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Fecal Weight, Colon Cancer Risk, and Dietary Intake of Nonstarch Polysaccharides (Dietary Fiber)

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Low fecal weight and slow bowel transit time are thought to be associated with bowel cancer risk, but few published data defining bowel habits in different communities exist. Therefore, data on stool weight were collected from 20 populations in 12 countries to define this risk more accurately, and the relationship between stool weight and dietary intake of nonstarch polysaccharides (NSP) (dietary fiber) was quantified. In 220 healthy U.K. adults undertaking careful fecal collections, median daily stool weight was 106 g/day (men, 104 g/day; women, 99 g/day; $P = 0.02$) and whole-gut transit time was 60 hours (men, 55 hours; women, 72 hours; $P = 0.05$); 17% of women, but only 1% of men, passed <50 g stool/day. Data from other populations of the world show average stool weight to vary from 72 to 470 g/day and to be inversely related to colon cancer risk ($r = -0.78$). Meta-analysis of 11 studies in which daily fecal weight was measured accurately in 26 groups of people (n = 206) on controlled diets of known NSP content shows a significant correlation between fiber intake and mean daily stool weight ($r = 0.84$). Stool weight in many Westernized populations is low (80–120 g/day), and this is associated with increased colon cancer risk. Fecal output is increased by dietary NSP. Diets characterized by high NSP intake (approximately 18 g/day) are associated with stool weights of 150 g/day and should reduce the risk of bowel cancer.

Large bowel disorders, especially colon cancer,[1–4] account for substantial morbidity in industrialized countries. Although the etiology of bowel cancer is now better understood, the epidemiological evidence still points to diet as a major factor.[5] Diet, notably dietary fiber, is now established as a major contributor to the control of colonic function and bowel habit.[6,7]

At a population level there are no recognized risk factors for large bowel disease. Daily stool weight and intestinal transit time have been discussed much but poorly documented. Burkitt's proposal[8,9] that fecal output is a good index of bowel disease risk has not been properly tested since it was first suggested 20 years ago. In fact, no systematic data on stool weight and transit time have been compiled for any population. Moreover, the changes in bowel habits caused by dietary fiber need to be assessed quantitatively alongside any relationship between stool weight and cancer risk.

We therefore obtained bowel habit data for normal individuals in the United Kingdom and present a population average for stool weight and transit time. These data, together with all reliable informati ›n that could be found on stool weight in other countries, have been compared with bowel cancer risk. Finally, a quantitative estimate of change in stool weight caused by fiber intake is made and discussed in the context of reducing bowel disease risk.

Materials and Methods

United Kingdom

Information on the stool weight and transit times of 132 healthy adults in the United Kingdom consuming their normal diet has been obtained from six studies,[10–15] three of which required us to write to the authors and obtain the results for each individual. The other three studies were done by the authors of the present report. Criteria for inclusion in this study were data collected or published since 1970, usual diet being eaten, age >18 years, and stool samples collected for 5 days or more, preferably using fecal markers. Transit time was measured by a variety of methods, principally using radio-opaque pellets. Studies performed before 1970 were not included because few reliable bowel cancer data exist before that time, and the present study is an attempt to examine current bowel disease risk factors.

In addition, new (unpublished) data on stool weight are

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presented for 88 subjects recruited separately. They were medical students, staff members, undergraduates, and other healthy volunteers in Cambridge and subjects aged 18–80 years in Edinburgh. All subjects collected stools for a minimum of 5 days while leading their usual lives. Radio-opaque markers were given to ensure complete collections. Transit time was assessed by measuring the excretion of markers in feces.

Other Populations

Information on stool weight in other world populations was obtained from 13 studies published since 1970 and from personal communication with authors (as summarized in references 16–23). Data for individual subjects are not available for most of these studies. Criteria for inclusion are therefore necessarily less stringent than for the U.K. data. The duration of stool collection varied between 1 and 5 days and in some cases is unknown. Transit measurements have been discounted because they were done by various methods, some of which are too imprecise to be useful.

Cancer incidence data appropriate to these populations were obtained from *Cancer Incidence in 5 Continents*[1–4] using the volume that was published nearest in time to the date of the paper from which stool weight data are derived.

Analysis of diet and stool weight is based on the results of five of our published studies[24–28] and our unpublished data on diet and stool weight as well as four other reports published since 1970.[29–32] In all these studies, healthy volunteers ate diets of known controlled composition, and for one study period a defined change was made in dietary fiber intake to observe its effects on bowel habits. Diets were eaten for at least 2 weeks except in two studies,[31,32] and stools were collected for a minimum of 5 days. The data comprise 30 different diets and 206 subjects. For this report dietary fiber is calculated as nonstarch polysaccharides (NSPs) measured using the Englyst method.[33] NSPs comprise those carbohydrate polymers in the diet that are not α-glucans. NSPs include the cell wall polysaccharides of plants such as cellulose, hemicellulose, and pectin, together with storage polysaccharides (guar), seed mucilages (ispaghula) and plant gums and exudates (sterculia, karaya). Values for NSP intake for each study are either taken directly from the appropriate publication or calculated using food tables[34,35] and the menus reported or obtained from authors. In one case[29] the authors kindly provided data from analysis of diets.

Ethical permission for studies of bowel habits and dietary studies was granted by the ethical committees of the authors' institutions.

Statistical analysis of all data was performed using conventional techniques of correlation and regression using Systat. For the U.K. population, median values are quoted, but averages are used in comparisons with other countries because individual values were not always available.

Results

United Kingdom

Individual information on bowel habits was available for 220 persons. Age and sex are known for 190 subjects; 106 were male and 84 were female, with an overall mean age of 39.5 years (range, 18–80 years). The distribution was 40% aged 18–25, 25% aged 26–45, 15% aged 46–65, and 20% aged >65 years. Table 1 shows data for stool weight and transit time, and Figure 1 gives the distribution of stool weights and transit times for both sexes. The data for both men and women are positively skewed. Men had a significantly greater median daily stool weight than women (104 vs. 99 g; $P = 0.02$). From Figure 1 it may be seen that stool weights were <100 g/day in 47% of men and 51% of women and <50 g/day in 17% of women (1% of men). Median transit time was significantly shorter in men (55 hours) than in women (72 hours) ($P = 0.05$). Transit times were >120 hours in 4.7% of men and 11.1% of women. Age was associated with both transit time and mean daily fecal weight ($r = -0.39$ for stool weight; $r = 0.42$ for mean transit time).

Other Populations

Table 2 lists the available data for daily stool weight in countries other than the United Kingdom and divides the U.K. data into England and Wales together and Scotland. The range in average stool weight is substantial (72–470 g/day) among these countries. Highest values came from rural areas in the Third World and Finland and Japan, and the lowest values were found in the United States, the United Kingdom, and New Zealand.

Stool Weight and Bowel Cancer

The stool weight data from Table 2 are plotted against colon cancer incidences in the corresponding populations in Figure 2. Age-standardized cancer in-

Table 1. Stool Weight and Transit Time in 220 Healthy Adults in the United Kingdom

Cases	Arithmetic mean (SEM)	Median	Range
	Daily stool weight (g/day)		
All (n = 220[a])	117 (3.8)	106	19–415
Men (n = 106)	122 (5.9)	104	46–415
Women (n = 84)	102 (5.4)	99	19–259
	Mean transit time (h)		
All (n = 185)	70 (2.6)	60	23–168+
Men (n = 104)	64 (2.9)	55	23–168+
Women (n = 81)	78 (4.3)	72	26–168+

NOTE. Differences between sexes in stool weight ($F = 5.82$, $P = 0.02$) and transit time ($F = 8.15$, $P = 0.05$) are significant.
[a]Age and sex data were not available for every case.
Data from references 10–15 and unpublished observations.

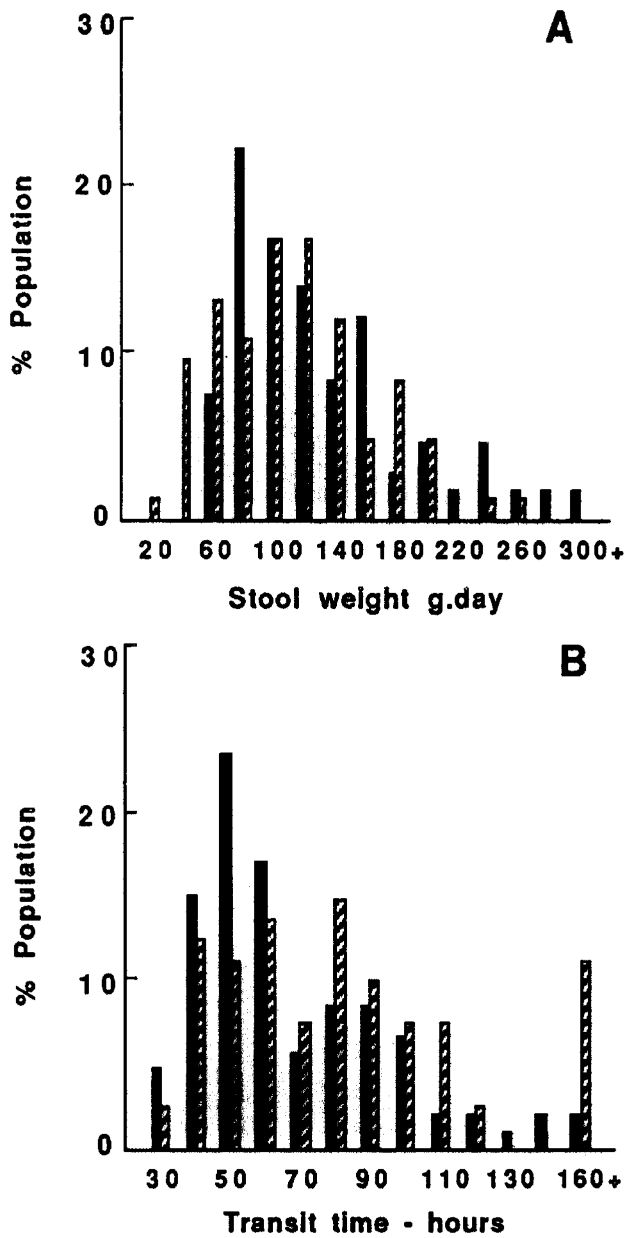

Figure 1. Frequency distribution of (*A*) mean daily stool weight (in grams) (n = 220) and (*B*) transit time (in hours) (n = 190) from healthy U.K. adults. ▨, Female; ■, male. (Data from references 10–15 and unpublished observations.)

cidences have been averaged for men and women where necessary; otherwise, rates are for the appropriate sex. Cancer data for the Malay-Malaysian population were not available. Overall there is a significant (r = −0.78) inverse association between the log of stool weight and cancer risk. The correlation with rectal cancer was not as good (r = −0.50). The regression shows that the age-standardized colon cancer risk is 25 per 100,000 persons/yr at a stool weight of 104 g/day [95% confidence interval (CI), 87–128 g/day] and falls to 10 per 100,000 at a stool weight of 189 g/day (95% CI, 166–215 g/day).

Diet and Stool Weight

Figure 3 shows the results of nine published and two unpublished studies of dietary NSP intake and stool weight and includes all data for intakes of 4–32 g/day NSP. A total of 26 dietary periods were available. A linear regression has been fitted using weighted means: $y = 5.3x + 38$ (n = 206). These data predict that at an NSP intake of 12.5 g/day, which is the U.K. average,[36] stool weight is 104 g/day (95% CI, 99–108 g/day) and that on an NSP-free diet it would be 38 g/day. The NSPs in these studies came from a variety of sources. When only cases in which NSPs from mixed dietary sources are included in the regressions (n = 107), (i.e., bran and purified fiber sources are excluded), the line is similar ($y = 4.9x + 35$) with a predicted stool weight at 12.5 g NSP/day of 97 g/day (95% CI, 92–101 g/day). Few studies have reported NSP intakes of >32 g/day, and they mostly concern purified sources of NSP such as pectin and guar.[24,25]

Discussion

A number of publications have appeared in the past 20 years[8–12,16–23] in which stool weights for various populations are described. This report draws these together, and with the addition of new data shows the relationship between bowel cancer and fecal output.

The population samples were not all randomly selected and neither were the countries chosen for study because they represented particular categories of bowel cancer risk. Some referral bias may therefore have been introduced. However, a wide range of average stool weights and bowel cancer risk are reported, covering the expected known distribution of both variables. The high average values for stool weight in several countries reported in Table 2 may call into question the health of these populations. Current textbooks state that daily stool weights of >200 g/day are characteristic of diarrhea.[37] However, it is clear both from the study of the distribution in Figure 1 of the normal U.K. population and from Table 2, in which large numbers of healthy people have stool weights of >200 g/day, that diarrhea cannot be defined by this criterion. It must always be considered in the context of what is normal for the local population.

Similarly, for the U.K. data there may be some bias because of the difficulty of collecting stools from a random sample of the population. However, approximately equal numbers of men and women are included, as are representatives of all age ranges. The reliability of these data is supported by the close concordance between the observed median value for stool weight in the United Kingdom of 106 g/day

Table 2. Stool Weight and Bowel Cancer Incidence in Various Populations

	Fecal collections					Cancer incidence[a]		
Country	Average daily fecal weight (g)	n	Sex	No. of days collected	Reference	Colon	Rectum	Reference
Scotland	72	43	F	5+	—	18.8	8.3	4
Scotland	93	47	M	5+	—	20.5	13.2	4
United States: New York	99[b]	99	M & F	1–2	17, 18	28.3	12.6	4[c]
New Zealand: European	113	25	F		19	28.4	11.7	4
New Zealand: Maori	119	19	F		19	11.5	4.8	4
United States: Hawaii								
White	120	18	M	5	20	25.3	14.1	3
Japanese	120	47	M	5	20	27.5	21.4	3
Japan: Hyogo	133	11	M	3	21	12.1	10.6	4[d]
England & Wales	134	41	F	5+	—	14.7	7.9	4
Denmark: Copenhagen	136	30	M	1	22	22.8	19.3	22
England & Wales	145	59	M	5+	—	16.6	13.7	4
Sweden: Malmo, Umea	150	45	M & F	2	18	16.3	9.7	4[c]
Denmark: Taarnby	151	60	M	1	23	22.2	18.8	23
Denmark: Them	169	30	M	1	22	12.9	15.0	22
Malaysia: Indian urban	170		M & F		16	6.5	5.3	3[c,e]
Finland: Helsinki	176	30	M	1	22	17.0	8.7	22
Japan: Akita	195	17	M	5	20	8.3	9.2	3[f]
Finland: Parikkala	196	30	M	1	22	6.7	7.5	22
Finland: Kuopio	209[b]	75	M	1–2	17, 23	5.6	6.1	23
Malaysia: Chinese urban	227				16	13.8	11.2	3[c,e]
India: New Delhi	311	514			16	2.2	3.1	4[c,g]
Peru	325	20	M & F		16	3.6	3.3	1[c,h]
Malaysia: Malay	465				16	—	—	—
Uganda	470	15			16	0.4	1.8	1[c]

[a]Cases per 100,000 population per year; age-standardized for world population.
[b]Weighted average.
[c]Average male and female rates.
[d]Osaka Cancer Registry data.
[e]Singapore Cancer Registry data.
[f]Myagi Cancer Registry data.
[g]Nagpur Cancer Registry data.
[h]Chile Cancer Registry data.

based on 220 carefully performed stool collections (Table 1) and the predicted stool weight of 104 g/day at the U.K. average NSP intake of 12.5 g/day, this prediction coming from a completely different series of studies (Figure 3).

Low stool weights and slow transit times are associated with a number of conditions, including constipation,[38] irritable bowel syndrome,[39] gallstones,[40,41] disordered anorectal function,[42] and abnormal cells in breast ducts.[43] The present study shows a significant inverse relationship between stool weight and colon cancer incidence (Figure 2). This relationship was first suggested by Burkitt et al.,[9] and we have now quantitated this risk. Statistically the association is with the log of stool weight. At a stool weight of approximately 100 g/day, cancer risk is high (25 cases/100,000 per year); the risk decreases to approximately one third of this at a stool weight of 200 g/day. At greater stool weights, cancer risk becomes very low. Low stool output cannot of itself cause bowel cancer but presumably is characteristic of metabolic events in the large bowel, especially the sigmoid colon, that favor the development of cancer.

The association between cancer risk and stool weight has been shown recently using semipermeable magnetic microcapsules, which are able to trap gastrointestinal carcinogens in humans. After transit through the gut of healthy subjects, extensive core to membrane cross-linking of the microcapsules was found and was inversely related to fecal output.[44] Thus low stool weight is associated with events in the large bowel lumen that lead to DNA damage.

The difference between the bowel habits of men and women is not reflected in overall colon cancer rates.[4] However, female rates of colon cancer at premenopausal ages exceed male rates, and the incidence of cancer at proximal (cecum and ascending colon) sites is higher in women than in men at all ages. Male rates predominate for descending and sig-

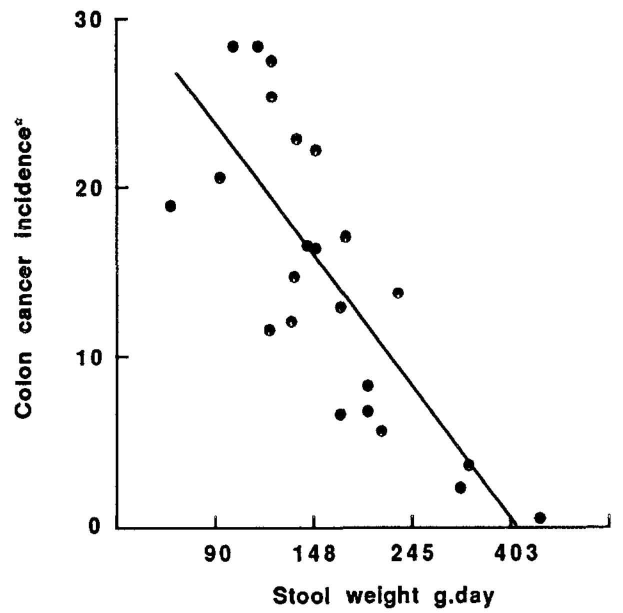

Figure 2. Average stool weight ($\log_e$) and colon cancer incidence (cases per 100,000 persons per year; age-standardized world population) from 23 population groups in 12 countries (r = 0.78). (Data from Table 2.)

moid colon in the older age groups.[45] Thus it is not possible to generalize with regard to cancer incidence and the physiological difference in bowel function between the sexes.

Stool weight is the net result of a number of processes, the principal ones being transit time and diet. The factors controlling transit are largely unknown. Exercise, emotional state, and hormones have been suggested as altering transit time, but there are few good data to support this.[46,47] Transit time and stool weight are related; slow transit (≥100 hours) is seen with stool weights of approximately 50 g/day.[9,48–50] The relationship is logarithmic for transit time, and once stool weights exceed 150 g/day only relatively small reductions in transit time are seen. With diet constant, altering transit times by therapeutic means changes stool output accordingly.[27] In the present study of adults in the United Kingdom, transit time and stool weight are again related (r = −0.52). However, it is not possible to perform an adequate correlation between transit time and bowel cancer risk for the other population data because the information is not available from every group and a great variety of methods have been used, some of which are too imprecise to be of value. There is a need for further measurements here because transit time is an important determinant of bowel function and hence possibly of cancer risk.

The effect of diet on stool bulk has been well documented. In more than 100 studies it has been shown that NSP (fiber) consumption increases the amount of stool passed and affects bowel function in other ways.[7] These studies include purified NSP sources such as ispaghula and cellulose, concentrated NSP preparations as found in various brans, and "natural" NSP-containing foods. However, in few of these reports is the NSP content of either diets or NSP sources given. This is mainly because accurate methods for the measurement of NSP have been available only since 1982.[33] When sufficient information on diet is available in the published reports, we have reinterpreted the data using NSP values from current food tables[34,35] (Figure 3). These data together clearly show a linear relation between stool weight and NSP intake over the range found in most countries of 4–32 g/day. Although NSP from whole wheat has the greatest effect on bowel habits, the relationship holds even when studies using added wheat fiber are excluded from the analysis. Thus NSP has been adequately demonstrated by experiment to alter stool weights of individuals, and physiological mechanisms whereby NSP increases stool weight are established.[51] No study has shown convincingly that dietary fat, protein, or energy has a significant effect on bowel habits, although some forms of starch are laxative.[52]

These data do not provide direct evidence for a protective role of dietary fiber against colon cancer. In few studies have bowel cancer risk been measured properly and adequate estimates of NSP intakes made. In the International Agency for Research on Cancer studies in four Scandinavian

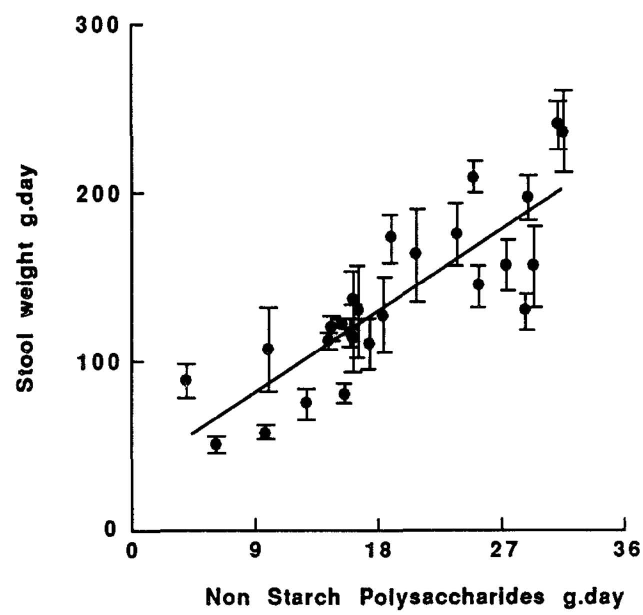

Figure 3. Mean daily stool weight (±SEM) in 11 groups of healthy subjects (total n = 206) eating controlled diets (26 dietary periods) with different amounts of NSP (dietary fiber) ($y = 5.3x + 38$). (Data from references 24–32 and unpublished observations.)

groups, NSP intake was inversely related to bowel cancer risk,[22,23] and in other population studies dietary fiber has been shown to protect against bowel cancer.[53–55] However, it is clear from these data that other factors are involved and that the correct association is really with diets "characterized by" high fiber rather than with fiber alone.

To reduce the risk of bowel cancer and constipation in a Western country, the population's median stool weight would need to be shifted to the right. Other factors being equal, an increase to 150 g/day would remove much of the population from below 100 g/day (Figure 1), thus reducing the risk of constipation and bowel cancer. The dietary change needed to bring this about (from Figure 3) would be an increase in NSP intake from approximately 12 to 21 g/day. This is a large increase (nearly 70% above current levels), but if the likely effect on bowel habit of starch is also taken into account[52] then diets characterized by an NSP intake of approximately 18 g/day that are also likely to be high in starch would be needed. Such dietary changes have been recommended in recent reports from the World Health Organization[56] and the U.K. Department of Health.[57]

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