ORIGINAL ARTICLE

WILEY

Dietary fibre intake in childhood or adolescence and subsequent health outcomes: A systematic review of prospective observational studies

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Abstract

Aim: To determine whether higher fibre intakes during childhood or adolescence effect a broad range of intermediate markers of cardiometabolic risk or other health related issues.

Materials and Methods: We used online searches up to January 2020 and manual searches to identify prospective observational studies reporting on childhood or adolescent intakes of dietary fibre, vegetables, fruit and refined or whole grains. Outcomes measured later in life were body weight, blood lipids, blood pressure, glycaemia, bone health, cognition, growth and bowel habits. Potential age-specific ranges for dietary fibre were extrapolated from published adult data.

Results: We identified 45 publications reporting on 44 354 participants from 30 cohort studies. Mean age at dietary assessment varied from 1 to 19.3 years. Follow-up duration varied from 4 months to 27 years. Although well-conducted studies reported improvements in body weight, blood lipids and glycaemia, the diverse nature of studies precluded meta analysis. The quality of evidence was very low to low given the limited data available per outcome and the inability to synthesize results from multiple studies. Potential dietary fibre intake begins at 13-16 g a day for 2-year-olds and increases until the age of 10 years, when values are comparable with an adult range of 25-30 g a day.

Conclusions: Given the inconsistency in findings from cohort studies other than an absence of detrimental effects, it seems appropriate that recommendations regarding childhood fibre intake are extrapolated from relevant adult data.

KEYWORDS

body composition, cardiovascular disease, cohort study, glycaemic control, observational study, systematic review

1 | INTRODUCTION

Previous systematic reviews of prospective studies involving cohorts of adults have identified a robust body of evidence showing

reductions in premature mortality and non-communicable disease occurrence with higher intakes of dietary fibre and high-fibre foods.[1-3] Randomized controlled trials (RCTs) in adults have shown improvements in several cardiometabolic risk factors including blood lipids, body weight and measures of glycaemic control when fibre intake is increased.[2,3] Short-term and mechanistic studies have shown that dietary fibre is a determinant of satiety and that consumption of fibre-rich foods slows the rate of digestion, altering glycaemic and lipid responses.[4,5] What has not yet been considered is the potential of dietary fibre and high-fibre foods in childhood and adolescence to influence subsequent health status.

Previous work in this area has failed to identify relevant RCTs in childhood or adolescence,[2] however, concern has been expressed that a high-fibre intake may impede trace element and mineral bioavailability, particularly in those children who are undernourished.[6,7] Therefore, the aim of this systematic review is to examine potential benefits or detriments associated with higher fibre intakes during childhood or adolescence and a broad range of intermediate markers of cardiometabolic risk and other health-related issues. This work was undertaken to inform the development of World Health Organization (WHO) recommendations regarding carbohydrate intake.

2 | MATERIALS AND METHODS

In accordance with the WHO guideline development process,[8] we followed recognized procedures[9] and reporting standards for systematic reviews and meta analyses.[10] The protocol for this systematic review is registered with PROSPERO (CRD42020142402). This commissioned review was presented to the WHO Nutrition Guidance Expert Advisory Group (NUGAG) Subgroup on Diet and Health to inform the development of WHO recommendations on carbohydrate intake in children. Because the results of this systematic review did not provide quantitative information on dietary fibre intake for children and adolescents, NUGAG further requested an extrapolation of adult values[1] to derive quantitative values for children and adolescents. These values were calculated by the research team and revised after discussion with NUGAG.

2.1 | Eligibility criteria

The earlier review of carbohydrate quality[2] did not identify RCTs that examined the effects of dietary fibre or high-fibre foods on a range of relevant health outcomes in young people. Therefore, the aim of this systematic review was to identify prospective observational studies where childhood or adolescent dietary intakes were measured and considered in relation to a broad range of subsequent health outcomes. Eligible participants were those in prospective cohorts or studies nested in cohorts where dietary intakes were assessed before 20 years of age. The exposures considered were intakes of dietary fibre, refined or whole grains, vegetables, legumes and fruit. The outcomes were measures of blood lipids, body weight, glycaemic control, bowel habits, blood pressure, occurrence of type 2 diabetes, growth, gut health, bone health, anaemia and neurocognition. These criteria were discussed and developed by the WHO NUGAG Subgroup on Diet and Health, and are specified in PICO tables (Appendix S1).

Retrospective studies were excluded, as were cohorts with purposeful sampling of those with specific health conditions such as type 1 diabetes, as instructed by NUGAG. Prospective studies of body weight where the outcome was self-assessed were not included. Studies that used a general dietary question and not a recognized dietary assessment technique to measure the exposure amount were not eligible for this review.

2.2 | Literature search and data extraction

Eligible studies were identified using an online search strategy (Supporting Information 2 in Appendix S1). OVID Medline, Embase, PubMed and Scopus were searched from database inception up to 6 January 2020 and augmented by manual searches of reference lists. Commercially available software was used to remove duplicates and aid screening.[11] No date or language restrictions were applied to the searches. Study selection was undertaken by at least two researchers working independently. Discrepancies were resolved through consensus. Data from each eligible publication were extracted using pretested forms[2] by one reviewer, with a double pass by a second reviewer. We extracted the most adjusted values as a conservative approach to compare higher with lower intakes. Values are shown as reported either by coefficients, ratios or as P-values. The information extracted was sufficient to describe each eligible publication (Supporting Information 3 in Appendix S1) and their results (Supporting Information 4 in Appendix S1).

2.3 | Risk of bias assessment and data analysis

Study risk of bias was assessed independently by two reviewers with the Newcastle-Ottawa Scale.[12] For study follow-up, we considered greater than 3 years to be sufficient. Our intention was to consider the available evidence by meta analysis where possible, as stated in our review registration (CRD42020142402). Once identified, however, the data could not be combined. Instead, results are presented as per a systematic review without quantitative synthesis. Quality of the evidence was assessed by the research team using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework[13] and was revised if required after discussion with the WHO NUGAG Subgroup on Diet and Health (Supporting Information 4 in Appendix S1).

2.4 | Extrapolation of adult data

We calculated potential age-specific ranges of daily fibre intake for children and adolescents based on an adult intake of 25-30 g,

as suggested in a recent meta analysis.[2] We used the equation: adult recommendation per 1000 kJ × median energy intake level (per 1000 kJ) of that age.[14] The total energy expenditure (TEE) of children[15] was used as the basis of their energy intake with a composite of male and female TEEs, and an additional 5% of TEE added from the age of 6 years onwards because of additional physical activity.[16] Body weight was taken from the WHO growth charts[17,18] with a composite value for male and female body weights.

3 | RESULTS

A flowchart of the study identification process is shown in Figure 1. Forty-five publications reporting on 44 350 participants from 30 cohorts were identified as eligible for this review, providing 260 837 person-years of data. The median age at which diet was assessed in children was 9.6 years (IQR 9.3 years, range 1 to 19.3 years). The median follow-up duration was 4 years (IQR 7 years, range 4 months to 27 years). Of the 30 cohorts, 14 (47%) were from North America, 11 (37%) were from Europe, three (10%) were from Australia and there was one each (3%) from Iran and Japan. Twenty-five studies reported on body weight, nine on blood pressure, eight on blood lipids, seven on glycaemia, four on metabolic syndrome, three on bone health, three on cognition and development, two on growth and one on bowel habits. A summary of the content identified from eligible studies is shown in Table 1. Full GRADE tables for each outcome are shown in Supporting Information 4 in Appendix S1.
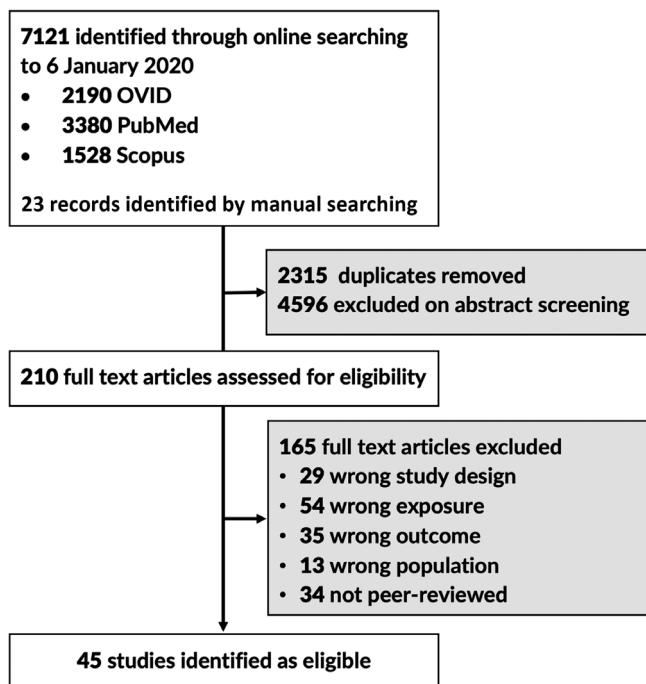

7121 identified through online searching to 6 January 2020
- **2190** OVID
- **3380** PubMed
- **1528** Scopus

23 records identified by manual searching

2315 duplicates removed
4596 excluded on abstract screening

210 full text articles assessed for eligibility

165 full text articles excluded
- **29** wrong study design
- **54** wrong exposure
- **35** wrong outcome
- **13** wrong population
- **34** not peer-reviewed

45 studies identified as eligible

FIGURE 1 Flowchart of the study identification process

3.1 | Body weight

Body weight was reported by 13 studies of dietary fibre, 11 studies of fruit intake, 10 of vegetable intake, four of vegetables and fruit as a composite measure, and two studies of refined or whole grains. Of the dietary fibre studies, two of 453 participants followed for up to 24 years reported a decrease in body weight measures,[19,20] while one study of 438 children reported an increase in body weight after nearly 8 years with higher fibre intake.[21] A further study reported that maintaining a high body mass index (BMI) over time was associated with consuming a lower fibre diet.[22] For fruit, three studies[23–25] of 1601 participants followed for up to 24 years identified a decrease in body weight with higher intake. For vegetables, three studies of 5187 participants followed for up to 24 years identified a decrease[26–28] in measures of body weight, while two studies of 2485 followed for up to 1 year identified an increase in body weight with higher intake.[24,29] Two studies of refined or whole grains reported on body weight: one study of 373 participants observed no difference between high and low intake,[26] while the other study of 4646 participants reported that wholegrain intake was associated with less weight gain and refined grain was associated with increased weight gain after 5 years of follow-up.[27]

3.2 | Blood lipids

Six studies reported on dietary fibre and blood lipids. Two of these studies, consisting of 957 participants followed for up to 8 years, reported inverse associations between dietary fibre and total cholesterol, while another study of 2032 children followed for 5 years reported a reduction in triglycerides and an increase in HDL cholesterol with higher fibre intake.[21,30,31] In two studies of 1038 children and vegetable consumption, higher intake was associated with reduced total cholesterol[32] and total HDL cholesterol.[26] In the two studies of fruit, one study of 373 children reported an increase in total HDL cholesterol with higher intake.[26] The study of vegetable and fruit intake as a composite measure and the two studies of wholegrain intake[26,33] reporting on blood lipids did not report significant associations.

3.3 | Glycaemia and insulin measures

Fewer identified studies considered measures of glycaemia and insulin. Six studies reported on dietary fibre and glycaemia and insulin, with one study of 564 participants followed for nearly 10 years reporting an improvement in the Matsuda Index for insulin resistance with higher fibre intake.[34] The same study reported a similar finding for the Matsuda Index as well as a decrease in the Homeostatic Model Assessment of Insulin Resistance with higher vegetable and fruit intake.[34] In the remaining individual studies, vegetable intake,[32] fruit

TABLE 1 Summary of the content of identified studies

Exposures measured	Number of studies	Number of participants	Outcomes considered
Dietary fibre	19	19 240	Body weight[19–21,26,29–31,34,35,42,62–65] Blood lipids[19,26,30,31,66] Glycaemia[19,31,34,67,68] Blood pressure[19,31] Puberty[43] Bowel health[44]
Vegetables	16	19 487	Body weight[23,24,26–29,32,69–71] Blood lipids[26,32] Glycaemia[32] Blood pressure[32,38] Metabolic syndrome[47–49] Bone health[41] Cognition[51]
Fruit	17	22 216	Body weight[23–29,32,69–71] Blood lipids[26,32] Glycaemia[32] Blood pressure[25,32,38] Metabolic syndrome[48,49] Bone health[41] Cognition[50,51]
Vegetables and fruit	13	5286	Body weight[22,34,35,46,65,72] Blood lipids[33] Glycaemia[34] Blood pressure[36,73,74] Bone health[39,40] Cognition[45]
Refined or whole grains	6	10 037	Body weight[26,27] Blood lipids[26,33] Glycaemia[67] Metabolic syndrome[49] Cognition[51]

intake[32] and wholegrain intake[32] were not associated with an improvement in glycaemia.

3.4 | Blood pressure

There were three studies of dietary fibre and blood pressure, none of which reported an association between them.[19,31,35] Five studies reported on vegetable and fruit intake as a composite measure and blood pressure. Two of these studies (of 641 children followed for up to 10 years) indicated there were benefits with regard to systolic blood pressure.[36,37] The other three studies reported on fruit intakes and blood pressure: one study of 606 children followed for 2 years reported a potential decrease in diastolic blood pressure with higher fruit intakes in girls,[38] while two studies of vegetable intake and blood pressure did not report significant associations.[32,38]

3.5 | Bone health

Higher vegetable and fruit intake as a composite marker was associated with improved total body mineral content in one study of

152 participants followed for 7 years[39] but not arm bone growth in one study of 116 participants followed for 16 years.[40] Higher vegetable intake was associated with a percentage improvement in bone stiffnesrs, as was a higher intake of fruit in girls, but not in boys.[41]

3.6 | Other health outcomes

Additional studies reported on further health outcomes identified as relevant to this review. Findings on dietary fibre and markers of growth such as time of menarche were mixed.[42,43] One study of 8899 participants followed for 4 months linked higher fibre intake to a decreased frequency of hard stools.[44] Higher vegetable and fruit intake as a composite marker was associated with a decrease in school grades in 334 children,[45] but not becoming 'normal-weight metabolically unhealthy'.[46] Two[47,48] of three studies with 2554 participants identified decreased incidence of metabolic syndrome with higher vegetable intake, with the third study providing a non-significant odds ratio of 0.95 (95% CI 0.85 to 1.04).[49] The same two studies showed a significant reduction in metabolic syndrome with higher fruit intake.[47,48] For measures of cognition, both studies reporting on a cohort of 2868 students identified educational benefits

with a higher intake of fruit[50,51]; however, these benefits were not observed with higher vegetable or wholegrain intakes.[51]

3.7 | Study risk of bias and GRADE

All of the identified studies were assessed with the Newcastle-Ottawa Scale.[12] The mean score for all identified studies was 6.3 (SD 1.28) out of a possible 8. Scores ranged from 4 to 8. The average quality score, trial size and follow-up duration for studies reporting a statistically significant association were 6.2 (SD 1.33), 1195 (SD 1877) and 7.3 (SD 8.09) years, respectively. The average quality score, trial size and follow-up duration for studies reporting no statistically significant outcome were 6.5 (SD 1.22), 700 (SD 705) and 5.6 (SD 4.28) years, respectively. The primary area where individual studies showed potential bias was inadequate adjusting for potential confounding variables, such as other lifestyle factors. Study participants were typically reflective of the average child, as the primary recruitment site was hospitals for birth cohorts, or schools for young children. Because an exclusion criteria of this review was self-reported measures of body weight, the included studies scored well on objective outcome assessment. The quality of evidence identified in this systematic review when assessed with GRADE protocols was of very low to low certainty. As only prospective observational studies were used, all evidence started as low. There were no variables for upgrading the strength of evidence. Downgrading was primarily attributable to imprecision from low participant numbers per outcome.

3.8 | Extrapolation of adult data

A calculation for childhood intake ranges based on a daily adult intake range of 25-30 g dietary fibre is shown in Table 2. Given the increased energy requirements of adolescents for both growth and maintenance, values for those aged 10 years and older exceed the adult minimum value of 25 g.

4 | DISCUSSION

We identified 45 relevant publications representing 30 cohort studies. Several well-conducted individual studies found improvements in body weight,[27] blood lipids,[31] blood pressure,[36] glycaemia[34] and other outcomes,[39] with higher intakes of dietary fibre and high-fibre foods. What was clear for all dietary exposures was that the current literature identified no adverse effects from a higher intake of dietary fibre, vegetables, fruit or whole grains. Large differences between studies with regard to age at dietary assessment, duration of follow-up and measures of exposure and outcomes precluded formal synthesis and meta analysis of the data. For this reason the evidence linking childhood and adolescent intake of dietary fibre and high-fibre foods to the wide range of health outcomes examined was considered to be very low to low quality. Despite our inability to draw definitive conclusions from the currently available body of literature, the findings of our review indicate that it is reasonable to offer recommendations regarding children and adolescents based principally on the findings in adults. Such advice may have additional benefits, as dietary habits that are established in childhood likely continue into adult life,[52,53] with recommendations that promote the same food for children and adults supporting social structures such as families eating together.[54]

Data from cohort studies in adults have shown clear dose response relationships between dietary fibre and premature mortality, cardiovascular disease and type 2 diabetes.[2] Comparable findings have been reported for whole grains,[2] vegetables,[1] legumes[55] and whole fruit,[1] all primary sources of dietary fibre. RCTs that have examined the effects of increasing dietary fibre upon cardiometabolic risk factors supplement the findings of the epidemiological associations reported.[56-58] Several of the larger studies we identified provided confirmatory evidence of the beneficial effects of dietary fibre or foods rich in fibre on the lipid profile,[30-32] as have recent cross-sectional data in children and adolescents.[59] Many of the studies that showed no effect were comparatively short in duration or involved a limited number of participants. Of particular relevance when extrapolating from the adult data was the absence of reported detrimental

TABLE 2 Child and adolescent daily fibre intake values by energy intake based on an adult fibre intake range[2]

Child age, years	Child TEE, mJ per day	+5% TEE	Child value based on 25 g adult value	Child value based on 30 g adult value
2	4.50	—	13.45	16.16
3	4.99	—	14.90	17.91
4	5.40	—	16.13	19.39
5	5.81	—	17.35	20.86
6	6.23	0.31	19.53	23.48
7	6.73	0.34	21.10	25.38
8	7.30	0.37	22.91	27.54
9	7.93	0.40	24.88	29.91
10	8.60	0.43	26.96	32.41

Abbreviation: TEE, total energy expenditure.
Note: Adult daily energy intake value 8.368 mJ (2000 kCal) resulted in 2.99 g fibre per mJ for an intake of 25 and 3.59 g fibre per mJ for an intake of 30 g per day.

effects of high-fibre diets in any of the identified studies. In the light of these observations it seems appropriate to base recommended intakes for young people on the basis of a suggested range for adults, which translate into comparable intakes for those aged 9 years or older, with lesser amounts for younger children.

As far as we are aware this is the first systematic review that has attempted to aggregate and quantify potential beneficial or detrimental effects of dietary fibre and high-fibre foods when consumed by young people before adulthood. We followed the recommended processes for conducting a systematic review.[9,10,13] The limitations are those resulting from the attributes of the included studies. Almost all were conducted in North America or Europe, so the findings cannot necessarily be extrapolated to those countries where intakes of energy, micronutrients and minerals are marginal. Many of the studies involved comparatively small cohorts, dietary capture was at widely different time points and the duration of follow-up ranged from less than 1 year to 27 years. It is also probable that dietary assessment as a single point in time in childhood or adolescence is less certain to reflect habitual intake than would be the case for adults.[60]

While currently available relevant literature based on cohort studies of children and adolescents does not permit definitive conclusions, we consider that our systematic review supports extrapolation of data from adults relating to the beneficial health effects of dietary fibre, whole grains, vegetables, legumes and whole fruit. However, given that the studies identified in this review were undertaken in affluent societies, it is important that future researchers examine the effects of high intakes of such foods among undernourished children, where the intake of some essential nutrients may be less than optimal. Further research conducted in Africa, South America, Asia and Oceania would enable better guidance regarding the generalizability of our findings.

RCTs, rather that further cohort studies, offer the quickest way of investigating this issue, as well as confirming the effects of increased dietary fibre intake on cardiometabolic risk and other biomarkers of long-term health outcomes. Such studies might usefully include an investigation of the effects of legumes and pulses, which are rich sources of nutrients, such as dietary fibre, that can be produced at a comparatively low cost and with minimal environmental impact.[61] Future research should consider health outcomes for children and adolescents in relation to the extrapolated fibre values suggested, in order to support or revise their use.

Given the considerable benefit in terms of non-communicable disease risk reduction associated with comparatively high intakes of dietary fibre and high-fibre foods in later life, it seems prudent that children and adolescents are encouraged to choose diets high in naturally occurring fibre through intakes of whole grains, vegetables, legumes and whole fruit. From the age of 9 years, a range comparable with those for adults appears appropriate. Lesser amounts are appropriate for younger children. Action from policymakers, healthcare professionals, food producers and promoters will be required so that the appropriate high-fibre foods in the appropriate amounts are available for children and adolescents.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.