Moisture and Mineral Content of Human Feces
—High Fecal Moisture Is Associated with Increased Sodium and Decreased Potassium Content—

Mamoru NISHIMUTA1, Nozomi INOUE1, Naoko KODAMA1,2, Eiko MORIKUNI1, Yayo H. YOSHOKA1, Nobue MATSUZAKI1, Mieko SHIMADA1,3, Nanae SATO1,4, Tamami IWAMOTO1,5, Kazuko OHKI1,6, Hidemaro TAKEYAMA1,7 and Hironobu NISHIMUTA8
1 Laboratory of Mineral Nutrition, Division of Human Nutrition, The Incorporated Administrative Agency of Health and Nutrition, Tokyo 162–8636, Japan
2 Medical University of Yamanashi, Yamanashi 409–3898, Japan
3 Chiba College of Health Science, Chiba 261–0014, Japan
4 Seitoku University, Matsudo 271–8555, Japan
5 Prefectural University of Hiroshima, Hiroshima 734–8558, Japan
6 Showa Women’s University, Tokyo 154–8533, Japan
7 Nagoya City University Graduate School of Medical Science, Nagoya 467–8601, Japan
8 Third Department of Surgery, Toho University Ohashi Hospital, Tokyo 153–8515, Japan

(Received September 22, 2005)

Summary
Background: The origin of moisture in diarrhea feces is unknown but may represent the unabsorbed part of intestinal contents or alternatively, body fluid excreted into the digestive canal. If the latter mechanism contributes to moisture in the feces, active transport of water (H2O) associated with ion exchange channels may be involved. Objective: To investigate this possibility we measured the content of moisture and minerals (sodium [Na], potassium [K], calcium [Ca], magnesium [Mg], phosphorus [P], zinc [Zn], iron [Fe], copper [Cu] and manganese [Mn]) in feces collected during a 12-d metabolic study on 11 young Japanese female students. Design: The study was carried out as part of a human mineral balance study. The same quantity of food was supplied to each of the subjects throughout the study without consideration of body weight. Fecal specimens were collected throughout the study and were separated into those originating from the diet during the balance period based on the appearance of the ingested colored marker in the feces. Results: The moisture content of the feces ranged between 53 and 92%. Na content in the feces was low and stable when the moisture content was below 80%, whereas it increased up to serum levels when the moisture content increased above 80%. On the other hand, K content increased when compared to dry matter base. However, when comparing concentration/g moisture, K content increased when moisture was below 70%, but decreased when this rose above 70%.

Key Words: fecal moisture, fecal sodium, fecal potassium, diarrhea, human

Feces represent the sum of the indigestible parts of ingested food, digestive juices and cells shed by the mucous membrane lining of the digestive canal. Although fecal moisture and concentrations of some nutrients including minerals were reported in some papers (1, 2), the relationship between fecal moisture and mineral was not systematically analyzed. The origin of moisture in diarrhea feces is unknown but may come from either the unabsorbed part of dermal contents or body fluids excreted into the digestive canal. If body fluids do contribute to the moisture content of feces, it is possible that active transport of water (H2O) associated with ion exchange channels is involved in this process.

In order to investigate this possibility we measured moisture and mineral content (sodium [Na], potassium [K], calcium [Ca], magnesium [Mg], phosphorus [P], zinc [Zn], iron [Fe], copper [Cu] and manganese [Mn]) in feces during a 12-d metabolic study on 11 young Japanese female students.

SUBJECTS AND METHODS
This study was carried out as part of a human mineral balance study. The balance study was performed according to the rules of the Helsinki Declaration, and was approved by the ethical committee of the Incorporated Administrative Agency of Health and Nutrition, Tokyo. An 18-d metabolic study, including three successive balance study sessions of 4 d, was designed as shown in Table 1. Eleven female students took part in this study after receiving a full explanation of the purpose and methods of the investigations and then provided their written, informed consent. The results of the first blood specimen were reviewed to ensure all the subjects were in good health (Table 2). The subjects reported to a metabolic ward in the afternoon before
supper on day 0 and ate as much as they desired before retiring to bed at the scheduled time of 10:00 p.m.

The same quantity of food and drinks was supplied to each of the subjects throughout the study without consideration of body weight. The subjects ingested an indigestible marker that colored their feces (carmine 0.3 g: Merck KGaA, Germany) just before breakfast on the morning of the 1st (beginning), 5th, 9th and 13th days (final) of the balance period. The foodstuffs used in each study were selected from those commercially available, with the main protein source being meat.

Duplicate diet samples were collected throughout the study periods and kept in a refrigerator for 1 d before being blended. For blending, the refrigerated diet samples were weighed and put into a mixer (MX150S, National, Japan). An adequate volume of ion-free water was then added and the mixture homogenized gradually for approximately 30 min using a slidetrans (RIKO-SLIDETRANS RSA-5, TOKYO-RIKOSHA, Japan) attached to the mixer. The homogenized diet samples were prepared in triplicate and weighed into separate polypropylene bottles for assay of either mineral or moisture content. The samples for moisture assay were kept at 30˚C before being analyzed using a freeze-drying system (Dura-Fry, FTS Systems, Inc., USA).

For the mineral assay, 5 mL of nitric acid (UGR grade, Kanto Chemical Co., Inc., Japan) was then added and the mixture kept at room temperature until digested. Digestion was carried out in hard glass beakers (Pyrex, Iwaki Glass, Japan) on a hot plate at temperatures below 140˚C, using nitric acid and hydrogen peroxide for trace analysis (Wako Pure Chemical Industries, Ltd., Japan). The interior of the bottles was washed with nitric acid that was then added to the sample in the beakers. After digestion, an adequate volume of pure water (Milli-Q, MILLIPORE, Japan) was added to the samples, which were then put on a hot plate at temperatures below 90˚C for 1 night prior to measurement of P content. A quantity of 0.5 M nitric acid was then added to attain a fixed volume followed by measurement of P concentration using a spectrophotometer (Beckman DU-640, USA). The concentrations of the other minerals (Na, K, Mg, Zn, Fe, Cu and Mn) were measured using an atomic absorption spectrophotometer (AAS, Varian AA-5, Australia), after the mixture had been diluted to an appropriate concentration with 0.5 M nitric acid (3).

Fecal specimens were collected throughout the study and were classified as those originating from the diet during the balance periods (12 d) based on the appearance of the ingested coloring marker in the feces. The fecal samples were analyzed in the same way as the diet

| ID | Sex | Age (y) | Height (cm) | Weight (kg) | TP (g/dL) | Hb (g/dL) | T-Chol (mg/dL) | HDL-C (mg/dL) | T-G (mg/dL) | Glucose (mg/dL) | S-Na (mmol/L) | S-K (mmol/L) |
|----|-----|--------|-------------|-------------|-----------|----------|---------------|---------------|------------|----------------|-------------|-------------|
| a  | f   | 21     | 167.6       | 52.13       | 7.9       | 12.5     | 158           | 50            | 40         | 18             | 10          | 85          |
| b  | f   | 19     | 152.5       | 49.82       | 7.5       | 11.9     | 152           | 50            | 76         | 10             | 6           | 81          |
| c  | f   | 20     | 153.6       | 48.92       | 6.9       | 13.1     | 165           | 60            | 63         | 14             | 6           | 87          |
| d  | f   | 20     | 155.4       | 53.74       | 7.0       | 12.1     | 189           | 55            | 86         | 15             | 13          | 78          |
| e  | f   | 20     | 162.8       | 50.36       | 6.7       | 11.7     | 175           | 73            | 53         | 15             | 14          | 81          |
| g  | f   | 19     | 154.3       | 43.95       | 7.5       | 12.3     | 152           | 63            | 52         | 21             | 17          | 81          |
| h  | f   | 20     | 157.5       | 54.15       | 7.7       | 13.3     | 172           | 56            | 43         | 14             | 8           | 85          |
| i  | f   | 20     | 158.5       | 47.44       | 7.4       | 12.3     | 135           | 70            | 39         | 18             | 13          | 84          |
| j  | f   | 20     | 158.3       | 51.13       | 7.2       | 11.7     | 139           | 57            | 72         | 13             | 9           | 93          |
| k  | f   | 21     | 150.6       | 43.67       | 7.4       | 14.0     | 148           | 57            | 69         | 14             | 10          | 84          |
| l  | f   | 21     | 166.7       | 53.13       | 7.3       | 12.6     | 170           | 66            | 76         | 16             | 10          | 89          |

Mean: 20 158.0 49.92 7.3 12.5 160 60 61 15 11 84 136 4.1
SD: 1 5.6 3.61 0.4 0.7 16 8 16 4 3 4 3 0.2

TP: total protein, Hb: hemoglobin concentration, T-Chol: total cholesterol, HDL-C: high density lipoprotein cholesterol, T-G: triglyceride, S-Na: serum sodium, S-K: serum potassium, IU: international unit.
Moisture and Mineral Content in Human Feces

Statistical analysis of the data was carried out using StatView-J5.0. The relationships between selected variables were examined using correlation and regression analyses. A \( p \) value of \(<0.05\) for the correlation coefficients was considered as statistically significant.

RESULTS

Dietary intake of energy, nutrients and fibers

The dietary intake of energy, nutrients and fibers during the study, calculated using food composition tables (4), is shown in Table 3. Some of the nutrients did not meet the dietary allowances in Japan (5).

| Nutrient                  | Calculated\(^1\) | Measured | RDA\(^2\) |
|---------------------------|------------------|----------|-----------|
| Energy (kcal/d)           | 1,647±159        | 1,675    |           |
| Water (g/d)               | 1,012±146        |          |           |
| Protein (g/d)             | 61.2±6.4         | 55       |           |
| Lipid (g/d)               | 45.2±5.1         |          |           |
| Carbohydrate (g/d)        | 244±33           |          |           |
| Ash (g/d)                 | 15.2±2.4         |          |           |
| Sodium (mg/d)             | 3,448±819        | 3,266±916|           |
| Potassium (mg/d)          | 2,113±291        | 1,844±356| 2,000     |
| Magnesium (mg/d)          | 605±169          | 504±135  | 600       |
| Phosphorus (mg/d)         | 193±16           | 159±13   | 250       |
| Iron (mg/d)               | 975±166          | 841±122  | 700       |
| Zinc (mg/d)               | 6.8±1.2          | 7.69±1.05| 12        |
| Copper (mg/d)             | 0.94±0.16        | 1.02±0.21| 1.6       |
| Manganese (mg/d)          | 8.0±1.0          | 5.65±1.49| 9         |
| Retinol equivalents (µg/d)| 2,347±1,382      | 540      |           |
| Vitamin D (µg/d)          | 7.1±1.2          |          | 8         |
| α-Tochopherol equivalents (mg/d)| 99±35 |          | 55        |
| Vitamin K (µg/d)          | 1.21±0.18        |          | 0.8       |
| Thiamin (B₁) (mg/d)       | 1.36±0.30        |          | 1.0       |
| Riboflavin (B₂) (mg/d)    | 12.9±1.7         |          |           |
| Niacin (mg/d)             | 17.6±1.9         |          | 13        |
| Niacin equivalents (mg/d) | 0.99±0.17        |          | 1.2       |
| Vitamin B₆ (mg/d)         | 3.5±1.5          |          | 2.4       |
| Folate (µg/d)             | 219±23           |          | 200       |
| Pantotheneic acid (mg/d)  | 5.59±0.61        |          | 5         |
| Ascorbic acid (C) (mg/d)  | 74±20            |          | 100       |

Fatty acids

| Saturated (g/d)           | 14.21±2.06       |          |
| Monounsaturated (g/d)     | 15.85±2.92       |          |
| Polyunsaturated (g/d)     | 8.74±1.92        |          |
| Cholesterol (mg/d)        | 184±56           |          |

Dietary fibers

| Water soluble (g/d)       | 2.8±0.7          |          |
| Water insoluble (g/d)     | 9.1±1.9          |          |
| Total (g/d)               | 12.6±1.8         |          |

Dietary values are mean±SD (4 menus).

\(^1\) By the Food Composition Tables (4).
\(^2\) Recommended Dietary Allowances, 6th revised edition (5).
(Female, 20 y, 158 cm, 50 kg)

Statistical analysis of the data was carried out using StatView-J5.0.

![Fig. 1. Relationship between wet weight and moisture (%) in feces collected during a human metabolic study in 11 female students (n=125).](image-url)
Moisture and wet weight of feces

Total number of fecal samples for 11 subjects collected and analyzed was 125. The relationship between moisture and wet weight of feces is shown in Fig. 1. The moisture content (%) of the feces increased according to the increase in wet weight. Fecal number, weight and moisture for each subject were shown in Table 4.

Moisture and mineral contents of feces

The relationships between moisture and Na and K contents are shown in Fig. 2. The moisture content of the feces ranged between 53 and 92%. Na content of the feces was low and stable when the moisture was below 80%, whereas it increased to serum levels when moisture increased above 80%. In contrast, K content increased when compared to dry matter base, with concentration/g moisture increasing when moisture was below 70% and decreasing when moisture was above 70%. Accordingly, in the moisture range above 80%, there was a negative correlation between fecal Na and K content expressed as concentration/1,000 g moisture.

The relationships between moisture and the content per dry weight of feces of the other minerals (Ca, Mg, P, Zn, Fe, Cu and Mn) are shown in Fig. 4. There was no correlation between Mg fecal content and % moisture, whereas there was a negative correlation between the content of the remaining minerals and moisture content. Correlation coefficient ($r^2$) between minerals expressed as/g dry matter are shown in Table 5. There are significant correlations between minerals measured with the exceptions of those against potassium.

Total fecal weight and serum content of Na and K

The relationship between the total fecal wet weight and serum levels of Na and K at the initial specimen are shown in Fig. 5. These correlations are not significant statistically although the correlation coefficients ($r^2$)

### Table 4. Fecal number, weight and moisture ($n=11$).

| ID | $n$ | Wet weight (g) | Dry weight (g) | Moisture (%) Mean±SD |
|----|-----|----------------|----------------|----------------------|
| a  | 15  | 2.036          | 283            | 85±4                 |
| b  | 10  | 929            | 217            | 74±8                 |
| c  | 12  | 1.175          | 228            | 79±8                 |
| d  | 10  | 737            | 213            | 70±3                 |
| e  | 13  | 1.539          | 251            | 83±5                 |
| g  | 10  | 499            | 181            | 62±4                 |
| h  | 14  | 1.100          | 224            | 80±4                 |
| i  | 9   | 380            | 146            | 60±3                 |
| j  | 11  | 1.178          | 226            | 77±9                 |
| k  | 13  | 434            | 141            | 67±3                 |
| l  | 8   | 1.195          | 216            | 80±6                 |

Mean 11 1.018 211 74
SD 2 500 42 8

### Moisture and wet weight of feces

Fig. 2. Relationships between moisture and sodium (Na) and potassium (K) contents in feces of 11 young female students during a 12-d mineral balance study ($n=125$). The contents of Na and K are expressed as 3 different values.

Fig. 3. Relationship between concentrations of fecal Na and K when the fecal moisture is above 80% (diarrhea) ($n=45$).
Moisture and Mineral Content in Human Feces

DISCUSSION

This study is the first to demonstrate a significant negative correlation between fecal Na and K content when fecal moisture increases above 80%. This relationship indicates there is exchange of Na and K through the intestinal membrane when fecal moisture is increased, such as in diarrhea. As the exchange rate of Na/K is essentially 1 (Fig. 3), this exchange may increase the moisture content in feces as a consequence of Na entering the intestine accompanied by water. The maximum level of Na concentration measured in the feces was as high as Na levels in the serum, a finding consistent with the mechanism described above. Na intake may influence the relation between the fecal moisture and the contents of minerals. Serum levels of Na and K may be factors affecting fecal moisture as an indicator of hydration although these are not correlated significantly. Further investigation will be needed to answer these problems.

On the other hand, we found the content/dry matter of Ca, Zn, Fe, Cu and Mn was negatively correlated with the moisture content of feces (Fig. 4). These relationships may be a consequence of increased moisture resulting from enhanced production of secretions such as mucus. Our data demonstrated a strong correlation between the concentrations of these minerals and Mg (Table 5).

Drinking salt water is a traditional therapy for consti-
pation in Japan. This practice and the fact that the estimated average requirement (EAR) of Na is as high as 10 g/d (6, 7), suggest that the etiology of diarrhea may involve, in part, pathological metabolism of monovalent cations.

In conclusion, the fecal Na concentration/g moisture is increased to serum levels and is negatively correlated with K concentration when fecal moisture increases above 80%.

Acknowledgments

We thank the volunteers who graciously gave their time and effort for these studies.

MN and NK designed the studies. MN, NI, NK, EM, YHY, NM, MS, TI, KO, HT and HN conducted the human metabolic studies and analyzed the data, while MN wrote the manuscript. MN received grant funding from the Ministry of Health Labor and Welfare. None of the authors had a conflict of interest.

REFERENCES

1) McCamman S, Beyer PL, Rhodes JB 1977. A comparison of three defined formula diets in normal volunteers. *Am J Clin Nutr* 30: 1655–1660.

2) Etheridge RD, Seerley RW, Huber TL. 1984. The effect of diet on fecal moisture, osmolarity of fecal extracts, products of bacterial fermentation and loss of minerals in feces of weaned pigs. *J Animal Sci* 58: 1403–1411.

3) Kodama N, Nishimuta M, Suzuki K. 2003. Negative balance of calcium and magnesium under a relatively low sodium intake in human. *J Nutr Sci Vitaminol* 49: 201–209.

4) Resources Council, Science and Technology Agency, Japan. 2000. Standard Tables of Food Composition in Japan, 5th ed. Ookurashou Insatukyoku, Tokyo (in Japanese).

5) Ministry of Health and Welfare. 1999. Dietary Allowances for the Japanese. 6th ed. Daichi Shuppan, Tokyo (in Japanese).

6) Kodama N, Morikuni E, Matsuzaki N, Yoshioka YH, Takeyama H, Yamada H, Kitajima H, Nishimuta M. 2005. Sodium and potassium balances in Japanese young adults. *J Nutr Sci Vitaminol* 51: 161–168.

7) Nishimuta M, Kodama N, Morikuni E, Yoshioka YH, Matsuzaki N, Takeyama H, Yamada H, Kitajima H. 2005. Positive correlation between dietary intake of sodium and balances of calcium and magnesium in young Japanese adults—Low sodium intake is a risk factor for loss of calcium and magnesium. *J Nutr Sci Vitaminol* 51: 265–270.