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1 **Dietary fibre and cardiovascular health: a review of current evidence and policy**

2

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12 **Contributions**

13 CE wrote the first and subsequent drafts.

14

15 **Key words:**

16 Dietary fibre, wholegrain, nutritional epidemiology, behaviour change, nutrition policy

17

18 **Abstract**

19 Dietary fibre is comprised of many different, mainly plant based, compounds that are not
20 fully digested in the human gut. Insoluble fibres include cellulose, hemi-celluloses and lignin
21 and soluble fibres include pectins, beta-glucan and hydro-colloids. In the UK the daily
22 recommended amount has increased to 30g but only 13% of men and 4% of women meet this
23 recommendation. Currently the mean intake for adults is 21g for men and 17g for women.
24 There is a wealth of epidemiological evidence based on systematic reviews of trials and
25 cohorts to support the higher fibre recommendation. This includes evidence of reductions in
26 risk for cardiovascular disease (both heart disease and stroke) and lower risk of type 2
27 diabetes, lower blood pressure, lower LDL cholesterol, as well as some cancers. Beneficial
28 effects of fibre operate via a diverse range of mechanisms throughout the digestive system
29 including the mouth, stomach and small and large intestine; some of which are still not
30 completely understood. The updated recommendation for fibre is a long way from a typical
31 British diet and requires several daily portions of fruit and vegetables and wholegrain foods.
32 Improving dietary fibre intakes will require a variety of actions and policies from
33 stakeholders; however, there is currently more of a focus on reducing sugar than increasing
34 fibre. In order to increase the number of adults meeting the fibre recommendation, social
35 marketing and labelling of high fibre foods are warranted as well as reformulation and wider
36 availability of wholegrain versions of popular foods.

37 **Definition and sources of dietary fibre**

38 Dietary fibre is complex and includes a wide range of plant based compounds that are not
39 fully digested in the human gut. A universally agreed definition was only recently approved
40 in 2009 by the CODEX Alimentarius after nearly 20 years of deliberation⁽¹⁾. The CODEX
41 Alimentarius was founded in 1963 as part of the World Health Organisation Food and
42 Agriculture Organisation (WHO/FAO) and is the international body that sets guidelines for
43 national regulatory authorities. Dietary fibre is defined as “Carbohydrate polymers with 10 or
44 more monomeric units, which are not hydrolysed by the endogenous enzymes in the small
45 intestine of humans”. These polymers are usually naturally occurring in food but also include
46 carbohydrate polymers which have been obtained from food by physical, enzymatic or
47 chemical processes or are synthetic and have been shown to be beneficial to health. One of
48 the main reasons that an agreed definition is needed is to enable international harmonisation
49 for food labelling and food composition tables. In the UK the primary definition of dietary
50 fibre was traditionally the Englyst method which did not include lignin or resistant starch.
51 These components are now included in the approved definition which closely agrees with the
52 AOAC method traditionally used in most countries around the world.

53 Dietary fibre can be classified into different categories with each category having different
54 attributes. The most common method, although not necessarily the most appropriate, is
55 categorisation into four groups based on solubility. These include high molecular weight
56 soluble and insoluble fibres, resistant starches and prebiotics. Details on only the first 2
57 categories are provided here. Insoluble fibres include cellulose, lignin and hemi-celluloses
58 such as Arabinoxylan and Glucomannan. Soluble fibres include pectins, cereal beta-Glucan
59 and hydro-colloids such as gums (e.g.guar or mannan) and mucilages (including Psyllium).
60 These are found in varying amounts in different foods.

61 Fibre sources are generally plant based foods namely cereals and potatoes, beans and pulses
62 and fruits and vegetables; all foods that are encouraged as depicted on the UK Eat Well
63 Guide⁽²⁾. Approximately half of all dietary fibre comes from cereals and about a third from
64 fruits and vegetables⁽³⁾. Grains provide mainly cellulose and hemi-cellulose, fruits and
65 vegetables cellulose, hemi-cellulose and pectin, and legumes, hemi-cellulose, pectin and
66 resistant starches. Sources of fibre have changed over the last few decades in the UK.
67 According to data from 1940 to 2000 published by DEFRA, consumption of fruit, pasta and
68 rice has increased but intakes of bread, potatoes and vegetables have decreased⁽⁴⁾ inevitably

69 leading to changes in the mix of different types of fibre in the diet. Historically in hunter-
 70 gatherer times the main sources were fruits and vegetables but not cereals resulting in a
 71 dramatic shift from soluble to insoluble fibre. Common types of dietary fibre currently
 72 consumed in the UK and their main sources are provided in table 1.

73 **Table 1: Food sources of common types of dietary fibre in the UK**

Fibre type	Definition	Food sources
Cellulose	Polysaccharides of glucose	Main component of cell walls of most plants
Hemi-cellulose	Polysaccharides of other sugars	Cereal grains are main source
Lignin	Woody fibre	In outer layers of cell grains
gums, mucilages	hydrocolloids	In endosperm of grain, legumes, nuts and seeds
Pectins	Polysaccharides containing galacturonic acid	In cell walls and intracellular tissue of fruits, veg and legumes
Beta-glucans	Branched structure of glucose polymers	Cell walls in oats and barley
Resistant starch	Starch not digested in small intestine	Legumes, unripe bananas, potatoes (stored)

74

75 **Actual and recommended intakes of dietary fibre**

76 Intakes of dietary fibre have varied over time in the UK and also vary greatly around the
 77 world. Many countries have high intakes of fibre but in general high income countries tend to
 78 have lower than optimal intakes⁽⁵⁾. Recommendations from WHO state that a healthy diet
 79 should contain more than 25g of dietary fibre⁽¹⁾ and most European countries recommend
 80 between 25 and 30 of fibre daily⁽⁵⁾. Some countries have different recommendations for men
 81 and women, e.g. Australia and New Zealand recommend 25g or more for women and 30g or
 82 more for men⁽⁵⁾. Many countries base recommendations at a level that equates to 3-4g per
 83 MJ which is the reason why men, who generally have higher energy intakes, sometimes have

84 a higher fibre recommendation than women⁽⁵⁾. In the UK the reference nutrient intake (RNI)
 85 for adults is 30g daily based on the AOAC method (which replaced the non-starch
 86 polysaccharides method in 2002). The new recommendations released in 2015 were based on
 87 the large review of carbohydrates and health commissioned by the Scientific Advisory
 88 Committee on Nutrition (SACN) in the UK and increased the fibre recommendation by
 89 approximately 25% from 24g (18g of NSP) to 30g. Based on the latest available data from
 90 the British National Diet and Nutrition Survey (NDNS) years 7-8, very few adults in the UK
 91 meet this recommendation and actual intakes are about two thirds of recommended levels.
 92 Mean daily intakes for men and women are 21g and 17g respectively with only 13% of men
 93 and 4% of women consuming 30g or more dietary fibre daily⁽⁶⁾. In order to meet the
 94 recommended intake it is necessary to eat several portions of fruit, veg, cereals and legumes
 95 daily. Some countries such as the US have even less success, with actual intakes at half the
 96 recommended intakes. Fibre sources as well as recommendations vary by country. Northern
 97 European countries including Germany, Sweden and Denmark (but not the UK) typically
 98 have high intakes of cereals such as wholemeal bread while Southern European countries
 99 typically consume more fruit⁽⁷⁾. In the UK, vegetable consumption is generally higher than
 100 fruit. From the same analysis legume intake was low in all the European countries included
 101 except for Spain. Table 2 provides information on fibre content per 100g and by portion of
 102 common foods that are major contributors to fibre intake in the UK.

103 In the UK there is currently no recommended intake for wholegrain foods. Median intake of
 104 wholegrain foods such as wholemeal bread is 20g per day but 20% don't consume any
 105 wholegrain foods. Given the health benefits there is evidence that this would be beneficial in
 106 the UK and it could be based on recommendations that currently exist in other countries. For
 107 example, the US Dietary guidelines for Americans recommend a minimum of 3 daily
 108 servings of wholegrain foods. One serving is the equivalent to 1 slice of bread or 1 small
 109 bowl of cereal or half a cup of brown rice⁽⁸⁾.

110 **Table 2: contribution by weight and portion of foods commonly contributing to fibre**
 111 **intake⁽⁹⁾**

Food	AOAC fibre per 100g	Portion (g)	AOAC fibre per portion (g)
White bread	2	35	0.7
Brown bread	4.5	35	1.6

Wholemeal bread	7.4	35	2.6
Jacket potato	2.4	200	4.8
Apple	2.0	100	2
Porridge oats	8.2	40	3
Banana	1.9	150	3
Baked beans	4.2	175	7.0
carrots	3.1	80	2.5
cabbage	2.0	80	1.6

112

113 **Mechanisms of fibre in the gut**

114 Fibre has an impact on health via many different mechanisms due to its interaction in many
115 parts of the digestive system including the mouth, stomach, small intestine and large intestine
116 (colon). The three most commonly documented health benefits include 1) colonic function
117 with reductions in transit time, increase in stool bulk and colonic fermentation (production of
118 short chain fatty acids; 2) reductions in blood cholesterol and 3) reductions in blood
119 glucose⁽⁵⁾. Additional published research has reported other mechanisms including improved
120 gut microbiota⁽¹⁰⁾ and reduced blood pressure⁽¹¹⁾. Brief descriptions of these are given with
121 references that provide further details if required. Reduced transit time and increased stool
122 bulk is mainly effected by insoluble fibres such as cellulose and hemicellulose as well as
123 psyllium. Diets high in legumes and wholegrain are particularly effective in reducing gut
124 transit time. The beneficial effects of fibre on cholesterol are well documented. Research into
125 the effect of beta-glucans is the most extensive and a minimum of 3g dose is recommended
126 for a health benefit ⁽¹²⁾. In the small intestine the beta-glucans increase viscosity and reduce
127 the reabsorption of bile acids which in turn reduce the levels of circulating cholesterol.
128 Pectin, psyllium and guar gum have also been reported to reduce LDL cholesterol albeit with
129 smaller reductions in cholesterol ⁽¹²⁾. Glucose and insulin responses are also influenced
130 mainly by soluble fibres such as beta-glucans in a similar way. In the small intestine, soluble
131 fibre entraps sugars. The increased viscosity of soluble fibre forms a barrier and leads to
132 slower glucose absorption and inhibits amylase leading to reduced starch digestion and
133 improved insulin sensitivity. Some fibres increase satiety which may lead to weight loss. For
134 example, soluble fibres mix with partially digested food in the stomach which slows down
135 stomach emptying. Beta-Glucans may also release appetite suppressants such as CCK that
136 could play a role in increased satiety. There is evidence that some types of soluble fibre lower

137 blood pressure. This may occur through the same pathway as the reduction in absorption of
138 sugars; as insulinaemia can lead to endothelial dysfunction and hypertension^(11; 13). It may
139 also be related to satiety and weight loss which are highly correlated to blood pressure.
140 Higher fibre consumption may reduce inflammatory markers such as C Reactive protein (and
141 increase in anti-inflammatory factors)⁽¹⁴⁾ although the evidence reports that quite large
142 increases are needed to reduce CRP to a useful degree. Although the focus of this paper is
143 cardioalvascular disease, it is important to mention that fermentation by faecal flora to short
144 chain fatty acids (SCFA) in turn dilutes carcinogens, the mechanism most likely to be
145 involved in reducing the risk of cancer of the colon⁽¹⁵⁾ and some fibres may affect oestrogen
146 metabolism inhibiting reabsorption and synthesis that could explain the link between dietary
147 fibre and reductions in breast cancer risk⁽¹⁶⁾. Less is known about the role of different types of
148 fibre on the gut microbiota, of which bacteria are the main component. Suggested hypotheses
149 include increasing favourable bacteria and modulating gene expression^(12; 17).

150 **Epidemiological evidence on dietary fibre and health**

151 Approximately a third of all deaths in the UK are due to cardiovascular disease (CVD)⁽¹⁸⁾ in
152 addition to considerable levels of morbidity. Potentially modifiable markers of higher risk for
153 CVD include type 2 diabetes mellitus (type 2 DM) and its precursors (high blood sugars and
154 low insulin sensitivity), obesity and high blood pressure. This review focuses on the links
155 between fibres and the risk of CVD as well as risk factors. The highest quality study design
156 that minimises potential bias is a randomised controlled trial, although this isn't always
157 possible to conduct. Systematic reviews of trials and prospective cohorts are included here as
158 evidence wherever possible.

159 The evidence available reports on different types of fibre including total fibre, wholegrain
160 and beta-glucans. The evidence from total fibre is reported first for each risk factor if
161 available, followed by any evidence available on specific fibre types. A systematic review of
162 prospective cohorts investigating the risk of CVD with fibre consumption reported a
163 reduction in CVD risk of 9% (95% CI 6-12%) with 7g higher intake of total fibre⁽¹⁹⁾. The risk
164 ratio for all of the 10 individual studies was consistently lower than 1 indicating a strong and
165 consistent association. Further analysis of the data using cubic splines indicated that the
166 relative risk was over 1 when total fibre was lower than 18g per day. Increasing fibre well
167 above 30g further reduced the risk ratio but the 95%CI widened due to the data being scarce
168 at this level of fibre intake. The pooled estimates for different types and sources of fibre in

169 the same review were all consistently below 1 for soluble fibre, insoluble fibre, fibre from
170 cereals, fibre from fruit and fibre from vegetables but the risk ratio reductions were not all
171 statistically significant. The number of studies was greatly reduced to 3-5 studies for each
172 fibre type which may mean that power was substantially reduced or it may indicate that not
173 all types of fibre are protective to the same extent. Results for coronary heart disease (CHD
174 are similar⁽¹⁹⁾. A separate review on associations between fibre consumption and first
175 stroke⁽²⁰⁾ also indicate that total fibre is protective although it is not clear whether certain
176 types of fibre are driving this relationship.

177 There is also evidence that total fibre reduces the risk of type 2 diabetes by 6% per 7g of
178 fibre⁽²¹⁾. Wholegrain foods may be particularly protective for type 2 diabetes. The pooled
179 estimate indicates that risk of type 2 diabetes is reduced by 32% (95% CI 19-42%) per three
180 servings of wholegrain. If one serving of wholegrain reduces risk by 1/3 of this amount, each
181 slice of wholemeal bread (equivalent to one serving) reduces risk by 10%⁽²²⁾. Certain types of
182 fibre may also have an effect on blood pressure in healthy individuals that are not
183 hypertensive. A systematic review of trials investigating the effects of seven different fibre
184 types found that diets rich in beta-glucans, with a median difference of 4g of beta-glucan
185 between control and intervention groups, reduced blood pressure by 2.9mmol Hg (95% CI
186 0.9 to 4.9) for SBP and by 1.5mm Hg (95% CI 0.2 to 2.7) for DBP. The effects may be
187 stronger for individuals who are already hypertensive⁽¹³⁾. Beta-glucans also appear to play a
188 role in reducing LDL cholesterol in healthy and hypercholesteraemic individuals. A review of
189 trials reported a reduction of 0.15mmol (95%CI 0.09-0.21) in unclassified participants and a
190 reduction of 0.20mmol (95% CI 0.13 – 0.26) in participants with hypercholesterolaemia.
191 These trials reported a similar median difference of 3.5g of beta glucans. This is the
192 equivalent to a bowl of oat based cereal such as porridge combined with an oat containing
193 snack such as a cereal bar.

194 **Increasing consumption of fibre**

195 There is a general consensus that a healthy diet is high in plant foods such as fruits and
196 vegetables and wholegrain foods with moderate amounts of protein and dairy foods and a
197 small amount of foods and drinks high in fats and sugars but few populations are anywhere
198 close to an optimal diet. A large review of the global effect of diet reported that non-optimal
199 intakes of whole grains, fruits and sodium accounted for half of deaths and two thirds of
200 disability adjusted life years (DALYs) related to diet⁽²³⁾. A focus on policies related to fibre

201 and whole grains is therefore highly recommended. The UK, compared to many European
202 countries, has low intakes of fibre from cereals although fibre intake from vegetables is
203 higher than average.

204 Changing dietary behaviour is difficult and complex. Despite many people being aware of
205 what constitutes a healthy diet, diet quality is generally poor in the UK⁽²⁴⁾. This is
206 particularly true of young people and British adolescents are reported to have some of the
207 worst diets in Europe⁽²⁵⁾. The British Nutrition Foundation (BNF) has designed a week's
208 menu of meals and snacks that meet the SACN recommendations of 5% free sugars and 30g
209 of fibre. It is a long way from what most people normally eat consisting of mainly high fibre
210 cereal foods with few puddings, cakes, biscuits, confectionery or sugary drinks. Public Health
211 England has initiated a range of strategies to reduce free sugars, particularly sugary drinks
212 since the recommendations were updated in 2015. The sugar reduction plan incorporates the
213 existing childhood obesity plan and the calorie reduction plan⁽²⁶⁾, both of which are in the
214 process of being evaluated with the first year progress report for sugar reduction published in
215 2018⁽²⁷⁾ and the second year progress report due in 2019. However, less attention has been
216 paid to increasing fibre since the recommendations were introduced in 2015. It is not clear
217 whether the priority areas identified by PHE for reducing free sugars⁽²⁸⁾ will have any impact
218 on fibre consumption. One reason for less focus on fibre could be the lack of any food based
219 guidelines. Some countries, for example the US have a wholegrain recommendation of 3
220 portions of wholegrain foods per day. According to the dietary guidelines for Americans, at
221 least half of grains should come from whole grains⁽²⁹⁾. One portion is one slice of wholemeal
222 bread, 1 tablespoon oats or 3 tablespoons of wholegrain cereal. The definition of what can be
223 included as a wholegrain food is not easily defined and has been formally discussed by a
224 roundtable of European and American experts in 2012⁽³⁰⁾. The expert panel recommended
225 that a food providing at least 8 g of whole grains/30-g serving be defined as a whole-grain
226 food. This is a lower proportion (around 27% wholegrain) than previously put forward in the
227 UK where at least 51% (equivalent to about 16g per portion) was recommended⁽³¹⁾. Seal et al
228 strongly encourage a unified global approach⁽³²⁾ to enable manufacturers and health
229 promoters to provide clear and consistent advice. For now there is no immediate plan to
230 introduce a recommendation for daily consumption of whole grain foods in the UK.

231 Rather than focussing on fibre alone it may be the case that fibre, or certain types of fibre, are
232 contributing to an overall healthy dietary pattern that is more strongly associated with health
233 benefits than fibre alone. Assessing the glycaemic index and glycaemic load are ways of

234 measuring the burden on the glycaemic response after eating and are affected by soluble fibre
235 in particular. However, the associations with metabolic disease do not appear to be stronger
236 with measures of glycaemic index/load than with fibre. For example, the association of beta-
237 glucans and blood pressure were broadly similar to the association of glycaemic index with
238 blood pressure⁽³³⁾ and heart disease risk⁽³⁴⁾ when comparing pooled estimates of meta-
239 analyses. Perhaps this is the case because sources of fibre are also sources of carbohydrates
240 which by definition increase the glycaemic response. It is beneficial to ensure that important
241 sources of fibre have as low a glycaemic response as possible and this may be influenced by
242 different factors. It may be possible to improve the glycaemic response for different cereals.
243 For example, oat flakes give a much lower secretion of glucose dependent insulinotropic
244 peptide (GIP) than oat flour⁽³⁵⁾ providing a rationale for processing and milling oats and other
245 cereals to give as large a surface area as possible. Other measures of diet quality are the
246 Mediterranean diet and the Nordic diet. These are both high in fibre and both associated with
247 positive health outcomes including blood lipids, blood pressure and insulin sensitivity^{(36; 37;}
248 ³⁸⁾.

249 Currently in the UK the recommendation to increase fibre is based on total fibre (in addition
250 to the 5 a day fruit and vegetable policy). Policy areas that could improve fibre intake include
251 improved labelling and education, social marketing based on fibre, increased marketing of
252 wholegrain foods and fruits and vegetables and increased availability of wholegrain foods
253 and fruits and vegetables.

254 The agreement to use AOAC for food labelling in the UK helped to provide clarity and
255 consistency and enable comparisons with food packaging produced in other countries.
256 European Commission rules state that foods containing at least 3g of fibre/100g can be
257 labelled as a source of fibre and foods containing at least 6g of fibre/100g can be labelled as
258 high in fibre⁽³⁹⁾. However, information on the fibre content of foods is not as accessible as
259 information on other nutrients such as saturated fat and sugar. There is usually nothing on the
260 front of pack food label to indicate how much fibre is in the food. The front of pack traffic
261 light label includes details on energy, total fat, saturated fat, total sugar and salt. Given the
262 wealth of evidence on the health benefits of fibre, wholegrain and fruits and vegetables
263 updates of the traffic light system could consider the inclusion of fibre. This would
264 necessitate losing one of the existing nutrients. On balance, the existing evidence on
265 associations with health is weakest for total fat as high intakes of poly-unsaturated fat such as
266 olive oil as part of the Mediterranean diet are associated with positive health outcomes⁽⁴⁰⁾.

267 Social marketing as part of the Change 4 Life Campaign also has a role to play in raising
268 awareness of the benefits of high fibre diets. To date, there is little information on fibre on the
269 website or in the advertising campaign⁽⁴¹⁾. Providing consistent information in different
270 formats to raise awareness and change attitudes is known to be effective in improving public
271 health behaviours⁽⁴²⁾. Evaluations should always be carried out to ensure that interventions do
272 not widen inequalities, a common problem with interventions relying on interest in health,
273 levels of education and ability to pay⁽⁴³⁾.

274 Reformulation of foods has successfully improved the quality of food sold in the UK in terms
275 of salt⁽⁴⁴⁾ and trans fats⁽⁴⁵⁾. A particular marker of success is the reduction in inequalities in
276 trans fats consumption in the UK⁽⁴⁵⁾. The new recommendations for fibre have motivated and
277 challenged the food industry to improve foods in terms of fibre content in an attempt to
278 reduce the 12g gap between current and recommended intakes. The Institute of Grocery
279 Distribution (IGD) have produced a free guide for nutritionists and food scientists working in
280 industry to help increase fibre content in a range of foods⁽⁴⁶⁾. Their fibre working group
281 recommends holistic reformulation so that the whole food is taken into account not just
282 specific nutrients to ensure that improvement of one nutrient does not come at the detriment
283 of another – e.g. free sugars or energy. Inevitably some foods are high in both types of
284 nutrients. Flapjack is an obvious example as it is high in both fibre and saturated fats and
285 sugars. Are we able to say that the positive health benefits of the fibre outweigh the negative
286 effects of the saturated fats and sugars? This is very difficult to achieve at the individual food
287 level. IGD encourages reformulation to increase fibre for a number of reasons not solely due
288 to the recommendations. As a result of public consultation they recommend higher fibre for
289 health benefits, to enable health claims to be made, to respond to consumer demand and to be
290 more in line with the values of certain customer groups. The growth in avocados and chia
291 seeds are cited as examples of high growth areas in the interactive guide. Currently,
292 availability of wholegrain versions of popular flour based foods such as pastries and cakes,
293 either in supermarkets or outside the home in cafes is very low and they are rarely available.
294 This may be because despite recipes using wholemeal flour improving texture and taste in
295 baked products, wholegrain foods have a reputation for being dry and boring⁽⁴⁷⁾. More
296 positive marketing is needed to encourage a cultural shift in attitudes. A comprehensive range
297 of strategies are needed to encourage people to consume healthier diets not just a focus on
298 negative aspects of diets such as fats and sugars⁽²³⁾ Introducing a wide range of different
299 policies and actions also has the added benefit of reducing the risk of widening inequalities in

300 diet and health⁽⁴⁸⁾. The shift in focus by public health nutritionists to reduce sugary foods and
301 drinks as well as fats rather than encouraging healthier foods may have come at the expense
302 of policies promoting higher intakes of healthy foods including those rich in fibre.

303 **Conclusions**

304 In summary, high intakes of fibre are associated with a wide range of health outcomes
305 including type 2 diabetes and cardio-vascular health. However, despite increases in the
306 recommended values for fibre released in 2015 most of the UK population consume
307 considerably less than the 30g of fibre recommended daily. Action is needed from a range of
308 stakeholders including the food industry, supermarkets, restaurants, public health nutritionists
309 and government to ensure improvements in information and labelling, availability and
310 popularity of high fibre diets. Furthermore, evaluation of interventions and programmes at
311 regional or national level are needed to ensure the needs of different groups are met but
312 particularly to ensure that interventions do not widen inequalities in diet and health. New
313 food based policies such as recommended daily portions of wholegrain foods could be
314 considered in the future and are likely to improve population health.

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