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Macronutrient intake, glycaemic index and glycaemic load of older Australian subjects with and without diabetes: baseline data from the Blue Mountains Eye Study

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Individuals with diabetes receive more nutrition advice than other population segments yet little is known about how well they comply or differ in nutrient intake from the rest of the population. The present study determined the mean macronutrient intake, glycaemic index (GI), and glycaemic load (GL) of a cohort of 3654 older Australians, with and without diabetes. Fasting pathology tests, including plasma glucose, were obtained for 88 % of the 3654 residents, and a 145-item semi-quantitative food-frequency questionnaire was completed by 2900 residents (89 %) between 1992 and 1994. In total, 6 % of participants had diagnosed diabetes. Valid food-frequency data were available for 2736 without and 164 individuals with diabetes. The GI and GL were calculated from a customised database of Australian foods. Individuals with diabetes consumed significantly more protein ($P=0{\cdot}001$) and less sugars ($P\leq 0{\cdot}001$) than the general population. Only seven individuals with diabetes (4·3 %) met all macronutrient recommendations and only four (2·4 %) met fibre recommendations as well. Those with diabetes had a lower mean GI (55 (SD 5) *v.* 57 (SD 4); $P=0{\cdot}007$, respectively) and GL (122 (SD 26) *v.* 134 (SD 24); $P<0{\cdot}001$, respectively) than the general population. In conclusion, older individuals with diabetes living in Australia in the 1990s chose a diet that had significantly more protein and less sugars than those without diabetes. This difference had little impact on the average GI, but it led to a moderate reduction in the average GL. Only a small percentage, however, was able to meet nutritional recommendations for optimal diabetes management.

Glycaemic index: Glycaemic load: Macronutrient intake: Diabetes: Blue Mountains Eye Study

Management of diabetes includes lifelong adoption of a healthy diet, regular physical activity and use of hypoglycaemic medication and/or insulin to help achieve and maintain as near normal glycaemia as possible. In the year 2000, The Australian Diabetes, Obesity and Lifestyle Study (Cameron *et al.* 2003) estimated that 7 % of Australian women and 8 % of Australian men aged 25 years or older had diabetes. Based on these estimates, there were approximately 1·2 million individuals with diagnosable diabetes living in Australia in the year 2004, with half not knowing they had the condition (Diabetes Australia, 2004). The annual total cost of diabetes to the Australian community is in excess of US$ 4·4 billion (Diabetes Australia, 2004).

Approximately 85–90 % of all cases of diabetes in Australia are type 2 (Diabetes Australia, 2004), which is characterised by insulin resistance and relative insulin deficiency (American Diabetes Association, 2004). Lifestyle factors including smoking, physical inactivity, excessive energy intake and associated overweight or obesity are established risk factors for the development of type 2 diabetes (van Dam, 2003).

Because carbohydrate is the main dietary component affecting postprandial glycaemia, it has also been implicated in the aetiology of type 2 diabetes (Brand-Miller, 2004). Both the amount and type of carbohydrate consumed have an impact on postprandial glycaemia, and the difference cannot be explained by glucose chain length (Wahlqvist *et al.* 1978). In the early 1980s the concept of the glycaemic index (GI) was introduced by Jenkins *et al.* (1981) to quantify the glycaemic responses to carbohydrates in different foods. Glycaemic load (GL), the mathematical product of the GI of a food and its carbohydrate content, has been proposed as a global indicator of the glucose response and insulin demand induced by a serving of food (Salmeron *et al.* 1997*b*).

Overall dietary GI and/or GL have been positively related to diabetes risk in three large cohort studies in the USA (Salmeron *et al.* 1997*a*,*b*; Schulze *et al.* 2004), but no association was seen in two other studies (Meyer *et al.* 2000; Stevens *et al.* 2002).

The Blue Mountains Eye Study (BMES) is a population-based cohort study of vision and common eye diseases in an urban population that was aged 49 years or older, and resident

Abbreviations: BMES, Blue Mountains Eye Study; FFQ, food-frequency questionnaire; GI, glycaemic index; GL, glycaemic load.

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in two postcode regions of the Blue Mountains area west of Sydney, Australia. This area has a stable, homogeneous population, which is representative of Australia for income and socio-economic status (Mitchell *et al.* 1998).

Individuals with diabetes receive more nutrition advice than other segments of the population yet little is known about how well they comply or differ in nutrient intake from the rest of the population. The goal of this initial analysis was to determine the mean macronutrient intake, GI and GL of older Australians with and without diabetes, using detailed nutrient intake data obtained from the BMES. A secondary goal was to compare the nutritional habits of participants with diabetes with those of the background population and to evaluate compliance with nutritional recommendations current at the time of the initial survey. These baseline data will be used to determine associations between key macronutrients, GI and GL, and the risk of developing type 2 diabetes in the BMES prospective cohort study.

Methods

The methodology used in the BMES has been previously described (Attebo *et al.* 1996), and is presented in Fig. 1. Briefly, the present study concerns the baseline study, BMES I, which identified 4433 eligible non-institutionalised permanent residents in a door-to-door census conducted during 1991, of whom 3654 (82·4 %) participated in detailed examinations during the period from 1992 to 1994. Of the 779 (17·5 %) individuals identified in the census who did not participate, 353 (8·0 %) permitted only an interview, 148 (3·3 %) refused, 210 (4·8 %) had moved out of the area, and sixty-eight (1·5 %) had died before the examinations were conducted. The overall response was 82·4 %, though after excluding the latter two groups, it was relatively high at 87·9 %. Baseline differences between participants and non-participants were minimal (Attebo *et al.* 1996).

All study participants were invited to attend a local clinic for a medical history and examination, which included anthropometry, history of diabetes and associated risk factors. Fasting pathology tests, including plasma glucose, were obtained for 88 % of the 3654 residents on a second visit (Mitchell *et al.* 1998), and a validated 145-item semi-quantitative food-frequency questionnaire (FFQ) was completed by 3269 (89 %) of the residents (Smith *et al.* 1998).

Participants with at least 10 % of values missing from their FFQ were excluded, as were those with calculated daily energy intakes less than 2500 kJ or greater than 18 000 kJ (Willett & Stampfer, 1986). In total, 367 individuals were removed from further analysis (Smith *et al.* 1998), leaving a total of 2900 (89 %) individuals with usable FFQ. The FFQ contained additional questions about the type of breakfast cereals used to increase the accuracy of the GI and GL calculations.

A validation study of the FFQ was conducted, using weighed food records as a comparative dietary collection method, collecting 4 d weighed foods records on three occasions over 1 year (*n* 79) (Smith *et al.* 1998). The FFQ was found to show moderate to good agreement for carbohydrates and fats, yielding a correlation coefficient of 0·57 and correctly classifying nearly 80 % of individuals within one quintile for carbohydrate, and a correlation coefficient of 0·68 and correctly classifying over 70 % of individuals within one quintile for total fat (Smith *et al.* 1998). The correlation coefficient for protein was 0·18, and 62 % of individuals were classified within one quintile (Smith *et al.* 1998).

A dietitian coded data from the semi-quantitative FFQ into a customised database (DBASE IV; Borland International Inc., Scotts Valley, CA, USA) which incorporated the Australian food composition tables (NUTTAB 90; Department of Community Services and Health, 1990) and published GI values using the glucose = 100 scale (Foster-Powell *et al.* 2002). Additional GI data were obtained from the Sydney University Glycaemic Index Research Service (SUGiRS) online database (www.glycemicindex.com). In total, 88·9 % of the GI values were obtained direct from published values, while the remaining 11·1 % were interpolated from similar food items.

The overall GI of each participant's diet was calculated by summing the weighted GI of individual foods in the diet, with the weighting proportional to the contribution of the food to total carbohydrate intake. The glycaemic load of each food item was calculated by multiplying each food's GI by the amount of available carbohydrate (g) per serving. Overall dietary glycaemic load was then determined as the product of food's glycaemic load and the participant's frequency of consumption, summed over all foods. Energy and macronutrient

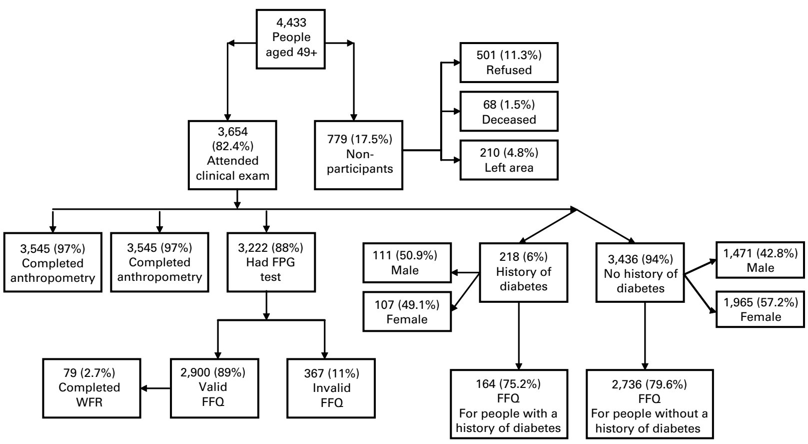

Fig. 1. Recruitment process for Blue Mountains Eye Study participants. FFQ, food-frequency questionnaire; FPG, fasting plasma glucose; WFR, weight food record.

intakes, including protein, fat, saturated fat, available carbohydrate (starch + sugars), total sugars (naturally occurring + added sugars) and fibre were calculated. GI and GL values were adjusted for total energy intake using the residual method (Willett & Stampfer, 1986).

Statistical analyses were performed using SPSS 11.5.0 (SPSS Inc., Chicago, IL, USA). Results are expressed as mean values and standard deviations unless otherwise stated. Comparisons between groups were undertaken using independent-sample *t* tests. All data were approximately normally distributed with the exception of alcohol; these data were therefore log-transformed before statistical analysis. Statistical significance was set at $P<0·05$.

Results

A history of diabetes was reported by 218 (6·0 %) of the 3654 participants, including 11·1 % who had been diagnosed for less than 1 year, 33·6 % for 1–4 years, 19·4 % for 5–9 years, 24·4 % for 10–29 years, and 10·1 % for 20 years or longer. Diabetes duration was not known for 1·4 % of participants.

Among this group, 111 were male (diabetes history in 7·0 %) and 107 were female (diabetes history in 5·2 %). Another sixty-six (2·2 %) had a fasting blood glucose ≥7·0 mmol/l, indicating undiagnosed diabetes. Therefore a total of 8·2 % of participants had diagnosable diabetes, although not all were aware of it.

Of the 218 individuals with a history of diabetes, forty-six (21 %) were treated with insulin, eighty-eight (41 %) with oral hypoglycaemic agents, and eighty-three (38 %) with dietary modification only. Four out of the eighty-eight individuals treated with insulin had started insulin therapy before age 30 years, and therefore most probably had type 1 diabetes (Mitchell *et al.* 1998). Hence, 98·2 % were considered to have type 2 diabetes. Individuals with a history of diabetes were slightly older (67·4 (SD 8·3) years) than the remaining population (66·1 (SD 9·8) years; $P=0·04$).

Valid height and weight measurements were obtained from 3545 participants. Over half of BMES I participants (56·1 %) were either overweight or obese (BMI $>25\,kg/m^2$). The mean height of individuals with a history of diabetes was not significantly different from those without (1·65 (SD 0·09) *v.* 1·65 (SD 0·09) m; $P=0·614$). However, individuals with a history of diabetes were significantly heavier (76·7 (SD 15·5) *v.* 70·9 (SD 14·3) kg; $P<0·001$) and therefore had a higher BMI (28·0 (SD 5·0) *v.* 26·0 (SD 4·5) kg/m^2; $P<0·001$). Significantly more individuals with a history of diabetes (193 individuals; 70·2 %) were overweight or obese, compared with the general population (1797 individuals; 54·9 %; $P<0·001$). Key characteristics of individuals with and without diabetes are presented in Table 1.

Mean macronutrient intakes, and energy-adjusted GI and GL in both groups are presented in Table 2. Individuals with a history of diabetes (*n* 164) consumed significantly more protein and less total sugars (naturally occurring and added sugars) than those without a history of diabetes (*n* 2736). Mean GI and GL were significantly lower in those with a history of diabetes than those without.

The macronutrient intakes, expressed as a percentage of energy, for individuals with a history of diabetes were compared with recommendations from the Diabetes and Nutrition Study Group of the European Association for the Study of Diabetes (Anonymous, 2000) (Table 3). Just over half of the individuals with a history of diabetes had macronutrient intakes within the recommended range for protein, and nearly all were within the range for alcohol, but most consumed more energy from fat and saturated fat, and less energy from carbohydrates than recommended. Only seven individuals with a history of diabetes (4·3 %) were able to meet all macronutrient recommendations and only four (2·4 %) met the recommendations for fibre as well as the macronutrients. Their dietary intake was not appreciably different from other groups of individuals living with diabetes in the developed world, including the Mediterranean basin (Thanopoulou *et al.* 2004), USA (Banini *et al.* 2003), Canada (Wolever *et al.* 1994), Spain (Diabetes and Nutrition Study Group of the Spanish Diabetes Association; Anonymous, 1997) and the UK (Close *et al.* 1992; Eeley *et al.* 1996) (Table 4).

Discussion

Individuals with diabetes living in Australia in the early 1990s reported eating more protein, fat and saturated fat and less

Table 1. Selected characteristics of individuals with and without diabetes in the Blue Mountains Eye Study
(Mean values and standard deviations)

	Individuals with diabetes (*n* 218)		Individuals without diabetes (*n* 3436)		
Characteristic	Mean	SD	Mean	SD	*P*
Age (years)	67·4	8·3	66·1	9·8	0·04
Female (%)	49·1		57·2		0·02
BMI (kg/m²)	28·0	5·0	26·0	4·5	<0·001
Overweight or obese (%)	70·2		54·9		<0·001
Fasting plasma glucose (mmol/l)	8·7	4	5·0	1	<0·001
Serum cholesterol (mmol/l)	5·8	1	6·0	1	0·003
Serum HDL-cholesterol (mmol/l)	1·2	0·4	1·4	0·4	<0·001
Serum triacylglycerols (mmol/l)	2·3	1	1·7	1	<0·001
Systolic blood pressure (mmHg)	150·6	25	145·9	21	0·007
Diastolic blood pressure (mmHg)	83·7	11	83·3	10	0·645
Time walking (min/d)	27·7	9·9	24·9	10·2	0·213
Time vigorous activity (min/d)	19·1	3·2	17·3	3·6	0·511

Table 2. Macronutrient intake, glycaemic index (GI) and glycaemic load (GL) of individuals with and without diabetes in the Blue Mountains Eye Study population (*n* 2900)

(Mean values and standard deviations)

	Individuals with a history of diabetes (*n* 164)			Individuals without diabetes (*n* 2736)			
	Mean	SD	% Energy	Mean	SD	% Energy	*P*
Energy (kJ)	8350	2420		8610	2600		0·203
Protein (g)	97	31	19·7	88	28	17·4	0·001
Fat (g)	78	30	34·6	77	30	33·1	0·685
Saturated fat (g)	30	13		30	14		0·779
Polyunsaturated fat (g)	14	6		13	6		0·456
Monounsaturated fat (g)	27	11		27	11		0·561
Total carbohydrate (g)	214	72	41	237	79	44	0·002
Starch (g)	102	36		104	38		0·354
Sugars (g)	109	48		131	54		<0·001
Alcohol (g)	4	5	1·4	5	6	1·7	0·138
Fibre (g)	29	12		28	12		0·791
GI	55	5		57	4		0·007
GL	122	26		134	24		<0·001

available carbohydrate and dietary fibre than recommended for optimal diabetes management. Only a small minority (<5 %) were able to meet all the macronutrient recommendations and the additional guideline for dietary fibre. The findings suggest that Australians living with diabetes at that time found it difficult to follow dietary recommendations and put excessive emphasis on avoidance of sugars at the expense of other dietary goals. This has been shown to have undesirable consequences for overall nutrient intake, including higher intake of saturated fat (Bolton-Smith & Woodward, 1994; Gibney *et al.* 1995). The present findings suggest recommendations for individuals with diabetes may be unrealistic or even counterproductive, although it is likely that only a minority received education and follow-up support from a dietitian (Close *et al.* 1992).

To our knowledge, the present study is the first report of dietary GI and GL of a large representative free-living population of individuals with type 2 diabetes. The GI provides a measure of carbohydrate quality (its glycaemic potential), while the GL takes account of both quantity and quality of carbohydrate and provides a global measure of overall postprandial hyperglycaemia (Wolever *et al.* 1994; Ceriello *et al.* 2004). However, at the time of data collection (the early 1990s), the GI was not being applied in general clinical practice, and it is unlikely that any individual received advice on low-GI foods. The mean GI and GL of 57 and 134 respectively in the BMES I population are higher than the median GI and GL of >88 000 nurses living in the USA in 1990 (53 and 105 respectively converted from the bread to glucose = 100 scale using the factor 0·7; Holmes *et al.* 2004). The mean GI of the BMES I cohort was lower than that reported of a group of 342 Canadians with diabetes in the early 1990s (60 converted from bread to glucose); however, this group received dietary counselling from a registered dietitian as part of a randomised controlled trial, and estimated nutrient intakes are not likely to be representative of their usual intake (Wolever *et al.* 1994). The GI value for BMES I is very similar to that of a group of 104 children with type 1 diabetes who were randomised to dietary instruction based on either carbohydrate exchanges or low-GI foods (57 *v.* 55 respectively; Gilbertson *et al.* 2001). However, children's data may not be as reliable because underreporting is more common. Moreover, children may have lower-GI diets than adults because of the nature of their food choices (for example, greater consumption of dairy produce and sweet foods) (Gilbertson *et al.* 2003). A recent study of thirty-two overweight free-living Japanese women with a mean age of 52 years estimated the mean GI to be 64 and the mean GL

Table 3. Key macronutrient intake of individuals with diabetes in the Blue Mountains Eye Study compared with recommended targets for optimal diabetes management

(Mean values and ranges)

	Recommended target for individuals with diabetes (European Association for the study of Diabetes; Anonymous, 2000)	Intake of individuals with a history of diabetes (*n* 164)		Percentage of cohort who achieved the recommendation
		Mean	Range	
Protein (% energy)	10–20	20	11–30	51
Total fat (% energy)	25–35	35	17–53	45
Saturated fat (% energy)	<10	13	6–23	21
Carbohydrate (% energy)	45–60	41	17·5–59·5	36
Alcohol (% energy)	<5	1·4	0–32	83
Fibre (g)	≥30	29	7–89	42

Table 4. International comparison of macronutrient intakes of individuals with diabetes compared with recommended targets for optimal diabetes management

	Recommended nutrient intakes for individuals with diabetes	Australia BMES I (*n* 164)	Mediterranean basin (*n* 1895)	USA (*n* 51)	Canada (*n* 342)	Spain DNSGSDA (*n* 30)	UK (*n* 132)	UK (*n* 67)
Energy (kJ)		8350	6328–10 954	9960	7170	7135	6897	7899
Protein (% energy)	10–20	20	17·6–21	17	20	20	21	18
Total fat (% energy)	25–35	35	27·2–40·8	45	34	37	37	40
Saturated fat (% energy)	10	13				12		
Total carbohydrate (% energy)	45–60	41	37·7–53·0	37	45	37	43	40
Alcohol (% energy)	5	1·4	0·3–7·6		2·3	4		1·5
Fibre (g)	30	28·6	19·0–28·6		17·2	15	22	23·4
Reference	Anonymous (2000)	Present study	Thanopoulou *et al.* (2004)	Banini *et al.* (2003)	Wolever *et al.* (1994)	Anonymous (1997)	Eeley *et al.* (1996)	Close *et al.* (1992)

BMES, Blue Mountains Eye Study; DNSGSDA, Diabetes and Nutrition Study Group of the Spanish Diabetes Association.

to be 150 (Amano *et al.* 2004), both higher than that reported for the BMES I cohort.

It is interesting that those with diabetes in BMES I had both a significantly lower GI and GL than participants without diabetes. There are a number of possible reasons. The main sugar added to foods in Australia is sucrose, which has a slightly higher GI (GI = 61, glucose = 100) than the mean population GI of this cohort (Foster-Powell *et al.* 2002). As traditional advice to individuals with diabetes has been to reduce added sugar, this advice may have also helped lower the average GI for the group as a whole, albeit by a small percentage. On the other hand, the main determinant of the lower GL was not the lower GI, but rather the lower total carbohydrate intake, due largely to the reduction in total sugars. As total carbohydrate content has been previously shown to explain 68 % of the variance in GL values (Brand-Miller *et al.* 2003), a greater influence of reduced carbohydrate intake on the GL of individuals with diabetes is not unexpected.

In the UK, Close *et al.* (1992) also showed that individuals with diabetes consumed less sugar and more protein than the non-diabetic population. While other studies (Eeley *et al.* 1996; Banini *et al.* 2003; Thanopoulou *et al.* 2004) have not assessed sugar intakes *per se*, individuals with diabetes were found to consume less carbohydrate in total and more protein than individuals without diabetes. Taken together, these studies suggest that individuals with diabetes substitute protein foods for sugar-containing foods, leading to higher than recommended intakes of protein and lower than optimal carbohydrate intakes (Anonymous, 2000). In the long term, greater intakes of protein may have implications for the development of microvascular complications (Franz, 2002).

In the present study, individuals with diabetes weighed significantly more than those without and had significantly greater BMI (28·1 *v.* 26·0 kg/m^2, respectively). Just over 70 % were classed as overweight (BMI $>$25 kg/m^2) or obese (BMI $>$30 kg/m^2) compared with about 55 % of those without diabetes. This is consistent with the known positive relationship between overweight or obesity and prevalence of type 2 diabetes (Chan *et al.* 1994; Scheen, 2003). The UK Prospective Diabetes Study found that the mean BMI of individuals with type 2 diabetes was 28 kg/m^2 (Eeley *et al.* 1996), almost identical to the BMES I (mean BMI of 28·1 kg/m^2). Despite higher body weight, those with diabetes did not report larger energy consumption; indeed, they appeared to report less. This may reflect either underreporting or a chronic energy intake deficit in order to lose weight. Others have reported that individuals with diabetes find it harder to lose weight and to maintain weight loss (Le Stunff & Bougneres, 1994; Ludwig, 2002; Kopp, 2003).

One of the significant limitations of all studies such as this is the accuracy and reliability of the FFQ. The FFQ was used not only to estimate macronutrient intake but also the GI and GL of the diet. While it was validated in the present study population (Smith *et al.* 1998), FFQ are subject to errors common to these kinds of tools, namely: the reliance on long-term memory, a relatively restricted list of foods, interpretation of frequencies and average serving sizes, and the poor ability of some individuals to estimate and describe their usual food intake. The FFQ was not originally designed to measure differences in the GI of foods, and the GI of certain foods such as breads and cold breakfast cereals is very brand-specific. However, Australia has a more extensive GI database than most other countries (Foster-Powell *et al.* 2002), minimising this potential source of error. While the GI is still controversial, many studies show that postprandial glycaemic profiles can be predicted from a knowledge of the carbohydrate content and the GI of the component foods (Schulze *et al.* 2004; Rizkalla *et al.* 2004; Diaz *et al.* 2005).

While a FFQ was used in both the BMES I and the Mediterranean Basin (Thanopoulou *et al.* 2004) study, diet records were used in other studies. A 3 d diet record was used in the USA (Banini *et al.* 2003) study, Canadian study (Wolever *et al.* 1994) and the UK study by Eeley *et al.* (1996). A 7 d diet record was used in the Spanish study (Diabetes and Nutrition Study Group of the Spanish Diabetes Association; Anonymous,1997) and in the UK study by Close *et al.* (1992). Weighed diet records differ from FFQ in their ability to estimate absolute rather than relative intakes of nutrients, providing a higher level of specificity than FFQ overall (Willett, 1998). Advantages of diet records over FFQ include non-reliance on memory and ability to determine exact amounts of foods eaten (Willett, 1998). However, the process of keeping a diet record may alter an individual's usual intake, and food intake may vary considerably over the course of 1 week, and even more so over 1 year (Willett, 1998). Direct comparison of the results of these studies may therefore be limited by the different sources of error inherent in the different tools used to estimate nutrient intakes.

Since the time of the first BMES examinations in 1992–4, the GI has become increasingly recognised around Australia. Diabetes Australia first recommended the use of healthy low-GI food choices in 1997. Other major diabetes associations around the world including Diabetes UK (Connor *et al.* 2003), the Canadian Diabetes Association (Canadian Diabetes Association Clinical Guidelines Expert Committee, 2003) and most recently, the American Diabetes Association (Sheard *et al.* 2004) now recommend its judicious use in clinical practice. For this reason, it is possible that the BMES II (5-year examinations) and BMES III (10-year examinations) will reveal changes in the mean dietary GI and GL of individuals both with and without diabetes.

Conclusions

We conclude that a representative population of older individuals with diabetes living in Australia in the early to mid-1990s chose a diet that had significantly more protein and significantly less sugar than that chosen by individuals without diabetes. This difference had little impact on the average GI, but it led to a moderate reduction in the average GL. Moreover, it made no difference at all to total and saturated fat intakes. Only a small proportion of individuals with diabetes were able to meet the nutritional recommendations for the optimal management of their condition. This may be due to difficulties in self-selecting diets that meet these recommendations, or to a lack of education and support from suitably qualified health professionals.

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