

The metabolizable energy value of Polydextrose® in a mixed diet fed to rats

BY S. COOLEY AND G. LIVESEY*

AFRC Institute of Food Research, Norwich Laboratory, Colney Lane, Norwich NR4 7UA

(Received 6 May 1986—Accepted 20 October 1986)

1. The digestible energy (DE) and metabolizable energy (ME) values of a commercial Polydextrose® product and the polymer that it contained were determined by metabolic energy balance in male Wistar rats and compared with values obtained by radiochemical balance using a radiochemical analogue. The energy values of the whole preparations and of the polymer fractions were estimated.

2. In the energy-balance study of 6 d duration, 100 g maize starch/kg control diet were replaced by Polydextrose® to provide a test diet. Polydextrose® had no significant effects on food intake, body-weight gain, digestibility of nitrogen and N retention but significantly increased the water consumption to 143% of the control value ($P < 0.05$) and the water content of fresh faecal pellets from 548 (SE 10) to 646 (SE 15) g/kg wet weight ($P < 0.01$).

3. By energy balance the DE in the Polydextrose® product and in the polymer that it contained were 13.5 and 12.8 (SE 1.9) kJ/g respectively. The corresponding ME values were 12.7 and 12.1 (SE 1.8) kJ/g respectively. These values were higher ($P < 0.05$) than the corresponding values obtained by the radiochemical balance procedure: DE 8.8 and 8.6 (SE 0.4) kJ/g polymer respectively and ME 8.0 and 7.8 (SE 0.5) kJ/g polymer respectively.

4. These findings indicate relatively high energy values for Polydextrose® by comparison with previously published values and illustrate a potential difficulty when using energy values obtained by certain radiochemical methods to estimate the energy values of a mixed diet given to rats. Several alternative explanations of the discrepancies are advanced.

The complexity of the structure of Polydextrose® (Ministry of Agriculture, Fisheries and Food, 1980; Figdor & Rennhard, 1981; Rennhard, 1981) makes it resistant to hydrolysis by a number of *O*-glycosidases including human salivary α -amylase (*EC* 3.2.1.1) and hog pancreatic α -amylase (*EC* 3.2.1.1) (Rennhard, 1981; R. M. Faulks and G. Livesey, unpublished results). Polydextrose® is more readily fermented anaerobically by organisms from monkey colonic flora and human faeces than hydrolysed by enzymes of the small intestine (Rennhard, 1981; Solomons & Rosenthal, 1985). When U-¹⁴C-labelled polydextrose (freed from monomeric material) was given to rats (Figdor & Rennhard, 1981), 55–60% of the administered dose was recovered in urine and faeces over 3 d indicating that energy available from Polydextrose® is considerably lower in comparison with sucrose, starch and fat which it is reported to replace in foods (for examples, see Liebrand & Smiles, 1981; Torres & Thomas, 1981; Allingham, 1982; Freeman, 1982; Smiles, 1982). Consistent with the supply of dietary energy from Polydextrose® are the small increases in circulating levels of glucose in man after oral dosage (Bachmann *et al.* 1982) and the greater production of volatile fatty acids (Figdor & Rennhard, 1981; Figdor & Bianchine, 1983; Grossklaus *et al.* 1984). The recovery of orally administered ¹⁴C-labelled polydextrose as ¹⁴CO₂ is approximately 35% in the rat (Figdor & Rennhard, 1981) and 25% in man (Figdor & Bianchine, 1983) of that expected had [U-¹⁴C]glucose been administered. On the basis of these ¹⁴CO₂ recoveries the utilization of energy from Polydextrose® has been estimated (Figdor & Rennhard, 1981; Figdor & Bianchine, 1983) to be 4.184 kJ (1 kcal)/g when assuming a gross energy value of 16.736 kJ (4.0 kcal)/g for Polydextrose®.

The basis of the derivation of the low energy value of Polydextrose® (Figdor & Rennhard, 1981; Figdor & Bianchine, 1983) differs from the basis of the derivation of food energy values of proteins, fats and available carbohydrates in conventional foods, which is by way

* For reprints.

of energy conversion factors derived empirically from energy-balance studies (Rubner, 1901; Atwater, 1910; Merrill & Watt, 1955; Southgate & Durnin, 1970; Paul & Southgate, 1978; Allison & Senti, 1983; Goranzon *et al.* 1983; Livesey & Elia, 1985). The question arises as to whether the two approaches are compatible so that the 4.184 kJ (1 kcal)/g Polydextrose® can be used in the prediction of the metabolizable energy (ME) value of a mixed diet. The present paper describes the determination of the energy values of Polydextrose® by the conventional energy-balance procedure, which is regarded as the absolute standard for assessing dietary energy values and against which other indirect methods should be compared. The distribution of ¹⁴C from a radiochemical analogue of polydextrose is examined separately for comparison.

MATERIALS AND METHODS

Polydextrose® was purchased from Pfizer Chemicals, Kent.

Preparation of the radiochemical analogue of polydextrose

A radiochemical analogue of polydextrose was prepared as described by Rennhard (1973). D-[U-¹⁴C]glucose and [U-¹⁴C]sorbitol (Amersham International plc, Amersham, Bucks) were mixed (10:1, w/w) in solution before being mixed with unlabelled glucose and 1 g unlabelled sorbitol (10:1, w/w). The aqueous mixture was lyophilized to dryness and powdered before being dry-mixed with finely powdered citric acid. The dry mixture was heated under vacuum for 3 h at 160°. The specific radioactivity of the product was 1240 μ Ci/g.

Examination of the preparation by high-performance liquid chromatography, nuclear magnetic resonance and Fourier transform infra red spectroscopy showed the identity of the labelled preparation and the commercial product. Chromatography on Bio-Gel P60 showed the labelled preparation to contain slightly more of the higher molecular weight material which can be interpreted as to predict the preparation to be slightly more resistant to utilization than the commercial material (approximately 2–3%). The molecular weight distributions for the labelled preparation and for the commercial product are given in Table 1.

Table 1. *Molecular weight distributions (% of total) of the ¹⁴C-labelled analogue of polydextrose and the commercially available Polydextrose®*

Molecular wt	Labelled preparation	Polydextrose®
0–350	10.1	11.8
350–2500	68.9	73.6
2500–5000	10.5	8.0
5000–10000	7.9	5.0
10000–18000	2.6	1.6

Animals and diets

For the energy-balance study, male Wistar rats, 80–100 g, were housed at 26 ± 1° with light between 08.00 and 20.00 hours. All animals were kept in pairs in wire-bottom cages and provided with water and the control diet (see p. 237) for 7 d *ad lib.* before the energy-balance study. The animal pairs were transferred to wire-bottom metabolism cages: two animals per cage, six cages per dietary group, two dietary groups. For the next 6 d animals received, *ad lib.*, water and either the control diet or the control diet in which some

maize starch was replaced with the commercial Polydextrose® product at 100 g/kg diet. The control diet was compounded with (g/kg diet): maize starch 306, sucrose 301, maize oil 80, fish meal 213 (containing 22.4 nitrogen), cellulose (Solka floc) 40, mineral mix 40, vitamin mix 20. The minerals were (g/kg diet): CaHPO₄ 13.0, CaCO₃ 8.20, KCl 7.03, Na₂HPO₄ 7.40, MgSO₄.H₂O 4.00, MnSO₄.H₂O 0.18, ZnCO₃ 0.10, FeSO₄.7H₂O 0.144, CuSO₄ 0.015, KIO₃ 0.001. The vitamins were (mg/kg diet): nicotinic acid 60, cyanocobalamin in mannitol 50, calcium D-pantothenate 40, thiamin hydrochloride 10, riboflavin 10, pteroylmonoglutamic acid 5, D-biotin 1, menadione 1, Rovimix E-25 (Roche) 300, Rovimix A-500 (Roche) 25, Rovimix A-500/D3 (Roche) 15, choline bitartrate 1800.

Body-weights of each animal and food and water intakes per pair of animals were measured daily between 09.00 and 11.00 hours. Spillage of food external to the cage was accounted for daily. Spillage into the cage was collected together with the faeces and separated after collection and drying. The faeces and urine were collected at the end of the 3rd and 6th days with urine being collected into 1 ml 1 M-hydrochloric acid which had been placed in the urine-collection flasks before the urine collection period. All samples were frozen at -20° after collection. A further sixteen animals (eight per dietary group) were kept under identical conditions to those described previously. At the end of the 6 d period these animals were killed by cervical fracture and pellets of digesta residue removed from the rectum for the estimation of water content by weight before and after freeze-drying.

For the radiochemical balance study, male Wistar rats, 100–120 g, were housed at 26 ± 1° with light between 08.00 and 20.00 hours. The animals were caged in groups of four in wire-bottom cages and provided with water and the control diet (as described previously) *ad lib.* for 7 d before the 4 d radiochemical experiment. The experiment was initiated at about 10.00 hours by gastric intubation of an accurately weighed dose (mean 1.02 g, range 1.017–1.022 g) of the radiochemical analogue of polydextrose dissolved in water (51.3 µCi and 41.4 mg/g solution). After intubation each animal was immediately placed into glass metabolism cages (Jencon Metabowl; Jencons [Scientific Ltd], Leighton Buzzard) and provided, *ad lib.*, with water and the control diet (as described previously but pelleted) in which 50 g maize starch was replaced with 50 g Polydextrose®/kg diet. Air, depleted of CO₂ with soda-lime, was drawn through each glass metabolism cage at a rate of about 1 litre/min, then through two CO₂-traps placed in series to collect gaseous ¹⁴CO₂. Each CO₂ trap contained 200 ml sodium hydroxide (150 g/l). Faeces and urine, mechanically separated, were collected into separate flasks with urine passing into 1 ml 1M-HCl. Faecal and urine collection flasks and NaOH solutions were changed after 3, 12, 24, 48 and 72 h. A further collection of faeces and urine was made at 96 h.

Analytical methods

Heats of combustion of freeze-dried diets, urine and faeces were determined using an Autobomb Adiabatic Bomb Calorimeter (Gallenkamp) standardized against benzoic acid thermochemical standard and further checked against anhydrous glucose. N was determined by the Kjeldahl method. Radioactivity in the carbohydrate preparations, faeces and urine samples was measured after combustion to ¹⁴CO₂ in a Biological-Oxidizer-OX400 (Harvey Instruments Corporation, Hillsdale, New York) with an efficiency of 95%. The ¹⁴CO₂-cocktail (Harvey Instruments Corporation) was assayed for radioactivity in a Philips PW4700 liquid scintillation counter with an efficiency of 65%. Radioactivity in the NaOH solutions was assayed after addition of small quantities (≤ 100 µl) to the scintillation cocktail.

Calculations

Digestible energy (DE) values of diets were calculated as the difference between the gross energy value of food intake and the gross energy value of collected faeces. ME of diets,

uncorrected initially to zero N balance, were calculated as the difference in the DE in the diet and the gross energy collected in urine. DE and ME of Polydextrose® were estimated according to the principle of partial nutrient availability (see Kleiber, 1975) from the following formulas:

$$\begin{aligned} \text{DE (kJ/g)} &= (\text{DE}_t - \text{DE}_c + i\text{DE}_s)/i, \\ \text{ME (kJ/g)} &= (\text{ME}_t - \text{ME}_c + i\text{ME}_s)/i, \end{aligned}$$

where i is the quantity of maize starch replaced by the test substance (g/g diet), DE_t , DE_c and DE_s are the DE in the test (Polydextrose®) diet, the control diet and the maize starch respectively (kJ/g) and ME_t , ME_c and ME_s are the corresponding ME values (kJ/g). DE_s and ME_s were taken to be 16.58 kJ/g (Metta & Mitchell, 1954). ME was corrected by subtracting from it 26.33 kJ/g N (Metta & Mitchell, 1954) retained in the test animals above that retained in the control animals.

In the radiochemical experiment, the digestibility (D) of the radiochemical analogue of polydextrose was calculated as the proportion of the radiolabelled dose that was not recovered in the faeces and the availability (A) as the proportion of the dose that was not recovered in the urine and faeces combined. Estimates of the DE and ME in the radiochemical analogue of polydextrose were made by multiplication of the gross energy of the analogue (kJ/g) by the values of D and A respectively.

In order to calculate DE and ME of the polymers from the commercial product and the analogue, it was assumed that the free glucose contained in these preparations was completely absorbed.

Statistics. Mean values are reported with their standard errors. Significance of differences were estimated using the unpaired Student's t test except when variances were assumed to be unequal. Equality of variances and the significance of differences of means with unequal variances were assessed as described in eqns (15), (25) and (26) of Bailey (1976).

RESULTS

The conventional energy-balance study

Body-weight, food intake and growth. Mean values for initial body-weight, food intake and growth of animals on the diet containing Polydextrose® were not significantly different from those for animals consuming the control diet and were: 131 (SE 3) and 124 (SE 4) g initial body-weight respectively; 201.0 (SE 4.4) and 200.0 (SE 10.0) g food intake (*ad lib.*) per animal pair over the 6 d respectively; 40 (SE 3) and 39 (SE 4) g increase in body-weight per animal over the 6 d respectively.

Faecal bulking, faecal water and water intake. The substitution of 100 g maize starch with 100 g Polydextrose®/kg diet only marginally elevated (not significantly) the dry weight of faeces collected over the 6 d period from a mean value of 26 (SE 1) to 29 (SE 1) g per animal pair. The water content of faecal pellets dissected from the rectum at the end of the 6 d was determined in separate groups of eight rats kept under identical conditions and was significantly increased ($P < 0.01$) by including Polydextrose® in the diet, from 548 (SE 10) to 646 (SE 15) g/kg wet weight. This was accompanied by an elevation in the mean value for water consumption from 296 (SE 30) to 422 (SE 44) g per animal pair over the 6 d period ($P < 0.05$).

DE and ME. When the gross energy of the test substance is only a small proportion of the gross energy in the diet, precise estimates need to be obtained for DE and ME in the diets. With the control diet a coefficient of variation (CV) of DE and ME was in the range 0.009–0.019 for days 1–3, 4–6 and 1–6. Values obtained for the Polydextrose® diet were in the range 0.016–0.028. In all cases the CV was small, indicating precision in the estimated values. The CV associated with the derived values of DE and ME (uncorrected to zero N

Table 2. Digestible and metabolizable energies in the control diet, the Polydextrose® diet and the derived values for Polydextrose®

(Mean values with their standard errors; the values of n are the no. of independent observations. The SE associated with Polydextrose® are combined errors from the two diets with $n = n_1 + n_2$ observations shown (see p. 238))

	Dietary period (d)	Digestible energy (kJ/g)		Metabolizable energy* (kJ/g)		n
		Mean	SE	Mean	SE	
Control diet	1-3	15.19	0.05	14.92	0.08	6
	4-6	15.20	0.08	14.93	0.06	4
	1-6	15.21	0.07	14.95	0.08	4
Polydextrose® diet	1-3	14.84	0.17	14.53	0.14	5
	4-6	14.92	0.16	14.58	0.18	6
	1-6	14.90	0.14	14.59	0.13	5
Polydextrose®	1-3	13.1	1.8	12.7	1.8	11
	4-6	13.5	2.5	13.1	2.5	10
	1-6	13.5	1.9	13.0	1.8	9

* Metabolizable energy values uncorrected to zero nitrogen balance.

balance) for the product was an order of magnitude greater ($P < 0.01$) and was in the range 0.22–0.30 for days 1–3, 4–6 and 1–6 (Table 2).

The estimates of DE and ME (Table 2) for the diets and for Polydextrose® for days 1–3 were not significantly different from those for days 4–6, suggesting that the values for days 1–6 were free from significant errors associated with residue of digesta from the pre-experimental diet being collected during the experimental period.

The derived value of ME for the Polydextrose® product using the balance procedure, uncorrected to zero N balance, was 13.0 (SE 1.8) kJ/g. Including the Polydextrose® product in the diet decreased slightly, but statistically non-significantly, the D of dietary N from 0.86 (SE 0.01) to 0.84 (SE 0.01) and may have increased, again not statistically significantly, the retention of N in the body from 67 (SE 3) to 74 (SE 2) % of the dietary N. Because of these small potential differences in the distribution of dietary N the previously derived value of ME for Polydextrose® may be overestimated by 0.25 kJ/g on account of N retention. Hence the N-corrected ME value for Polydextrose® was calculated to be 12.7 (SE 1.8) kJ/g compared with an apparent DE of 13.5 (SE 1.9) kJ/g. By assuming complete utilization of the free glucose in Polydextrose® the polymeric fraction was calculated to have a DE of 12.8 (SE 1.9) kJ/g and an ME of 12.1 (SE 1.8) kJ/g.

The radiochemical balance study

Time-course of release of ^{14}C into CO_2 , faeces and urine. After intragastric intubation of the uniformly-labelled radiochemical analogue of polydextrose, very little $^{14}\text{CO}_2$ evolved during the first 3 h and approximately one-third of the administered dose was collected as $^{14}\text{CO}_2$ by 72 h (Table 3). The appearance of ^{14}C in urine was small, being less than 5% of the dose over the 96 h collection period (Table 3). Almost half of the radioactivity administered to the rats was recovered in the faeces, 60% of this appearing in the 24–48 h collection period (Table 3).

DE and ME of the radiochemical analogue of polydextrose based on the radiochemical balance study. Before DE and ME values can be attributed to the radiolabelled polydextrose

Table 3. *Time-course for the distribution of the uniformly-labelled ^{14}C analogue of polydextrose between carbon dioxide, faeces and urine*

(Mean values with their standard errors for four determinations. Four rats, housed in separate metabolism cages, each received a precisely measured dose of between 52.18 and 52.44 μCi $\text{U-}^{14}\text{C}$ -labelled analogue of polydextrose. Animals were fed during the experimental period on a diet containing 50 g Polydextrose[®]/kg diet)

Collection period (h)	Percentage of dose recovered in					
	CO_2		Faeces		Urine	
	Mean	SE	Mean	SE	Mean	SE
0-3	2	1	0	0	0	0
3-12	17	1	0	0	2.4	0.6
12-24	9	2	15	10	1.4	0.9
24-48	5	1	31	7	0.6	0.1
48-72	1	0	2	1	0.1	0.1
72-96	—	—	0	1	0.1	0.0
Total	33	2	48	3	4.6	1.2

Table 4. *Summary of the assessments of energy availability in Polydextrose[®] and the radiochemically labelled analogue and in the corresponding polymer fractions*

	Polydextrose [®]		Labelled analogue		
	Whole material	Polymer fraction	Whole material	Polymer fraction	SE
Gross energy (kJ/g)	16.9*	17.5*	16.9*	17.5*	—
Radiochemical balance study:					
Digestible energy (kJ/g)	—	—	8.8	8.6	0.4
Metabolizable energy (kJ/g)	—	—	8.0	7.8	0.5
Energy balance study:					
Digestible energy (kJ/g)	13.5	12.8	—	—	1.9
Metabolizable energy (kJ/g)	12.7†	12.1†	—	—	1.8

All values obtained by the energy-balance procedure were found to be significantly ($P < 0.05$) greater than the values obtained by the radiochemical procedure when estimated for unequal variances (see p. 238).

* Calculated from the composition of Polydextrose[®] and the radiochemical analogue (see below).

† Metabolizable energy values corrected to zero nitrogen balance.

it is necessary to derive its gross energy value. Rather than combusting the radiolabelled material, the gross energy was derived from the analysed composition of the radiolabelled preparation. The product composition was (g/kg): 930 polymer (gross energy 17.5 kJ/kg) derived from a glucosyl: hydrogenated glucosyl residues ratio of 9:1), 43 glucose monohydrate (14.15 kJ/g) and 10 anhydrous glucose (15.6 kJ/g) which combine to give a value of 16.95 kJ (4.05 kcal)/g radiolabelled substance.

Since 48 (SE 3) % of the radiolabelled dose appeared in the faeces, D was 0.52 (SE 0.03) and DE was 8.8 (SE 0.4) kJ/g. The recovery of radiolabel in the urine and faeces combined was 53 (SE 4) % of the dose, giving an A of 0.47 (SE 0.04) and an ME of 8.0 (SE 0.5) kJ/g. After correction for 5% of radioactivity being in glucose, the D and A of energy in the polymer alone were calculated to be 0.49 and 0.45 respectively which correspond to DE and ME values of 8.6 (SE 0.4) and 7.8 (SE 0.5) kJ/g respectively.

The observations made on the energy values of both the Polydextrose[®] and the

radiochemical analogue of the polydextrose preparation and of both their polymeric fractions are summarized in Table 4. DE and ME obtained by the radiochemical procedure were significantly smaller (approximately 35%, $P < 0.05$) than the corresponding values obtained by the energy-balance procedure.

DISCUSSION

There is a growing interest in the food-energy values of poorly digested artificial substrates intended as low-energy bulking agents (Oku *et al.* 1971, 1984; Rennhard & Bianchine, 1976; Grupp & Siebert, 1978; Figdor & Rennhard, 1981; Kearsley *et al.* 1982; Lian-Loh *et al.* 1982; Figdor & Bianchine, 1983; MacDonald & Daniel, 1983; Bird *et al.* 1985; Van Es *et al.* 1986). A particular difficulty in making precise estimates of these quantities by conventional energy-balance procedures is that poorly digested substances in the diet are generally not well tolerated so that only relatively small quantities can be added to the diet. The variation in the energy from the whole diet then becomes a considerable proportion of the energy in the test substance. Consistent with this the findings in the present paper, together with those from previous published work (Rennhard & Bianchine, 1976; Figdor & Rennhard, 1981; Bird *et al.* 1985; G. Livesey, unpublished results), show the energy-balance procedure to give a significantly higher variance than the radiochemical procedure (f_1 32, f_2 21 respectively, $P < 0.02$). However, this advantage of the radiochemical procedure must be balanced against the possibility that the substance under test might also significantly modify the utilization of energy from other dietary substances. When this is the case energy values obtained by the radiochemical method would not be of great value in predicting the energy value of the whole diet. It is of interest therefore to compare the DE and ME values for the whole diet containing polydextrose and that which would have been predicted had the various values for the energy utilization of polydextrose been used in the prediction. Whereas the DE of the Polydextrose® diet was experimentally determined as 14.90 (SE 0.14) kJ/g (Table 2) the predicted values, based on the energy values of the control diet and the modifications made to it, were 14.34, 14.26, 14.19 (SE 0.07) kJ/g when taking D of the polydextrose polymer to be 0.49 (present study), 0.397 (Figdor & Rennhard, 1981) and 0.361 (based on the recovery of $^{14}\text{CO}_2$ and urinary radioactivity, Figdor & Rennhard, 1981) respectively; these values being significantly different ($P < 0.05$, 0.02 and 0.02 respectively). Similarly, whereas the ME (uncorrected to zero N balance) of the Polydextrose® diet was experimentally determined as 14.59 (SE 0.13) kJ/g (Table 2), the predicted values were 14.08, 13.97, 13.92 and 13.78 (SE 0.08) kJ/g when taking A of energy from the polydextrose polymer to be 0.448 (present study), 0.379 (Figdor & Rennhard, 1981), 0.348 (based on $^{14}\text{CO}_2$ recoveries, Figdor & Rennhard, 1981) and 0.25 (a value based on $^{14}\text{CO}_2$ recoveries and suggested by Figdor & Rennhard, 1981) respectively; these differences being significant ($P < 0.05$, 0.02, 0.02 and 0.01 respectively). Whatever the reason (see below) it is clear that the energy values obtained by the radiochemical procedures cannot be used to predict the energy value of the whole diet with accuracy and the predictions are least accurate using energy values derived from $^{14}\text{CO}_2$ recovery values.

The ME of Polydextrose® obtained by energy balance (12.7 (SE 1.8) kJ/g; Table 4) finds some support from independent unpublished work of J. L. Hamer and B. A. Rolls carried out at the National Institute for Research in Dairying, Shinfield, Reading (now the Institute of Food Research, Reading Laboratory). Their preliminary evidence from a metabolic-balance study, with a crossover design in which animals serve as their own controls, suggests an ME value of 11–12 kJ/g Polydextrose®. An unanswered question is: why is the arguably truer ME value obtained in the radiochemical balance study less than that of the apparent ME value obtained by energy balance? It is more usual for the utilization of a substance to be greater than expected from ME-balance studies, which may be explained

by the increased faecal loss of other substances (Cunningham *et al.* 1962). This is a phenomenon which has been encountered with cellulose (Solka floc) and guar gum (I. R. Davies and G. Livesey, unpublished results). One possibility is that the distribution of the radiolabelled material depends on its mode of administration. In the present study an oral dose was given similar to that used in the study of Figdor & Rennhard (1981) so that comparisons could be made easily. It is possible that the extent of the utilization of bulking agents depends on whether or not other dietary substances are consumed simultaneously and in future work it may be more appropriate to mix the radiochemical species with the diet. Another possibility is that the presence of Polydextrose® results in the improved utilization of other dietary substances. However, no supporting evidence has arisen within the presently-reported experiments to add support to this assertion. An interesting possibility is that the ME of Polydextrose® in rats is dependent in some circumstances on the quantity of the product present in the diet, low quantities such as in the radiochemical studies favouring a low energy value and higher quantities such as fed to rats in the energy-balance study giving high values. Generally, however, it might be expected that the proportional utilization of a poorly digested substance would decrease as the capacity for degradation within the alimentary tract becomes exceeded. Using values from Figdor & Rennhard (1981) for the recovery of ^{14}C in urine and faeces of rats previously given unlabelled Polydextrose® at 0, 1 or 10 g/kg body-weight for 90 d before dosage with radiolabelled material (≤ 100 mg) and our gross energy value of 17.5 kJ/g Polydextrose® polymer gives ME values of 7.6, 8.3, and 9.8 kJ/g respectively. These values compare with the 7.8 kJ/g found in the present study in rats fed approximately 5 g Polydextrose®/kg body-weight (Table 4, present paper) and, if not the result of adaptation to polydextrose, are consistent with the previous assertion but do not comply with the previous generalization.

Since it has been shown that coprophagy increases the apparent D of dietary fibre in rats (Williams & Senior, 1985) it is of interest to evaluate to what extent coprophagy could explain the larger recovery of $^{14}\text{CO}_2$ observed in the present study (Table 3) compared with the study of Figdor & Rennhard (1981) (33 v. 20%) and the higher energy values obtained in the energy-balance study by comparison with those reported by Figdor & Rennhard (1981). This can be done by hypothesizing the worst cases. First, that in the radiochemical studies no coprophagy occurred in the study by Figdor & Rennhard (1981) but that it did occur in the present radiochemical-balance study and, second, that no coprophagy occurred in the animals fed on the control diet in the energy-balance study but that the presence of Polydextrose® somehow initiated considerable coprophagy. A further 6% of $^{14}\text{CO}_2$ is recovered from recycled ^{14}C -labelled polydextrose (Figdor & Rennhard, 1981), which indicates that as much as 152% of the faeces would need to be consumed to raise the 20% $^{14}\text{CO}_2$ -recovery value reported by Figdor & Rennhard (1981) to the 33% $^{14}\text{CO}_2$ -recovery value found in the present work (Table 3). In the energy-balance study, by assuming the D of recycled polydextrose to be 0.10 (Figdor & Rennhard, 1981) and that digesta residue has a similar value, as much as 263% of the faeces would need to have been eaten to explain the differences had the D of polydextrose been 0.397 as reported by Figdor & Rennhard (1981) or 281% of the faeces had energy utilization been 34% as given by Figdor & Rennhard (1981). It is impossible that the animals could eat so much of their faeces and it is unlikely that the value exceeded 10%, a value reported for rats fed *ad lib* under similar circumstances by Williams & Senior (1985).

In conclusion, the energy values obtained using the radiochemical procedures do not predict the effects Polydextrose® has on the DE and ME of the whole diet. The possibility that the manufactured material is more readily digested than the radiolabelled material used in the present and previous work cannot be discounted. The findings reported here do not validate the comparative $^{14}\text{CO}_2$ -production procedure for estimating ME.

The authors are grateful to Drs B. A. Rolls and D. Hewitt, AFRC Institute of Food Research, Reading, and Dr D. A. T. Southgate, AFRC Institute of Food Research, Norwich, for their discussions on this subject. Thanks are also due to Miss J. Brown, IFRN, who helped considerably with laboratory work during the writing of this manuscript and Mrs J. Cook for help with animal management.

REFERENCES

- Allingham, R. P. (1982). *Chemistry of Foods and Beverages: Recent Developments*, pp. 293–303. London: Academic Press.
- Allison, R. G. & Senti, F. R. (1983). *A Perspective on the Application of the Atwater System of Food Energy Assessment*. Bethesda, Maryland: Federation of American Societies for Experimental Biology.
- Atwater, W. O. (1910). *Principles of Nutrition and Nutritive Value of Food, Farmers' Bulletin no. 142*. Washington DC: United States Department of Agriculture.
- Bachmann, W., Haslbeck, M. & Mehnert, H. (1982). *Aktuelle Endokrinologie und Stoffwechsel* **3**, 124–125.
- Bailey, N. T. J. (1976). *Statistical Methods in Biology*. London: Hodder and Stoughton.
- Bird, S. P., Hewitt, D. & Gurr, M. I. (1985). *Proceedings of the Nutrition Society* **44**, 40A.
- Cunningham, H. M., Friend, D. W. & Nicholson, J. W. G. (1962). *Canadian Journal of Animal Science* **42**, 167–175.
- Figdor, S. K. & Bianchine, J. R. (1983). *Journal of Agricultural and Food Chemistry* **31**, 389–393.
- Figdor, S. K. & Rennhard, H. H. (1981). *Journal of Agricultural and Food Chemistry* **29**, 1181–1189.
- Freeman, T. M. (1982). *Cereal Foods World* **27**, 515.
- Goranzon, H., Forsum, E. & Thilen, M. (1983). *American Journal of Clinical Nutrition* **38**, 954–963.
- Grossklauss, R., Klingebiel, L., Lorenz, S. & Pahlke, G. (1984). *Nutrition Research* **4**, 459–468.
- Grupp, U. & Siebert, G. (1978). *Research in Experimental Medicine* **173**, 261–278.
- Kearsley, M. W., Birch, G. G. & Liah-Loh, R. H. P. (1982). *Stärke* **8**, 283–297.
- Kleiber, M. (1975). *The Fire of Life*. Huntington, New York: Robert E. Kreiger Publishing Co.
- Liah-Loh, R., Birch, G. G. & Coates, M. (1982). *British Journal of Nutrition* **48**, 477–481.
- Liebrand, J. & Smiles, R. (1981). *The Manufacturing Confectioner* November, 35–40.
- Livesey, G. & Elia, M. (1985). *Clinical Nutrition* **4**, 99–111.
- MacDonald, I. & Daniel, J. W. (1983). *Nutrition Research* **28**, 1083–1090.
- Merril, A. L. & Watt, B. K. (1955). *Energy Value of Foods, Basis and Derivation, United States Department of Agriculture Handbook no. 74*. Washington, DC: United States Department of Agriculture.
- Metta, V. C. & Mitchell, H. H. (1954). *Journal of Nutrition* **52**, 601–611.
- Ministry of Agriculture, Fisheries and Food (1980). *Report of Food Additives and Contaminants Committee FAC/REP/32*. London: H. M. Stationery Office.
- Oku, T., Inoue, Y. & Hosoya, N. (1971). *Journal of the Japanese Society for Food and Nutrition* **24**, 399–404.
- Oku, T., Tokunaga, T. & Hosoya, N. (1984). *Journal of Nutrition* **114**, 1574–1581.
- Paul, A. A. & Southgate, D. A. T. (1978). *McCance and Widdowson's The Composition of Foods*, 4th ed. London: H. M. Stationery Office.
- Rennhard, H. H. (1973). *U.S. Patent no. 3, 766 165*
- Rennhard, H. H. (1981). *182nd National Meeting of the American Chemical Society*, New York, AGFD 24 Washington, DC: Abstr. American Chemical Society (unpublished manuscript available from Pfizer Inc., Pfizer Central Research, Groton, Connecticut 06340, USA.)
- Rennhard, H. H. & Bianchine, J. R. (1976). *Journal of Agricultural and Food Chemistry* **24**, 287–290.
- Rubner, M. (1901). *Zeitschrift für Biologie* **42**, 261–305.
- Smiles, R. E. (1982). *Chemistry of Foods and Beverages: Recent Developments*, pp. 305–322. London: Academic Press.
- Solomons, N. W. & Rosenthal, A. (1985). *Journal of Laboratory and Clinical Medicine* **105**, 585–592.
- Southgate, D. A. T. & Durnin, J. V. G. A. (1970). *British Journal of Nutrition* **24**, 517–535.
- Torres, A. & Thomas, P. (1981). *Food Technology* July, 44–49.
- Van Es, A. J. H., de Groot, L. & Vogt, J. E. (1986). *British Journal of Nutrition* **56**, 545–554.
- Williams, V. J. & Senior W. (1985). *Journal of Nutrition* **155**, 1147–1153.