Effect on blood pressure of two diets differing in total fat but not in saturated and polyunsaturated fatty acids in healthy volunteers[1-3]

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ABSTRACT The effects of a low-fat, carbohydrate-rich and a high-fat, olive-oil-rich diet on blood pressure were studied under strict dietary control. Forty-seven healthy normotensive men and women were fed a diet high in saturated fatty acids (20 en%) and total fat (38 en%) for 17 d. Twenty-four subjects then received a low-fat, carbohydrate-rich diet (total fat 22 en%) and the other 23 a high-fat, olive-oil-rich diet (oleic acid 24 en%, total fat 41 en%) for 36 d. Both test diets had the same level of saturated fatty acids (7–10 en%) and linoleic acid (4 en%). Systolic blood pressure fell by 2.3 and diastolic by 4.7 mm Hg in the carbohydrate group and by 2.7 and 4.4 mm Hg in the olive-oil group, respectively (differences between diets groups not significant). These results suggest that a high-fat diet rich in monounsaturated fatty acids has no deleterious effect on blood pressure in healthy normotensive subjects in comparison with a low-fat, carbohydrate-rich diet. *Am J Clin Nutr* 1988;47:976–80.

KEY WORDS Fat, fatty acids, blood pressure, dietary study, human

Introduction

Dietary fat may be involved in the regulation of blood pressure. Animal studies showed that deprivation of linoleic acid caused an increase of systolic blood pressure (1, 2). However, results from human studies were less conclusive. Epidemiological studies found a relationship between certain fatty acids and blood pressure (3, 4) but this was not confirmed (5, 6). Clinical studies suggested that increasing intake of linoleic acid lowers blood pressure (7, 8). Because linoleic acid can be converted into prostaglandins, which in turn influence blood pressure (9), it is tenable to attribute an effect of dietary fat on blood pressure to an increased intake of linoleic acid. However, available data do not exclude the possibility that blood pressure might be affected by the total amount of fat in the diet or by the polyunsaturated-to-saturated fatty acids (P:S) ratio rather than by the intake of polyunsaturates itself. We compare the effects of a low-fat, carbohydrate-rich diet and a high-fat, olive-oil-rich diet on blood pressure in healthy, nonobese, normotensive volunteers. By having the same level of saturated and polyunsaturated fatty acids in both diets, with only oleic acid intake different, blood pressure effects of the total fat intake can be differentiated from possible effects caused by particular saturated or polyunsaturated fatty acids.

Subjects and methods

Subjects

Fifty-seven healthy men and women entered this strictly controlled dietary experiment. None was hypertensive (diastolic blood pressure > 95 mm Hg and systolic > 150 mm Hg), as judged on two separate occasions 2 mo before the study, or received medication known to affect blood pressure immediately before or during the study. Data from nine subjects were eliminated before the analysis of the results because of departures from the protocol. For one male subject no blood pressure measurements were made because he was not available at the time of the measurements. Thus, data for 47 participants were processed. They were between 18 and 59 y of age (mean 27) and weighed 53–88 kg (mean 71); their height ranged from 160 to 202 cm (mean 177) and their body mass index from 18.9 to 28.4 kg/m^2 (mean 22.7).

Diets and design

The main purpose of the experiment was to test the effects of a low-fat, carbohydrate-rich diet and a high-fat, olive-oil-rich diet on serum lipids. Details of this study were previously published (10).

The experiment was carried out for 55 d. Before the experiment subjects were asked to weigh and record their food intake on three separate days including one weekend day. Foods were coded and nutrients were calculated using the 1985 edition of the computerized Dutch food composition table (11).

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During the experiment all subjects first consumed a Western-type diet high in total and saturated fatty acids for 17 d. Then two groups were formed by randomization with stratification for serum lipids and sex. One group (carbohydrate group, 12 men and 12 women) received a low-fat, carbohydrate-rich diet and the other group (olive-oil group, 11 men and 12 women) received a high-fat, olive-oil-rich diet for the next 36 d. Three women in each group used oral contraceptives. The baseline values (mean ± SD) were 5.19 ± 1.12 and 5.22 ± 0.86 mmol/L for total cholesterol, 1.49 ± 0.38 and 1.51 ± 0.35 mmol/L for HDL cholesterol, 1.00 ± 0.58 and 0.95 ± 0.49 mmol/L for triglycerides, and 22.8 ± 2.17 and 22.6 ± 2.26 kg/m^2 for body mass index for the carbohydrate and the olive-oil groups, respectively.

Each diet consisted of conventional, mixed solid foods and menus were changed daily. The amount of food necessary to meet each individual's energy requirement was weighed out. Body weights were recorded twice weekly and energy intake was adjusted when necessary. Weight changes did not exceed 2.5 kg over the 8 wk of the experiment and were on average −0.5 kg in the low-fat and −1.2 kg in the olive-oil group. All food was provided except for some free-choice items that were free from fat and cholesterol. Free-choice items were accorded points corresponding to their energy value, with one point equalling 41.8 kJ (10 kcal). Each subject was required to consume an exact number of points, which varied with total energy intake and ranged from 4.6 to 10.0% of the total energy intake. Typical choices were an apple (6 points), orange juice (5 points), or a glass of beer (8 points). The importance of not changing one's selection of free-choice items between periods was repeatedly explained and stressed. Subjects recorded in diaries their free-choice items, the amount of coffee used, and any deviations from the protocol. Coffee consumption was not different between the two diet groups nor did it change during the study. For each of the three diets, duplicate portions for one imaginary participant with an energy intake of 10 MJ/d (2390 kcal/d) were collected daily and stored at −20 °C for later analysis.

Measurements

Blood pressure was measured with an automatic sphygmomanometer with recorder (Copal UA-251, Adquipment Medical BV, Rotterdam, The Netherlands) on two occasions before and once a week during the experiment except for week 1. Diastolic pressure was recorded at Korotkoff phase V. Subjects were asked not to perform physical activity or to eat or smoke 1 h before the blood pressure measurements. Three measurements at 1-min intervals were made at each session before the experiment and four measurements per session during the experiment. Measurements were made on the left arm with the subject in the sitting position in a quiet room after at least 5 min rest. Three trained investigators, who were unaware of the diet group of a participant, performed the measurements. Measurements for one person were generally made at the same time of the day by the same person with the same sphygmomanometer. Serum total cholesterol was determined twice before the experiment, twice at the end of the control period, and three times at the end of the test period. Blood pressure and serum total cholesterol were also measured 7 wk after the experiment in 8 men and 10 women of the carbohydrate group and in 10 men and 9 women of the olive-oil group. The other 10 subjects were not available at that time.

The duplicate portions of each diet period were mixed thoroughly and then freeze-dried. The ash content and the moisture level were determined (12) and then the material was stored at −20 °C. Aliquots were analyzed for protein (13), total fat (14), the proportions of individual fatty acids after saponification and methylation (15), dietary fiber (16), and cholesterol (17). Carbohydrate was calculated by difference. Sodium, potassium, calcium, and magnesium were determined by atomic absorption photometry (18) in the freeze-dried material after it had been treated by the wet-ash method and neutralized. The mean composition of the diets were calculated from duplicate-portion analysis plus calculated contribution of free-choice items.

Statistical methods

The first blood pressure measurement of each session was discarded and the other measurements were averaged. The response of blood pressure to the low-fat, carbohydrate-rich diet or the high-fat, olive-oil-rich diet was calculated per subject as the change from the end of the Western diet period (week 3) to the end of the test period (week 8). Pearson correlation coefficients were computed between the response and the average systolic and diastolic blood pressure level over the course of the experiment (mean of weeks 3 plus 8) for both sexes per diet group. Body weights were averaged per week and the change was calculated as the difference between week 8 and week 1. Differences in effects on blood pressure of the test diets were examined by analysis of variance with diet, sex, and diet × sex interaction as independent variables. An unpaired *t* test was used if diet was the only significant variable. Changes within each diet group were examined by analysis of variance with sex as the independent variable. A paired *t* test was used if sex had no significant effect. In addition, blood pressures 7 wk after the experiment were compared with week 8, and cholesterol levels were compared with preexperimental values by the same techniques (19).

Results

Nutrient intake

The mean daily intake of energy and the composition of the diets during the preexperimental and the study period are shown in **Table 1.** Individual energy intakes ranged from 6.1 to 19.9 MJ (1460 to 4760 kcal) on the Western-type diet, from 6.3 to 20.5 MJ (1510 to 4900 kcal) on the low-fat, carbohydrate-rich diet, and from 7.1 to 15.5 MJ (1700 to 3700 kcal) on the high-fat, olive-oil-rich diet. The proportion of energy (en%) from saturated fatty acids increased from 15.0% during the preexperimental period to 20.0% during the Western-type-diet period. The intake of monounsaturated and polyunsaturated fatty acids decreased slightly. The intake of dietary fiber increased on average by 8 g/d during the control period. The intake of saturated fatty acid decreased by 13.3 en% on the low-fat, carbohydrate-rich diet and by 10.2 en% on the high-fat, olive-oil-rich diet. This decrease was compensated for by an increased intake of carbohydrates in the one group and of monounsaturated fatty acids in the other group. The proportion of energy from alcohol between subjects ranged from 0.0 to 7.3% on the Western-type diet, from 0.0 to 8.2% on the low-fat, carbohydrate-rich diet, and from 0.0 to 7.3% on the high-fat, olive-oil-rich diet. The mean daily intake of fiber increased by on average 18 g/d on the low fat, carbohydrate-rich diet. The intake of Na, K, Ca, and Mg was

TABLE 1
Composition of the diets and mean daily intake of energy (mean ± SD)*

	Habitual diet ($n = 45$)	Western diet ($n = 47$)	Carbohydrate-rich diet ($n = 24$)	Olive-oil rich diet ($n = 23$)
Energy intake				
MJ†	10.8 ± 2.9	11.1	11.8	10.9
kcal	2580 ± 694	2660	2820	2610
Protein (% of energy)	14.2 ± 2.7	13.6	14.1	12.2
Fat (% of energy)				
Total	37.3 ± 4.7	38.0	22.1	40.6
Saturated fatty acids	15.0 ± 2.0	20.0	6.7	9.8
Monounsaturated fatty acids	14.2 ± 2.7	12.4	9.3	24.0
Polyunsaturated fatty acids	5.6 ± 1.3	4.1	5.2	5.1
Linoleic acid	4.6 ± 1.3	3.4	4.3	4.2
Carbohydrates (% of energy)	47.1 ± 6.0	47.7	62.2	46.0
Alcohol (% of energy)	1.4 ± 2.0	1.3	1.6	1.2
Cholesterol				
mg/MJ	31.0 ± 12.4	35.1	33.1	31.7
mg/Mcal	129.6 ± 51.8	146.7	138.4	132.5
Dietary fiber				
g/MJ	3.1 ± 0.9	3.8	5.1	3.9
g/Mcal	13.0 ± 3.8	15.9	21.3	16.3
Sodium				
mmol/MJ	11.5 ± 3.7	14.1	14.3	12.8
mmol/Mcal	48.1 ± 15.5	58.9	59.8	53.5
Potassium				
mmol/MJ	9.2 ± 2.0	9.5	10.3	8.3
mmol/Mcal	38.5 ± 8.4	39.7	43.1	34.7
Calcium				
mmol/MJ	3.3 ± 1.0	2.7	2.7	2.2
mmol/Mcal	13.8 ± 4.2	11.3	11.3	9.2
Magnesium				
mmol/MJ‡		1.7	1.9	1.7
mmol/Mcal		7.1	7.9	7.1

* The between-subject variation in the composition of the diets provided during the study was negligible and therefore no SDs are given.
† SDs for energy intake on the experimental diets were 2.6, 3.0, and 2.6 MJ (620, 720, and 620 kcal), respectively.
‡ Excluding minor contributions from free-choice items because values for Mg were not available in the food composition table used.

higher on the low-fat, carbohydrate-rich diet than on the Western-type and the high-fat, olive-oil-rich diet.

Blood pressure

Changes in blood pressure were not related to sex, sex × diet interaction, or the average absolute blood pressure averaged over the duration of the trial. Therefore, results were pooled per diet group. Time courses of blood pressure values are shown in **Figure 1.** At randomization the groups were not matched for blood pressure. The higher mean blood pressure in the carbohydrate group throughout the study period is therefore not due to diet but to the innately higher blood pressures of some subjects. Mean blood pressures for both diet groups during the preexperimental and study period are shown in **Table 2.** The blood pressure changes for the two diet groups were the same. The systolic pressure of 37 subjects measured 7 wk after the experiment was on average 1.1 ± 10.0 mm Hg lower and diastolic pressure was 1.2 ± 9.4 mm Hg lower than the values at the end of the test period (changes not significant) and 5.9 ± 7.2 mm Hg and 4.7 ± 8.7 mm Hg lower than the preexperimental values. Repeating the full statistical analyses with only these 37 subjects produced results comparable with those for the full group (Table 2).

Serum total cholesterol levels 7 wk after the experiment equalled preexperimental values (change −0.02 ± 0.50 mmol/L, not significant). This suggests that subjects indeed had returned to their habitual diets and that the fall in blood pressure from preexperimental to postexperimental measurements was not due to changes in dietary habits.

No significant correlations were found between changes in weight and changes in blood pressure for either diet group (data not shown).

Discussion

An effect of fat-modified diets on blood pressure was reported by several authors. An increased intake of polyunsaturated and a decreased intake of saturated fatty acids lowered both systolic and diastolic blood pressure

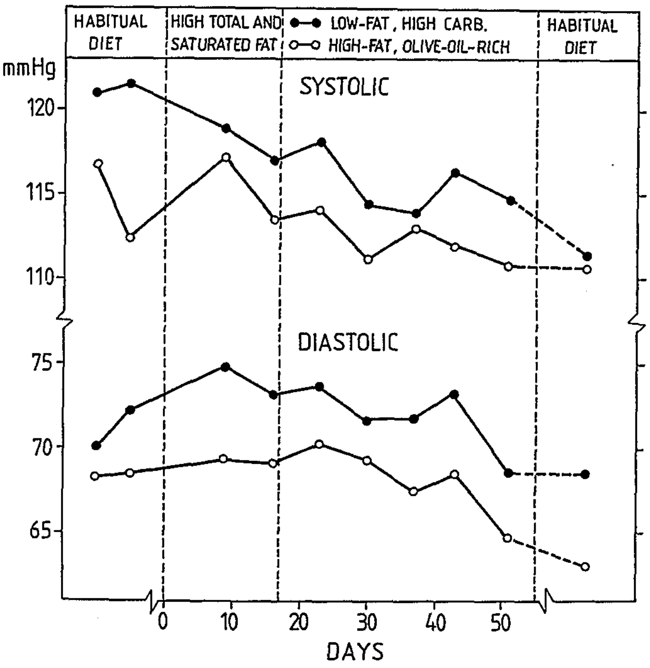

FIG 1. Mean systolic and diastolic blood pressure before, during, and after the experiment.

in middle-aged normotensive subjects (20, 21). Because both the amount of fat and the fatty acid composition of the diets had changed in these studies, it is not possible to attribute the observed effects to a single dietary component. We did not find an effect on blood pressure of a high-fat, olive-oil-rich diet relative to a low-fat, carbohydrate-rich diet with the same level of saturated and polyunsaturated fatty acids. This suggests that total fat is not a determinant of blood pressure in young normotensive volunteers and that the observed effects of fat-modified diets on blood pressure are attributable to an increase in linoleic acid intake. However, this conclusion is contradicted by several experiments. In the experiment of Puska et al (22), blood pressure was lowered on a low-fat diet with only a slight change in polyunsaturated fatty acids. An effect of polyunsaturated fatty acids on blood pressure was not demonstrated in other studies with normotensive subjects (23, 24). However, note that our subjects were young, nonobese, and normotensive, which may make it difficult to alter blood pressure. It has been shown that a diet known to lower blood pressure in middle-aged subjects (22) does not modify blood pressure in children (25).

Blood pressures were lower on both test diets than on the Western-type diet that was high in saturated fatty acids, which could be interpreted as a beneficial effect in general of diets low in saturated fatty acids on blood pressure. Puska et al (22) also noted an equal reduction in blood pressure on two low-fat diets with virtually the same level of saturated fatty acids but with different P:S ratios. However, blood pressure levels measured 7 wk after our study did not differ from values at the end of the study and were appreciably lower than preexperimental values even though serum total cholesterol levels had returned to preexperimental values. This suggests that the decrease in blood pressure in both groups during the trial might have been a habituation effect—a well-known phenomenon in blood pressure studies (26)—although this cannot be ascertained from the present study. Because there was no control group, it is possible that both diets had the same effect on blood pressure. However, results obtained so far are not uniform and additional well-controlled studies are needed before any firm conclusions can be drawn.

TABLE 2
Systolic and diastolic blood pressure levels before, during, and after the experiment (mean ± SD)

	All subjects		Subsample of subjects*	
	Carbohydrate group ($n = 24$)	Olive-oil group ($n = 23$)	Carbohydrate group ($n = 18$)	Olive-oil group ($n = 19$)
	mm Hg		*mm Hg*	
Systolic				
Preexperimental	121.3 ± 10.6	114.6 ± 10.9	119.2 ± 8.1	114.7 ± 11.9
Experimental				
Control diet	117.1 ± 10.2	113.6 ± 10.4	115.1 ± 8.4	113.8 ± 10.9
Test diet	114.8 ± 11.2	110.9 ± 10.3	113.3 ± 9.9	111.0 ± 11.0
Change	−2.3 ± 9.2	−2.7 ± 6.3†	−3.7 ± 9.7	−2.8 ± 6.4
Postexperimental			111.4 ± 10.4	110.6 ± 10.5
Diastolic				
Preexperimental	71.2 ± 10.6	68.5 ± 5.8	72.3 ± 9.3	68.6 ± 6.3
Experimental				
Control diet	73.2 ± 8.4	69.2 ± 7.6	73.1 ± 7.8	68.7 ± 8.3
Test diet	68.5 ± 10.7	64.8 ± 7.8	68.6 ± 11.0	65.3 ± 7.8
Change	−4.7 ± 9.0†	−4.4 ± 6.9‡	−4.5 ± 9.6	−3.4 ± 6.1†
Postexperimental			68.6 ± 11.0	63.0 ± 9.6

* The 37 subjects for whom postexperimental measurements were available.
† $p < 0.05$.
‡ $p < 0.01$.

Changes in body weight might also influence changes in blood pressure (27). However, changes in weights were small in this experiment and did not correlate with changes in blood pressure. From chemical analysis of duplicate portions the intake of Na, K, Ca, Mg, and dietary fiber was slightly higher in the carbohydrate group. All these dietary factors might influence blood pressure (28–32). Except for Na, the intakes of all these dietary factors were more favorable with respect to blood pressure in the carbohydrate group. However, there was still no excess fall in blood pressure in this group. This reinforces our conclusion that an intake high in monounsaturated fatty acids does not increase blood pressure in comparison with a low-fat, carbohydrate-rich diet.

In our experiment the standard deviation of the individual change in blood pressure from week 3 to week 8 was ~8 mm Hg. With 24 persons per diet group the statistical power for detecting a true difference of 2 mm Hg between the diets is only 22% and a true difference of 4 mm Hg is 55%. Thus we might have missed a small effect on blood pressure purely by chance. However, we may still conclude that the favorable effects on serum lipids (10) of a high-fat, olive-oil-rich diet as compared with a low-fat, carbohydrate-rich diet are not counteracted by an unfavorable effect on blood pressure in healthy normotensive subjects.

References

1. Düsing R, Scherhag R, Glänzer K, Budde U, Kramer HJ. Dietary linoleic acid deprivation: effects on blood pressure and PGI_2 synthesis. Am J Physiol 1983;244:H228–33.
2. Hoffmann P, Block HU, Beitz J, et al. Comparative study of the blood pressure effects of four different vegetable fats on young, spontaneously hypertensive rats. Lipids 1986;21:733–7.
3. Oster P, Arab L, Schellenberg B, Heuck CC, Mordasini R, Schlierf G. Blood pressure and adipose tissue linoleic acid. Res Exp Med (Berl) 1979;175:S287–91.
4. Berry EM, Hirsch J. Does dietary linolenic acid influence blood pressure? Am J Clin Nutr 1986;44:336–40.
5. McCarron DA, Morris CD, Henry HJ, Stanton JL. Blood pressure and nutrient intake in the United States. Science 1984;224:1392–8.
6. Fehily AM, Milbank JE, Yarnell JWG, Hayes TM, Kubiki AJ, Eastham RD. Dietary determinants of lipoproteins, total cholesterol, viscosity, fibrinogen, and blood pressure. Am J Clin Nutr 1982;36:890–6.
7. Stern B, Heyden S, Miller D, Latham G, Klimas A, Pilkington K. Intervention study in high school students with elevated blood pressures. Dietary experiment with polyunsaturated fatty acids. Nutr Metab 1980;24:137–47.
8. Comberg HU, Heyden S, Hames CG, Vergroesen AJ, Fleischman AI. Hypotensive effect of dietary prostaglandin precursor in hypertensive man. Prostaglandins 1978;15:193–7.
9. Heinemann HO, Lee JB. Prostaglandins and blood pressure control. Am J Med 1976;61:681–95.
10. Mensink RP, Katan MB. Effect of monounsaturated fatty acids versus complex carbohydrates on high-density lipoproteins in healthy men and women. Lancet 1987;1:122–5.
11. Commissie UCV. UCV Tabel. 's Gravenhage: Voorlichtingsbureau voor de Voeding, 1985.
12. Osborne DR, Voogt P. The analysis of nutrients in foods. London: Academic Press, 1978.
13. Williams S, ed. Official methods of analysis of the association of official analytical chemists. 14th ed. Arlington, VA: AOAC Inc, 1984.
14. Folch J, Lees M, Sloane Stanley GH. A simple method for the isolation and purification of total lipids from animal tissues. J Biol Chem 1957;226:497–509.
15. Metcalfe LD, Schmitz AA, Pelka JR. Rapid preparation of fatty acid esters from lipids for gas chromotographic analysis. Anal Chem 1966;38:514–5.
16. Prosky L, Asp NG, Furda J, de Vries JW, Schweizer TF, Harland BF. Determination of total dietary fiber in foods, food products and total diets: interlaboratory study. J Assoc Off Anal Chem 1984;67:1044–53.
17. Van de Bovenkamp P, Katan MB. Cholesterol content of chicken skin. J Food Sci 1981;46:291.
18. Perkin-Elmer Corporation. Analytical methods for atomic absorption spectrophotometry. Norwalk, CT: Perkin-Elmer Corporation, 1976.
19. Snedecor GW, Cochran WG. Statistical methods. 7th ed. Ames: Iowa State University Press, 1980.
20. Iacono JM, Puska P, Dougherty RM, et al. Effect of dietary fat on blood pressure in a rural Finnish population. Am J Clin Nutr 1983;38:860–9.
21. Puska P, Iacono JM, Nissinen A, et al. Controlled, randomised trial of the effect of dietary fat on blood pressure. Lancet 1983;1:1–5.
22. Puska P, Iacono JM, Nissinen A, et al. Dietary fat and blood pressure: an intervention study on the effects of a low-fat diet with two levels of polyunsaturated fat. Prev Med 1985;14:573–84.
23. Lemkbe A, Greggersen H, Kay HW, Rathjen G, Steinicke F. Dietary linoleate and blood pressure. Milchwissenschaft 1985;40:329–33.
24. Margetts BM, Beilin LJ, Armstrong BK, et al. Blood pressure and dietary polyunsaturated and saturated fats: a controlled trial. Clin Sci 1985;69:165–75.
25. Vartiainen E, Puska P, Pietinen P, Nissinen A, Leino U, Uusitalo U. Effects of dietary fat modifications on serum lipids and blood pressure in children. Acta Paediatr Scand 1986;75:396–401.
26. Burstyn PG. Variability in blood pressure measurements. Am J Clin Nutr 1982;36:379 (letter).
27. Borkan GA, Sparrow D, Wisniewski C, Vokonas PS. Body weight and coronary disease risk: patterns of risk factor change associated with long-term weight change. The Normative Aging Study. Am J Epidemiol 1986;124:410–9.
28. Beard TC, Cooke HM, Gray WR, Barge R. Randomised controlled trial of a no-added-sodium diet for mild hypertension. Lancet 1982;2:455–8.
29. Khaw KT, Thom S. Randomised double-blind cross-over trial of potassium on blood pressure in normal subjects. Lancet 1982;2:1127–9.
30. Belizan JM, Vilar J, Pineda O, et al. Reduction of blood pressure with calcium supplementation in young adults. JAMA 1983;249:1161–5.
31. Dyckner T, Wester PO. Effect of magnesium on blood pressure. Br Med J 1983;286:1847–9.
32. Wright A, Burstyn PG, Gibney MJ. Dietary fibre and blood pressure. Br Med J 1979;2:1541–3.