64

* In the 19th week a polished rice diet was consumed.

had a positive balance of 109 mg. with an intake of 465 mg., whereas subject no. 9 had a negative balance of 10 mg. on an intake of 883 mg.

Basu and his co-workers have studied the problem of calcium metabolism in Indian subjects consuming different types of diet. They have calculated the maintenance calcium requirement as 432 mg./man-value (Basu, Basak & De, 1941); this is less than the 10 mg./kg. recommended for occidental peoples. They have made no direct comparison of the effects of different varieties of rice on the calcium balance but they reached the significant conclusion that the replacement of a portion of the rice of a diet by an equal weight of sago, which contained the same percentage of calcium as the rice but much less phosphorus, improved the calcium balance (Basu, Basak & Rai Sircar, 1939). In their experiments the diets were changed every 6 days, so that any process of adaptation would not have been revealed.

Calculated composition of the diets. There is always some doubt, in assessing the data of a dietary survey, about the accuracy of the calculated chemical composition of the diets. During our own nutritional surveys in Ceylon we have used the tables compiled by Platt (1945), McCance & Widdowson (1946), and Joachim & Pandittesekere (1938), with, in addition, some figures obtained in our own laboratories from analyses on some of the common cooked dishes of Ceylon. This investigation gave us the opportunity to check the reliability of our calculations against the actual estimations for calcium, phosphorus and iron. One such comparison for the unpolished rice diet is shown in Table 6. The agreement in most instances is remarkably close.

Table 6. *Comparison of the calculated and measured calcium, phosphorus and iron intakes of subjects consuming the unpolished rice diet*

Subject no.	Calcium (mg./day)		Total phosphorus (mg./day)		Iron (mg./day)	
	Calculated	Measured	Calculated	Measured	Calculated	Measured
1	575	618	1746	1703	16·2	15·5
2	609	632	1754	1783	16·0	14·9
3	613	619	1458	1489	15·7	16·1
4	803	826	1820	1720	21·1	21·1
5	499	504	1549	1637	18·6	16·7
6	411	465	1498	1463	18·5	16·9
7	631	648	1654	1664	19·2	20·7
8	450	471	1481	1467	11·2	11·8
9	836	883	1916	1826	18·1	17·3
10	539	552	1029	1103	10·7	12·8
11	426	445	1066	979	10·6	11·7
12	490	505	856	862	22·2	19·7

SUMMARY

1. The metabolism of calcium, magnesium, phosphorus, phytate phosphorus and iron was studied in twelve healthy Ceylonese male medical students for periods lasting from 12 to 31 consecutive weeks. Each subject consumed daily 9 oz. rice and the type of rice was varied from time to time.

2. Consumption of polished rice gave a better calcium and magnesium balance than the consumption of unpolished rice. A moderately polished rice with a high calcium content and a moderate phytic-acid content gave the best balances.

3. Three of the subjects consumed an unpolished rice diet for a continuous period of 18 weeks and during this period the calcium and magnesium balances improved. This is taken as definite evidence of a process of adaptation.

4. The metabolism of iron was not consistently influenced by the type of rice consumed.

5. Unpolished rice diets resulted in greater excretions of phosphorus in faeces and urine and in greater phosphorus retentions than the polished rice diets.

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