

## **Evaluating an intervention to increase cereal fiber intake in children: a randomized controlled feasibility trial.**

\*Angela S Donin<sup>1</sup>, Claire M Nightingale<sup>1</sup>, Michael R Perkin<sup>1</sup>, Michael Ussher<sup>1,2</sup>, Susan A Jebb<sup>3</sup>, Rikard Landberg<sup>4</sup>, Paul Welsh<sup>5</sup>, Naveed Sattar<sup>5</sup>, Peymane Adab<sup>6</sup>, Chris G Owen<sup>1</sup>, Alicja R Rudnicka<sup>1</sup>, Derek G Cook<sup>1</sup>, Peter H Whincup<sup>1</sup>

Affiliations:

<sup>1</sup> Population Health Research Institute, St George's, University of London, UK, SW17 0RE

<sup>2</sup> Institute for Social Marketing and Health, University of Stirling, UK FK9 4LJ

<sup>3</sup> Nuffield Department of Primary Care Health Sciences, Medical Sciences Division, University of Oxford, UK OX2 6GG

<sup>4</sup> Division of Food and Nutrition Science, Chalmers University of Technology, Gothenburg, Sweden.

<sup>5</sup> Institute of Cardiovascular & Medical Sciences, University of Glasgow, UK, G12 8TA

<sup>6</sup> Institute of Applied Health Research, University of Birmingham, UK, B15 2TT

\*Corresponding author:

Angela S Donin, Population Health Research Institute, St George's, University of London, UK, SW17 0RE. Tel: 0208 725 5557. Email: [adonin@sgul.ac.uk](mailto:adonin@sgul.ac.uk)

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Abbreviations: AR – Plasma Alkylresorcinol

BCT – behaviour change techniques

HOMA – Homeostasis Model Assessment

IQR – Interquartile range

95% CI – 95% confidence interval

## 1 *Abstract*

2 Background: Observational studies have shown that higher cereal fiber intake is associated  
3 with reduced type 2 diabetes risk. However, it remains uncertain whether this association is  
4 causal.

5 Objective: This study evaluated the feasibility of an intervention to increase cereal fiber  
6 intake in children using breakfast cereals.

7 Methods: The study was a two-arm parallel group randomized controlled trial in 9-10-year-  
8 old children, who received free supplies of high fiber breakfast cereals (>3.5 gram/portion) or  
9 low fiber breakfast cereals (<1.0 gram/portion) to eat daily for one month with behavioral  
10 support to promote adherence. Children provided baseline and one-month fasting blood  
11 samples, physical measurements and 24-hour dietary recalls. The primary outcome was the  
12 group difference in change in plasma total alkylresorcinol (AR) concentration; secondary  
13 outcomes were group differences in nutrient intakes and adiposity indices. Analyses  
14 (complete case and multiple imputation) were conducted by regressing final AR on baseline  
15 AR in models adjusted for sex, ethnicity, age and school (random effect).

16 Results: 272 children were randomized (137 low fiber, 135 high fiber) and 193 (71%)  
17 provided fasting blood samples at baseline and follow-up. Among randomized participants,  
18 median (IQR) baseline AR was 43.1 nmol/L (24.6, 85.5 nmol/L) and median (IQR) cereal  
19 fiber intake was 4.5g (2.7, 6.4g), 87% reported consuming the cereal on most or all days.  
20 Compared to changes in the low fiber group, the high-fiber group had greater increases in AR  
21 (40.7 nmol/L; 95% CI 21.7, 59.8 nmol/L,  $p<0.0001$ ) and in reported cereal fiber intake  
22 (2.9g/d; 95% CI 2.0, 3.7g,  $p<0.0001$ ). There were no appreciable differences in other  
23 secondary outcomes.

24 Conclusions: We have developed a simple and acceptable nutritional intervention which  
25 increases markers of daily cereal fiber intake in children. This intervention could be used to  
26 test whether increases in cereal fiber intake in children might reduce insulin resistance.

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28 Key words: Cereal fiber, children, type 2 diabetes risk, feasibility trial, dietary intervention.

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## 44 *Introduction*

45 Foods high in dietary fiber have long been considered an important component of human  
46 diets and beneficial for good health, particularly gastrointestinal health. However since the  
47 mid-20<sup>th</sup> century observations that societies with very high fiber diets had very low chronic  
48 disease risk (1) created interest in the possibility that dietary fiber may have wider health  
49 protection benefits. Over the past few decades, large prospective observational studies have  
50 reported that adults with high fiber diets have lower risks of a range of chronic diseases  
51 including cardiovascular disease, obesity, some cancers and type 2 diabetes (2-6), in strongly  
52 graded associations (7). In common with many other Western societies, intake of fiber in the  
53 UK is well below recommended levels (30g fiber/day in adults, 20g/day in children).  
54 National surveys have shown that adults need to increase their fiber intakes by around 50%  
55 for men and 75% for women to meet recommendations for good health, in children with  
56 lower recommendations they would need to increase intakes by over a third, with greater  
57 increases needed in children from lower socioeconomic groups (8). A population-wide  
58 intervention to increase dietary fiber intake could therefore have substantial public health  
59 benefits.

60 Recent systematic reviews and large-scale meta-analyses have suggested that for reducing  
61 risks of type 2 diabetes higher intakes of cereal fiber may be particularly important compared  
62 with fiber from fruit or vegetables (7, 9, 10). However, compelling experimental evidence of  
63 a causal relationship between cereal fiber and type 2 diabetes is limited (11). Moreover,  
64 inconsistent definitions, doses and durations have made reviewing the available evidence  
65 problematic (12). Trials which have focused specifically on increasing fiber intakes to reduce  
66 diabetes risk have tended to be small with limited statistical power and often lacking  
67 objective data on adherence (13, 14). In contrast, large diabetes prevention trials have often

68 aimed to change multiple aspects of the diet and other health behaviors to achieve the greatest  
69 potential reduction in disease risk (15, 16), making it difficult to examine the causal role of  
70 individual dietary components. This limitation in the literature has been noted by several  
71 large-scale systematic reviews (7, 17). Well designed, large scale trials are urgently needed  
72 to robustly test the impact of cereal fiber on the risks of type 2 diabetes and its precursors  
73 (18). Before embarking on such a study, it is essential to develop interventions which are  
74 well tolerated and which lead to appreciable increases in cereal fiber intake.

75 We have previously shown that children who consume high fiber breakfast cereals have  
76 lower insulin resistance (assessed using fasting insulin and Homeostasis Model Assessment  
77 [HOMA]) than children who ate a low fiber breakfast (19), suggesting that the association  
78 between cereal fiber and emerging type 2 diabetes risk may be apparent in childhood.  
79 Improving diet quality in children offers the potential to establish healthy dietary habits  
80 which may persist into later life (20). However, there is currently little evidence in children  
81 on the effects of increasing cereal fiber intake on emerging type 2 diabetes risk. We therefore  
82 developed and evaluated a dietary intervention aiming to increase cereal fiber intake over a  
83 one-month period in 9-10-year-old children. Measuring dietary fiber intake is challenging;  
84 we therefore used a biomarker of whole-wheat fiber intake (fasting plasma total  
85 alkylresorcinol [AR]) to test whether the intervention had been successful in its primary aim  
86 to bring about a sustained change in dietary cereal fiber intake. Dietary recalls were collected  
87 to examine any further changes in dietary intakes and biological markers were included to  
88 estimate secondary effects of dietary change (body composition and type 2 diabetes risk  
89 markers, e.g. insulin resistance). If shown to be effective, such an intervention could be used  
90 in future studies to examine the effect of increasing cereal fiber intake on insulin resistance  
91 and glycaemic control.

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## 93 *Subjects and Methods*

### 94 Study overview

95 The CeReal nUtrition for Child Health (CRUNCH) study was a two-armed parallel group  
96 randomized controlled feasibility trial investigating whether providing a free supply of high  
97 fiber breakfast cereal (high fiber group) to children currently consuming a low fiber breakfast  
98 cereal, would increase cereal fiber intake over a one-month period. As a feasibility trial for a  
99 larger full-scale trial, the one-month duration of the trial was chosen to represent a sustained  
100 dietary change of sufficient duration to bring about a change in metabolic outcomes such as  
101 fasting insulin and insulin resistance (21). The comparison group (low fiber group) were also  
102 given a free supply of breakfast cereal but which had a low fiber content. The study was  
103 based on use of commercially available high-fiber and low-fiber cereals, widely available  
104 from UK supermarkets (see Supplementary Table 1 for details of cereals and their fiber  
105 contents). All participants received support and encouragement based on behavior change  
106 techniques (BCTs), detailed below. Ethical approval was granted by the St George's  
107 University Ethics Committee (SGREC17.0007). Written, informed parental consent was  
108 obtained separately for the initial assessments which included a question on child allergies  
109 (detailed below) and for the feasibility trial; child assent was also obtained for all participants  
110 at entry to the study.

### 111 Participants and initial procedures

112 A total of 23 London Primary schools agreed to take part in the study (70% response rate)  
113 between September 2017 and June 2018. All Year 5 pupils in those schools (aged 9-10  
114 years) were invited to take part in initial eligibility assessments including a brief  
115 questionnaire on their current breakfast habits (including the name of their current breakfast  
116 cereal) and a taste test, which included all the breakfast cereals (both low and high fiber) that

117 would be offered in the feasibility trial. They were also asked about parental and  
118 grandparental place of birth, used to define child ethnicity. Participants were asked to rate  
119 the palatability of each cereal they tasted on a five-level Likert scale, with the following  
120 anchors; awful, not good, alright, good, brilliant. Data from these initial assessments were  
121 used to identify children eligible for the trial. Inclusion criteria were: currently eating a  
122 breakfast cereal with a low fiber content (<1-gram cereal fiber per portion), scoring at least  
123 one of the high fiber and one of the low fiber cereals in the highest two Likert scale  
124 categories and no relevant food allergies. This was to ensure that trial participants would be  
125 given breakfast cereals that they had previously tasted and found to be palatable. Children  
126 with diabetes were excluded from participation. Eligible children were given a briefing  
127 session about the trial by a member of the research team and were then given invitation letters  
128 and consent forms for the feasibility trial to take home to their parents/carers.

#### 129 Randomization and interventions

130 After baseline assessment, eligible participants consenting to take part in the trial were  
131 individually randomized to either receive a one-month free supply of high fiber breakfast  
132 cereals (>3.5 grams fiber per portion) or a one-month free supply of low fiber breakfast  
133 cereals (<1 gram of fiber per portion). Randomization was carried out using the King's  
134 Clinical Trials Unit (KCTU) online randomization service, stratified by school and using a  
135 block size of two to maintain balanced randomization within schools. The study co-  
136 ordinator (not blinded) implemented the randomization on the same day by preparing a two-  
137 week supply of the high or low fiber cereal preferred by each child in the taste test in plain  
138 packaging. This was given out to each child at school ready to be taken home; children were  
139 not informed which cereal group they had been allocated to.

#### 140 Intervention Procedures



141 Participants in both the high fiber and low fiber groups were seen by the trial co-ordinator on  
142 the day of baseline assessments, to provide a supply of the allocated cereal and to implement  
143 behavioral intervention procedures underpinned by the Social Cognitive Theory of behavior  
144 change (22) which were coherent with standard BCT taxonomy (23) and were designed to  
145 encourage daily breakfast cereal consumption (Supplementary Table 2).

146 The participants were given a 'Participant Pack' at the end of the school day which included;  
147 a two-week supply of their allocated cereal, a breakfast diary, a wall chart and stickers (to  
148 chart their progress), pens, pencils, fridge magnets and badges. These items were used to  
149 provide reminders for the children to increase their adherence and engagement with the study.  
150 Participating children were asked to eat the cereal provided for them every day for one month  
151 and to record in their breakfast diary what they ate for breakfast, including non-allocated  
152 items. They were given information on how to contact the research team, including via a  
153 study website ([www.crunch.sgul.ac.uk](http://www.crunch.sgul.ac.uk)) which had a message box they could use. The trial  
154 coordinator visited each school after one week and ran a quiz about breakfast and general  
155 nutrition, to keep the participants interested in and engaged with the study. During this visit  
156 participants were asked whether the allocated cereal was still acceptable and the supply  
157 adequate; additional or replacement cereals were provided where needed. A further two-  
158 week supply of cereal was delivered to the children (via the primary school) half way through  
159 the trial to take home.

#### 160 Outcome measures

161 Assessments were made at baseline and after one month by research outcome assessors, who  
162 were blind to group allocation. On each occasion, each child was asked to provide a blood  
163 sample taken after an overnight fast and was asked about the last time of eating and drinking;  
164 s/he was then provided with breakfast. Measurements of height, weight and body fatness

165 (using a Tanita body composition analyser BC-418 MA Tanita Inc. Tokyo, Japan) were  
166 made, followed by a 24 hour recall dietary assessment using the Intake24 software  
167 programme ([www.intake24.co.uk](http://www.intake24.co.uk)). On the one month visit, children were also given a short  
168 questionnaire which included a question asking how often they had eaten the breakfast cereal,  
169 with the following four options; every day, most days, some days and never/hardly ever, and  
170 if they had enjoyed taking part with the following five options: I did not enjoy it at all, I did  
171 not really enjoy it, it was alright, I enjoyed taking part, I really enjoyed it.

172

173 The primary outcome was change in total plasma alkylresorcinol (AR) concentration (which  
174 is the sum of C17:0, C19:0, C21:0, C23:0 and C25:0 homologues), a biomarker of whole  
175 grain wheat and rye intakes, measured from fasting blood samples taken at baseline and at  
176 follow-up. Secondary outcomes included change in cereal fiber intakes measured through  
177 self-reported 24 hour recalls and changes in dietary intakes of total energy, carbohydrates, fat  
178 and protein intakes, body weight and body composition. Fasting measurements of plasma  
179 insulin, glucose and blood lipids were made to inform the design of potential future outcome  
180 trials. Participants were defined as fasting if they reported consuming nothing other than  
181 water on the morning of assessment and had a plasma insulin concentration of less than 25  
182 mU/L.

183 Laboratory analysis: Blood samples were centrifuged and aliquoted within 6 hours of  
184 collection; aliquots were then deep frozen at -70°C and transferred to central laboratories for  
185 measurement within 12 months of collection. Plasma total AR was measured using a LC-  
186 MS/MS method as described by Ross et al (24). Both baseline and follow-up samples from  
187 each child were analyzed in the same batch. Intra- and inter batch coefficient of variation  
188 were both < 10%. Plasma total and HDL-cholesterol and glucose were measured using an  
189 automated analyzer (c311, Roche Diagnostics UK); HbA1c was measured in whole blood

190 using the same analyser. Plasma insulin was measured with an automated immunoassay  
191 method (411, Roche Diagnostics UK), which does not cross-react with proinsulin.

### 192 Study size and Statistical analysis

193 We estimated 100 participants with complete data in each group were required to have 90%  
194 power at the 1% significance level, to detect a difference of 0.7 SD in AR level at the end of  
195 the trial between the high fiber and low fiber groups. We over-recruited by 35% to allow for  
196 withdrawals and for non-adherence with the requirement for fasting.

197 All analyses were carried out using STATA/SE software (Stata/SE 14 for Windows;  
198 StataCorp LP, College Station, TX, USA). Multilevel linear regression models were fitted  
199 using the *mixed* procedure to examine the effect of the high fiber breakfast cereal intervention  
200 on levels of fasting AR and secondary outcomes compared to controls who received low fiber  
201 breakfast cereal, and Wald's test examined statistical significance. Fasting AR at follow-up  
202 was regressed on fasting AR at baseline and intervention group, to estimate change in AR  
203 between intervention groups efficiently while allowing for regression to the mean; school was  
204 adjusted for as a random effect in all analyses. The effect of further adjustment for  
205 participant characteristics including sex, age (quartiles) and ethnic group (white European,  
206 black African origin, South Asian and mixed/other) (all fitted as fixed effects) was also  
207 examined. The same approach was used for secondary outcomes (cereal fiber intake, total  
208 energy intake, carbohydrate, protein and fat intakes, body weight, fat mass and fat mass  
209 percentage).

210 The primary analysis was a complete case analysis based on all children randomized with  
211 data on the primary outcome (fasting plasma AR) both at baseline and follow-up. A  
212 sensitivity analysis (effectively an intention to treat analysis) was carried out for the primary  
213 outcome by examining the impact of missing fasting plasma AR data at baseline (n=8) or

214 follow-up (n=59), using multiple imputation methods with chained equations (*mi impute*)  
215 using 40 simulations; 12 subjects with AR missing at both baseline and follow-up were  
216 excluded. Predictors included in the multiple imputation were AR at baseline or follow-up as  
217 well as sex, age quartiles, ethnic group and cereal fiber intervention group because they were  
218 potential predictors of missingness; 260 of 272 children randomised were included in this  
219 imputation analysis. Finally, an exploratory per protocol analysis was conducted which  
220 included only children who reported eating the cereal on most or all days.

221

## 222 **Results**

223 Figure 1 summarizes numbers of children recruited and randomized into the study. Between  
224 September 2017 and June 2018, a total of 782 children took part in initial eligibility  
225 assessments (response rate of 63%). Of these 782 children, 377 (48%) children were eligible  
226 to take part in the trial (all reported that they were currently eating a low fiber breakfast  
227 cereal and all of whom scored at least one high fiber and one low fiber cereal in the top two  
228 palatability categories). In total, consent was received for 299 participants, of whom 272  
229 children (72% of eligible) attended the baseline assessment and were randomized (see figure  
230 1), 135 children were allocated to receive the high fiber breakfast cereal and 137 children the  
231 low fiber breakfast cereal. Complete fasting plasma total AR data at baseline and one month  
232 were available for 193 children who were included in the complete case analysis (87 in the  
233 high fiber group and 106 in the low fiber group); the sensitivity analysis for missing AR data  
234 was carried out in 260 children with at least one AR value.

235 Table 1 presents the baseline characteristics of the participants. There were more girls than  
236 boys; white European origin was the largest ethnic group, with smaller proportions of black  
237 Africans, South Asians and other/mixed ethnicities. Total plasma AR and reported cereal

238 fiber intakes were slightly higher at baseline in the group allocated to high fiber, while  
239 protein and fat intakes were higher at baseline in the low fiber group. Total energy intakes  
240 and the anthropometric measures did not differ markedly between the intervention groups.

241 Most children (87%) reported eating the allocated cereal on most or all days through the  
242 intervention period, although this proportion was higher in the low fiber group (94%) than the  
243 high fiber group (80%) (mean difference: 13.8%; 95% CI: 9.8, 18.7%). Table 2 presents  
244 differences in changes in the primary and secondary outcomes during the one-month trial  
245 period between the high fiber group and the low fiber group in the complete case analysis; all  
246 analyses included a term for school (random effect) whilst model 2 also included adjustments  
247 for sex, age quartiles, ethnic group (fixed effects). At follow-up, the high fiber cereal  
248 intervention group was associated with a significantly greater adjusted increase in fasting AR  
249 compared to changes in the low fiber cereal group and a greater adjusted increase in self-  
250 reported cereal fiber intakes. There were no changes in any of the other secondary outcomes  
251 measured, including dietary intakes (total energy, carbohydrate, fat and protein) and indices  
252 of adiposity (body mass index or fat mass index). Multiple imputation was used to impute  
253 fasting AR values which were missing either at baseline (n=8) or at follow-up (n=59) and  
254 included in the analysis; 12 children with missing AR data at both time points were excluded  
255 from this analysis. In this analysis, very similar increases in fasting AR were observed in the  
256 high fiber cereal group compared to the low fiber group to that observed in the complete case  
257 analysis. Differences in changes in the blood-based risk markers over the study period  
258 between the two groups were examined (Table 3), no significant differences were observed.

259 At follow-up, most children (60%) reported that they had “really enjoyed taking part”, and  
260 25% reported that they had “enjoyed taking part”, with the remaining children reporting that  
261 “it was alright” (12%) or “did not really enjoy it” (3%). Similar proportions of acceptability  
262 were recorded for both high fiber and low fiber groups.

263

264 ***Discussion***

265 An intervention which provided free supplies of palatable high fiber breakfast cereals to 9-10  
266 year-old children, and free supplies of palatable low fiber cereals for the control group, with  
267 support and encouragement provided to both groups to eat breakfast based on recognised  
268 BCTs, successfully increased cereal fiber intakes in the intervention group over a one-month  
269 period. This was documented both by a difference in change in plasma AR (appreciably  
270 higher in the high fiber group compared to the low fiber group following the one-month trial  
271 period) and by data from a 24-hour recall taken at the end of the one-month period, showing  
272 that nearly 3 grams more cereal fiber was consumed in the high fiber group compared to the  
273 low fiber group, with no other changes observed in dietary intakes or adiposity measures  
274 between the two groups. Adherence (children who recalled eating the breakfast cereal every  
275 day or most days) was good, although slightly lower in the high fiber group compared to the  
276 low fiber group.

277 This intervention in children was unique in its design; the main aim was to change cereal  
278 fiber intake without altering other components of the diet, through the provision of  
279 replacement foods rather than nutritional supplements. This appears to have been  
280 successfully achieved, with changes in cereal fiber in the high fiber group (documented both  
281 by changes in AR and dietary recall) achieved without changes in energy intake, in  
282 macronutrient or micronutrient intakes or in weight and other anthropometric measures.

283 Previous intervention trials in children have tended to be multi-component and have changed  
284 numerous aspects of the diet, including fiber intakes, to achieve an improvement in health  
285 outcomes (25-27). Often these approaches led to changes in total energy intakes and weight  
286 status (26). Some previous interventions which aimed to increase fiber intakes were

287 unsuccessful (26, 27), even when substitute foods were provided (28), emphasising the  
288 importance of the behavioral support to encourage consumption of the breakfast cereal. The  
289 behavior change techniques (BCTs) used were based on the key constructs of the Social  
290 Cognitive Theory of behavior change (22). They aimed to increase self-efficacy, self-  
291 regulation and create environmental triggers to help to remind and motivate the participants  
292 to eat the breakfast cereal daily throughout the study period. The BCTs were applied in both  
293 groups to maximise the achieved difference in cereal fiber intake we might achieve, this also  
294 meant that both researcher and participant could remain blind to allocated cereal group.  
295 Although the participants may have been able to identify the cereal they were eating (a  
296 common issue for dietary interventions), they were unaware of the trial aim to increase fiber  
297 intakes in the high fiber group.

298

299 *Strengths and Limitations:* A particular strength of this trial was the use of an objective  
300 marker of whole-wheat cereal fiber intakes (AR), used in conjunction with subjective self-  
301 reported measures to compare the change in intakes in the different breakfast cereal groups;  
302 both measures consistently showed higher cereal fiber intakes in the high fiber intervention  
303 group. Reassuringly, these differences in the primary outcomes suggest that any  
304 contamination which took place between the intervention and control groups was limited (in  
305 the light of the marked differences in cereal fiber intake observed). Participants were  
306 individually randomized (rather than using a cluster randomized design) for greater statistical  
307 efficiency. The consistency of the AR differences between the high and low fiber groups in  
308 the complete case analysis and the imputation (intention to treat) analysis is reassuring.  
309 However, we acknowledge that even the MAR analyses cannot guard against data that are  
310 not missing at random conditional on the covariates. ARs are phenolic lipids which are  
311 present in the bran fraction of wheat and rye, once consumed they are absorbed and

312 detectable in plasma. They have therefore been suggested as potential biomarkers of  
313 wholegrain wheat and rye intakes (29). There are clear advantages of using objective  
314 markers of dietary intakes and although not a precise measure of cereal fiber intake at an  
315 individual level, plasma AR provides both a degree of ranking in individuals (28,29) and an  
316 objective marker of recent cereal fiber intake from whole wheat and rye at a group level (30).  
317 In the current trial, participants were asked to consume whole-wheat breakfast cereals  
318 therefore consuming all parts of the grain, the measure of plasma AR was used solely as a  
319 measure of adherence to the intervention and not to examine any potential relationship  
320 between AR and metabolic outcomes. In relation to previous studies, it is difficult to  
321 compare AR concentrations across different age groups as absorption, distribution and/or  
322 elimination appears to be highly influenced by age (higher AR values in younger children).  
323 Plasma AR concentrations in the present study were of a similar magnitude, though slightly  
324 lower than, 8-10-year-old Danish children with higher wholegrain intakes (31).

325

326 This feasibility study was not powered to detect moderate intervention effects on insulin  
327 resistance, glycaemic control or other markers of cardio-metabolic risk, which showed no  
328 statistically significant differences. However, potentially meaningful favourable population-  
329 wide changes in these markers (for example, a reduction in mean fasting insulin of 1.0  
330 mU/L) could not be confidently excluded. Thus, a substantially larger trial (estimated  
331 sample size of ~1500 participants based on data from this study) would be needed to  
332 investigate the efficacy of this intervention on fasting markers of insulin resistance, of a  
333 magnitude consistent with our earlier observational study (19). Although the current  
334 investigation suggested that large numbers would need to be screened to identify eligible  
335 children, over 70% of participants completed the trial which could potentially be increased  
336 with a strong focus on the importance of fasting and successful blood sampling. It is also



337 possible that the use of much larger doses of fiber (through supplements) and the use of  
338 maximally stimulated measures of insulin resistance (assessed with euglycaemic  
339 hyperinsulinaemic clamps) could reduce the size of trial needed, though these would increase  
340 its invasiveness and would probably limit its practical feasibility.

341

342 In summary, we have developed an acceptable intervention which appreciably increases  
343 markers of daily cereal fiber intakes in children. Given the current low population intakes of  
344 cereal fiber in this age group, an intervention which increases cereal fiber by up to 3  
345 grams/day could have widespread public health relevance and applicability. Future research  
346 is needed to see if this change in diet leads to an improvement in markers of type 2 diabetes  
347 and can be sustained in the longer term.

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353

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355 designed research (project conception, development of overall research plan, and study  
356 oversight); ASD and MP conducted research (hands-on conduct of the experiments and data  
357 collection); NS, PW and RL provided essential reagents or provided essential materials;  
358 ASD, CMN, ARR DGC analysed data or performed statistical analysis; ASD and PHW wrote  
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360 MU, MP and PA revised the work critically for important intellectual content. All of the

361 authors read and approved the final version. None of the authors have any conflicts of  
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Table 1: Baseline characteristics of all participants by intervention group<sup>1</sup>

	Intervention group, median (IQR)		
	Low fiber n=137	High fiber n=135	All n=272
Age, y	9.9 (9.6, 10.3)	9.9 (9.6, 10.2)	9.9 (9.6, 10.2)
Sex, % female	56	62	59
Ethnicity, n (%)			
White European	60 (43.8)	53 (39.3)	113 (41.5)
Black African	19 (13.9)	26 (19.3)	45 (16.5)
South Asian	34 (24.8)	33 (24.4)	67 (24.6)
Other	24 (17.5)	23 (17.0)	47 (17.3)
Total energy intake <sup>2</sup> , kcal/d	1,322 (1,095, 1,651)	1,345 (1,067, 1,676)	1,344 (1,081, 1,654)
Cereal Fiber intake <sup>2</sup> , g/d	4.2 (2.6, 6.5)	4.7 (2.7, 6.3)	4.5 (2.7, 6.4)
Carbohydrate <sup>2</sup> , g/d	194 (156, 239)	196 (153, 237)	194 (155, 237)
Protein <sup>2</sup> , g/d	53.3 (40.6, 63.1)	50.5 (38.4, 65.2)	51.1 (39.0, 63.9)
Fat <sup>2</sup> , g/d	47.0 (34.9, 59.4)	43.2 (29.4, 61.7)	44.8 (32.0, 61.0)
Weight, kg	34.5 (29.8, 41.5)	34.7 (30.7, 40.9)	34.6 (30.3, 41.1)
Fat mass <sup>3</sup> , kg	7.7 (6.1, 11.2)	8.1 (6.1, 11.1)	7.9 (6.1, 11.2)
Fat mass <sup>3</sup> , %	23.0 (20.1, 28.9)	23.1 (20.0, 27.6)	23.0 (20.0, 27.9)
Baseline fasting plasma analytes	n=128	n=124	n=252
Total AR, nmol/L	42.1 (22.2, 85.7)	43.8 (26.4, 82.5)	43.1 (24.6, 85.5)
Insulin, mU/L	6.8 (4.6, 10.3)	7.1 (4.9, 9.0)	7.0 (4.8, 10.0)
Glucose <sup>4</sup> , mmol/L	4.5 (4.2, 4.7)	4.5 (4.3, 4.7)	4.5 (4.2, 4.7)
LDL cholesterol, mmol/L	2.0 (1.7, 2.4)	2.0 (1.5, 2.5)	2.0 (1.6, 2.4)
HDL cholesterol, mmol/L	1.4 (1.2, 1.7)	1.4 (1.2, 1.7)	1.4 (1.2, 1.7)
TGs, mmol/L	0.6 (0.5, 0.8)	0.6 (0.5, 0.8)	0.6 (0.5, 0.8)
Vitamin C <sup>5</sup> , µmol/L	67.4 (52.6, 83.0)	69.4 (56.2, 81.0)	68.4 (54.6, 81.4)
Baseline fasting HbA1c <sup>6</sup> , mmol/mol	33.1 (31.4, 35.1)	33.2 (31.7, 34.7)	33.1 (31.6, 34.7)

<sup>1</sup>Values represented are median (IQR) or frequency (%)

Missing data: <sup>2</sup> low fiber: n=6, high fiber: n=1; <sup>3</sup> high fiber: n=1; <sup>4</sup> low fiber: n=3, high fiber: n=3; <sup>5</sup> low fiber: n=6, high fiber: n=6; <sup>6</sup> low fiber: n=3, high fiber: n=1;

Table 2: Effect of high fiber cereal intervention compared to low fiber cereal on total plasma alkylresorcinol, dietary intake, weight and adiposity in participants who provided baseline and follow up data: complete case analysis<sup>1</sup>

Outcome	N	Model	Effect of high fiber intervention	
			Difference (95% CI)	p
Plasma total AR, nmol/L	193	Model 1	41.6 (21.7, 61.5)	<0.0001
		Model 2	40.7 (21.7, 59.8)	<0.0001
Cereal fiber, g/d	252	Model 1	2.9 (2.0, 3.8)	<0.0001
		Model 2	2.9 (2.0, 3.7)	<0.0001
Energy intake, kcals/d	252	Model 1	44.6 (-80.6, 169.8)	0.49
		Model 2	47.3 (-79.6, 174.1)	0.47
Carbohydrate, g/d	252	Model 1	2.0 (-16.3, 20.3)	0.83
		Model 2	1.6 (-16.9, 20.1)	0.86
Protein, g/d	252	Model 1	-0.1 (-5.6, 5.3)	0.96
		Model 2	0.1 (-5.5, 5.7)	0.97
Fat, g/d	252	Model 1	4.0 (-2.4, 10.4)	0.22
		Model 2	4.4 (-2.0, 10.8)	0.18
Weight, kg	261	Model 1	0.0 (-0.1, 0.2)	0.67
		Model 2	0.0 (-0.1, 0.2)	0.63
Fat mass, kg	261	Model 1	0.0 (-0.2, 0.2)	0.87
		Model 2	0.0 (-0.2, 0.2)	0.88
Fat mass, %	261	Model 1	0.0 (-0.3, 0.4)	0.87
		Model 2	0.0 (-0.4, 0.4)	0.92

<sup>1</sup> Values represented are mean (95% confidence intervals)

Model 1: Outcome at follow-up was regressed on outcome at baseline and intervention group with adjustment for school (random effect)

Model 2: Outcome at follow-up was regressed on outcome at baseline and intervention group with adjustment for school (random effect), age (quartiles), sex, ethnic group (fixed effects)

p-values are based on a Wald test for statistical significance

Table 3: Effect of high fiber cereal intervention compared to low fiber cereal on blood markers in participants who provided baseline and follow up data: complete case analysis

Outcome	N	Model	Effect of high fiber intervention	
			Difference (95% CI)	p
Plasma Insulin, mU/L	193	Model 1	-0.1 (-1.0, 0.8)	0.85
		Model 2	-0.1 (-1.0, 0.8)	0.81
Whole blood HbA1c, mmol/mol	189	Model 1	-0.3 (-0.8, 0.3)	0.37
		Model 2	-0.3 (-0.9, 0.3)	0.32
Plasma Glucose, mmol/L	188	Model 1	0.0 (-0.1, 0.1)	0.84
		Model 2	0.0 (-0.1, 0.1)	0.74
Plasma LDL-chol, mmol/L	193	Model 1	-0.1 (-0.2, 0.0)	0.18
		Model 2	-0.1 (-0.1, 0.0)	0.27
Plasma HDL-chol, mmol/L	193	Model 1	0.0 (-0.1, 0.1)	0.74
		Model 2	0.0 (0.0, 0.1)	0.53
Plasma Triglyceride, mmol/L	193	Model 1	0.0 (0.0, 0.1)	0.47
		Model 2	0.0 (0.0, 0.1)	0.33
Plasma vitamin C, μmol/L	186	Model 1	0.4 (-4.4, 5.2)	0.87
		Model 2	0.8 (-3.9, 5.6)	0.73

Model 1: Outcome at follow-up was regressed on outcome at baseline and intervention group with adjustment for school (random effect)

Model 2: Outcome at follow-up was regressed on outcome at baseline and intervention group with adjustment for school (random effect), age (quartiles), sex, ethnic group (fixed effects) p-values are based on a Wald test for statistical significance

Figure 1: Trial participant recruitment, randomization and follow-up

