# Effects of dietary fibre type on blood pressure: A systematic review and meta-analysis of randomised controlled trials of healthy individuals

Short title: fibre and blood pressure

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## Abstract

**Objective** To determine the effect of different types of dietary fibre on systolic and diastolic blood pressure.

**Methods:** A systematic review of the literature and a meta-analysis of randomised controlled trials using random effects models. Eligibility criteria for studies included randomised controlled trials of at least 6 weeks duration testing a fibre isolate or fibre rich diet against a control or placebo published between 1st January 1990 and 1st December 2013.

**Results** 28 trials met the inclusion criteria and reported fibre intake and systolic blood pressure (SBP) and/or diastolic blood pressure (DBP). 18 trials were included in a meta-analysis. Studies were categorised into one of twelve fibre-type categories. The pooled estimate for all fibre types were -0.9 mmHg (95% CI -2.5 to 0.6 mmHg), and -0.7 mmHg (95% CI -1.9 to 0.5 mmHg) for SBP and DBP respectively. Analyses of specific fibre types concluded that diets rich in beta-glucans reduce SBP by 2.9 mmHg (95% CI 0.9 to 4.9 mmHg) and DBP by 1.5 mmHg (95% CI 0.2 to 2.7 mmHg) for a median fibre difference of 13 g. Heterogeneity for individual fibre types was generally low.

**Conclusions** Higher consumption of beta-glucan fibre found in oats and barley is associated with lower systolic and diastolic blood pressure; however evidence for other types of fibre was not consistent. In many countries total dietary fibre consumption is considerably lower than recommended. Policies which increase oat and barley consumption and reduce cardiovascular disease, through lowering blood pressure, should be encouraged.

**Keywords:**

Blood pressure; fibre; beta-glucans; CVD risk; systematic review; meta-analysis

## Introduction

A third of all deaths in the UK are attributed to diseases of the heart and circulatory system.[[1](#_ENREF_1)] Hypertension or high blood pressure is a major risk factor for stroke and myocardial infarction[[2](#_ENREF_2)] and is also a common cause of kidney disease. Hypertension, therefore, contributes significantly to morbidity and mortality rates.[[3](#_ENREF_3)] [[4](#_ENREF_4)] It is suggested that hypertension affects up to one quarter of the population worldwide [[5](#_ENREF_5)] although in Western Countries up to half of the adult population are reported to have blood pressure levels outside the desirable range.[[6](#_ENREF_6)] International guidelines recommend diagnostic and treatment thresholds for hypertension.[[7](#_ENREF_7), [8](#_ENREF_8)]

In addition to prescribed medications, the management of hypertension involves lifestyle changes. These include the maintenance of a healthy weight, stopping smoking, reducing alcohol consumption, and dietary changes such as a low salt diet rich in fruit and vegetables.[[9](#_ENREF_9)] The average individual effect size noted in dietary intervention trials is generally relatively small. For example, Neter *et al*. suggested that for every 1 kg weight loss, systolic and diastolic blood pressure would decrease by 1 mmHg.[[10](#_ENREF_10)] However, these small effects, can translate into important reductions in the incidence of hypertension at the population level.[[11](#_ENREF_11)] It is estimated that each 2mmHg reduction in systolic blood pressure and 1mmHg reduction in diastolic blood pressure is associated with a 10% reduction in the risk of CVD.[[12](#_ENREF_12)]

Although advice on increasing fruit and vegetable consumption is included in guidance to reduce blood pressure, advice on fibre consumption is not. Two reviews of fibre and blood pressure were published in 2005. Although they described a significant inverse relationship between fibre consumption and blood pressure, they did not describe the effects by fibre type. [[13](#_ENREF_13)] [[14](#_ENREF_14)] Since the publication of these reviews many more studies have been conducted exploring different fibre isolates and it is now timely to determine the effect of different types of fibre on blood pressure. A high fibre diet, particularly if higher in soluble fibre, is associated with additional health outcomes; including better glucose control and lipid profile[[15-17](#_ENREF_15)] but less data is available on different types of fibre and their importance on blood pressure.

This review categorises fibre into twelve groups based on their chemical structure, as recommended by Wanders et al.[[18](#_ENREF_18)] Nine categories of fibre are isolated fibres and three are complex mixtures of fibre rich diets. The aim of this review is therefore to determine the effects of specific types of dietary fibre on systolic and diastolic blood pressure in a healthy population.

## Methods

### Selection of trials

This review is part of a large review of carbohydrates and cardio-metabolic disease which followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[[19](#_ENREF_19)] Human studies published in English since 1990 until December 2009 were included in the original review and the search was updated to include studies up to 1st December 2013. The following electronic databases were searched in the original review: Medline, Pre-Medline (MEDLINE in process), Embase, CAB Abstracts, BIOSIS, ISI Web of Science and The Cochrane Library. The update search included Medline and Embase databases only. Electronic searches were supplemented with hand searches in key journals and citation lists of selected review articles. Search terms included MeSH terms for different types of fibre namely “fiber”, “fibre”, “fibre isolate”, “beta-glucans”, and “wholegrain” as well as the MeSH term for blood pressure. The BMJ search strategy for trials was used.[[20](#_ENREF_20)] The protocol was agreed by all research personnel prior to starting the review and peer-reviewed by panel members of the Scientific Advisory Committee on Nutrition (SACN) carbohydrate working group and Department of Health (DoH) personnel and is published on their website in a draft report.[[21](#_ENREF_21)]

Inclusion criteria were applied which were parallel or crossover randomised controlled trials (RCTs) of at least 6 weeks duration where they reported a difference in fibre intake between an intervention group and a comparator group and measured blood pressure at baseline and at least one other time point. There were no age or gender restrictions. Studies were excluded if ill health or history of disease was part of the inclusion criteria for the study. Specifically, studies in which >10% of the population were diagnosed with hypertension were excluded. Outcomes in the full review included markers of CVD such as blood pressure, blood lipids as well as markers of inflammation and markers of vascular function. Many outcomes that were included in the original search criteria are not reported here.

Studies were categorised into one of twelve possible groups including three for complex fibres and nine categories of isolated fibres. The first group includes arabinoxylan, beta-glucan and pectin rich diets. The second group includes glucans, resistant starch, dextrins, mannans, fructans, xylans, pectins, marine polysaccharides and chitosan. Arabinoxylan rich diets include trials where whole grain versions of foods are included which do not increase levels of other macronutrients in the diet such as protein. High fibre diets that solely increased fruit and vegetable intake were excluded as these foods contain a range of compounds in addition to fibre that may potentially affect blood pressure such as flavanols. Protein rich high fibre foods such as beans and legumes were also excluded as these foods would be likely to result in a change in the macro-nutrient profile of participants.

### Data screening and extraction

For each reference, the title and/or abstract were screened for article relevancy using the agreed guidelines established at the start of the review. Letters and editorials were marked as ‘not relevant’ as were all references clearly unrelated to the scope of the review. All other articles were marked as ‘potentially relevant’ and were reviewed independently by two members of the review team using an agreed Inclusion/Exclusion form. Where any disagreement occurred, a third member of the team arbitrated in the decision.

Data on exposures, outcomes, sample size, participants, study-design and length of intervention, were entered directly into an access database. Authors were not contacted, and only data reported in tables (but not figures) were extracted. . Data extraction was completed by one of several members of the review team with serial review for extraction errors.

### Quality assessment of trials

The review was not restricted on the basis of perceived quality of papers or the process of obtaining data cited in primary studies. The quality of trials included in at least one meta-analysis was assessed in duplicate using the Cochrane indicators of bias[[22](#_ENREF_22)] and covered the following issues: sequence generation criteria for random allocation, allocation concealment, blinding of participants, blinding of personnel and outcome assessors, incomplete reporting of outcome data, selective outcome reporting and other potential threats to validity. Each paper was categorised as containing bias, no bias or being unclear based on each of the above criteria.

### Statistical analysis

Data from all arms of the trial were extracted and the two arms with the largest difference in fibre were included in the analysis. Results of the trial were included if data were provided in one of the following two formats: a difference between the intervention and control group either adjusted or unadjusted for baseline results or a change from baseline to follow up for each arm. In the latter case the difference in the change between groups was calculated using a t-test to provide the difference between groups with a measure of variation. Studies were excluded if only a p value was provided for the difference between arms.

Where results from at least three included studies could be quantitatively combined for each fibre type, a random effects meta-analysis of the intervention trial data was reported. A weighted mean difference was calculated (weighted by the inverse of the variance). All the results of studies were expressed as the difference in systolic and diastolic blood pressure in mmHg between study arms.

Heterogeneity was presented as the proportion of total variation in study estimates that is due to between study heterogeneity (I2).[[23](#_ENREF_23)] It is common to interpret I2 as being excessive where the value is in excess of 50 to 75%; we chose to use 75% as our cut off.[[24](#_ENREF_24)] Where values were above this, a pooled estimate was reported but no conclusions were drawn. Small study effects such as publication bias were assessed using a funnel plot for all trials combined and for a specific fibre type if the number of studies exceeded ten. A broadly symmetrical funnel plot was taken to indicate no evidence of small study effects. Meta-regression was undertaken for factors potentially contributing to heterogeneity including gender, weight status and dose response. Dose response was analysed for total fibre intake as well as by individual fibre type for fibre categories with at least 3 results.

## Results

**Search results**

Twenty eight trials were identified which met all the exclusion and inclusion criteria; 19 from the original search and nine from the update search (see figure 1). The main reasons for exclusion were; no blood pressure data reported, participants not healthy or not a relevant fibre.

### Trial characteristics

The 28 trials were carried out in a number of different countries and therefore a range of populations with different diets were represented (see Table 1); Nearly half of the studies were conducted in the US (11 studies) and other countries included in the review were, Australia (3), Denmark (2), Finland (2), Sweden (2) with one study each from Japan, Norway, Italy, New Zealand, Germany, Israel, Netherlands and France. Most of the trials used a parallel group design while five studies used a crossover design. The duration of the intervention ranged from six weeks to 14 months (see table 1). All except one study[[25](#_ENREF_25)] included adults as participants, with a mean age of between 29 and 60 years. Six studies included men only[[25-30](#_ENREF_25)] and three studies included women only.[[31-33](#_ENREF_31)] Most trials were small and recruited between 21 and 172 participants in total with a mean of 62 participants.

Eighteen trials were included in at least one meta-analysis. Results from the remaining ten studies were excluded for the following reasons; a lack of information on estimates of variation, [[29](#_ENREF_29), [34-39](#_ENREF_34)] systolic and diastolic pressure not separately,[[40](#_ENREF_40)] difference between groups was based on molecular weight,[[41](#_ENREF_41)] or data were only provided in a figure.[[42](#_ENREF_42)]

The meta-analyses included a total of 1333 participants providing results for SBP and 1183 providing results for DBP. Although all the studies included generally healthy populations, many studies included overweight or obese participants, often as part of the inclusion criteria (see table 1). Body weight was usually reported to decrease in both arms of the trial with mean weight loss in the control group reported as 1.6 kg and mean weight loss in the intervention group reported as 1.8 kg. Twelve out of the eighteen studies included in the meta-analysis reported differences in body weight change between arms ranging from 2.5 kg more weight loss in the control group to 1.2 kg more weight loss in the intervention group. These differences were generally modest (mean and median difference in weight loss between arms of 0.2 kg,) and nine out of the twelve trials reported differences of less than 1 kg.

The interventions to increase fibre varied considerably in approach. Some studies used whole foods such as wholegrain cereals and breads and others used fibre isolates which were commonly provided as a flavoured powder added to water or incorporated into a food vehicle If high fibre foods were used these were usually substituted with low fibre foods in the control group. If fibre isolates were used, these were usually substituted instead of a low fibre supplement. The information on each intervention detailed in table 1 indicates that many of the studies were balanced in terms of energy and macronutrients for each group.[[43](#_ENREF_43)]

**Quality of trials**

The results of the quality check s are reported in table 2. No studies were excluded from the review based on the quality check although a sensitivity analysis was carried out on the trials which were reported to be double blind for all fibre types only and provided as supplemental data. The quality of the trials was generally good. Unlike many trials involving dietary manipulation many of the trials stated that they were either single or double blind. Thirteen of the trials reported participant blinding and eleven trials reported researcher blinding. The remaining trials either did not provide enough information or stated that there was no blinding. Blinding was possible due to the fact that fibre supplements can be given as a drink, with the vehicle being similar in appearance and flavour provided to the control group. Quality was poor in other areas of assessment, particularly in terms of reporting. In many trials allocation sequence generation and allocation concealment were not adequately reported.

**All fibre types**

Results included in the meta-analysis were obtained from seven out of the twelve possible groups of fibre namely, arabinoxylan rich diets (high in wholegrain foods), beta-glucan rich diets (high in oat and barley fibre), chitosans, mannans, pectins, xylans and alginates. There were no trials included in the review that assessed the effects of interventions containing pectin-rich foods, glucans, resistant starch, dextrins or fructans.

The difference in daily fibre intake for all fibre types between control and intervention groups ranged from zero to 30g with a median difference in intake between groups of 6g for all studies. The overall pooled results for SBP (figure 2) and DBP (figure 3) respectively for all trials, regardless of fibre type were -0.9 mmHg (95% CI -2.5 to 0.6 mmHg, p=0.25) and -0.7 mmHg (95% CI -1.9 to 0.5 mmHg, p=0.24) indicating that high fibre diets overall do not significantly reduce SBP or DBP Heterogeneity was moderate at 43% (p=0.02) and 58% (p<0.01) respectively. The funnel plots (see figure 1 and 2, Supplementary Digital Content) indicated little evidence of small study bias.

A number of factors were explored using meta-regression to determine whether an important amount of heterogeneity was due to any specific characteristics of the trials (see table 3). Baseline characteristics of participants, had no impact on heterogeneity, however dose of total fibre was statistically significant. Each daily gram of fibre reduced SBP by 0.20 mmHg (95% CI -0.39 to -0.02 mmHg, p=0.03) and DBP by 0.12 mmHg (95% CI -0.19 to -0.06 mmHg, p<0.01). Trials categorised by low (0-3 g), medium (4-9 g) and high (10 or more grams) fibre level are shown in figure 4 (SBP) and figure 5 (DBP) where a slight trend from top right to bottom left can be identified.

The sensitivity analysis of double blind trials included eleven out of eighteen trials. The pooled results for SBP (see figure 3, Supplemental Digital Content) and DBP (see figure 4, Supplemental Digital Content) were -0.8 mmHg (95% CI -2.9 to 1.2 mmHg, p=0.43) and -0.5 mmHg (95% CI -2.1 to 1.0 mmHg, p=0.49) respectively providing similar but attenuated results compared to the overall pooled estimate for all studies. Heterogeneity was higher when compared with all studies at 60% (p<0.01) and 72% (p<0.01) respectively. Only mannans maintained a minimum of three trials where all trials in the original analysis remained in the sensitivity analysis.

**Alginates**

One trial reported the effect of a diet supplemented with alginates and therefore there were insufficient data available to obtain a pooled estimate. Jenson et al. conducted a double blind trial in obese participants, who received either a drink supplemented with an alginate gel extracted from seaweed or a control drink in conjunction with a hypo-energetic diet. The authors reported attenuated reductions in blood pressure in the intervention group despite reporting higher weight loss in the intervention group.

**Arabinoxylan rich**

Data were extracted from three RCTs reporting information on blood pressure in relation to diets higher in dietary fibre from wholegrain food sources. Andersson et al. [[44](#_ENREF_44)] explored blood pressure differences in men and women consuming their usual diet with whole grain foods (Bread, crisp bread, muesli & pasta - minimum 50% wholegrain in provided foods = 112g wholegrain/day) or with refined grain foods (Bread, crisp bread, muesli & pasta). There was a marked difference in fibre content between the diets, and body weight increased in both groups possibly due to the test foods supplementing rather than substituting for usual foods. Olenzki et al.[[45](#_ENREF_45)] compared 3 hypoenergetic diets (high fibre, high fibre/low saturated fat and low fat). Body weight decreased in all 3 diet groups. Kristensen et al.[[33](#_ENREF_33)] similarly used a hypoenergetic diet comparing a diet rich in wholewheat products with a diet high in refined wheat foods. None of the studies reported evidence of an effect of a diet high in wholegrain foods on either systolic or diastolic blood pressure. The pooled estimates for SBP and DBP respectively were -.1 mmHg (95% CI -4.6 to 4.4 mmHg, p=0.97) and -0.7 mmHg (95% CI -3.7 to 2.2 mmHg, p=0.63) indicating that wholegrain foods had no significant effect on blood pressure. Heterogeneity was low for both SBP (0%, p=0.98) and DBP (0%, p=0.66). A meta-regression did not indicate a significant dose response (table 3)

**Beta-glucan rich**

Data were extracted from five RCTs reporting on trials of supplementing diets with beta-glucans derived from oats.[[27](#_ENREF_27), [43](#_ENREF_43), [46-48](#_ENREF_46)] The trials studied the effects of whole oats, oat bran-supplemented foods or oat-based breakfast cereals compared with similar wheat-based test foods.

Maki et al. compared a high oat beta-glucan diet from oatmeal, ready-to-eat cereal with oat bran and a powdered form of oat beta-glucan, which provided 8g beta-glucan per day with a control diet (wheat-based cereal, maltodextrin powder and a low fibre hot cereal, providing 0g beta-glucan per day).[[43](#_ENREF_43)] Saltzman *et al*. compared wheat-based breakfast cereal with oat-based cereal.[[46](#_ENREF_46)], He and Davy compared wheat with oats and/oat bran[[27](#_ENREF_27), [47](#_ENREF_47)] and Charlton [[48](#_ENREF_48)] compared a bowl of oat porridge and oat cereal bars with puffed rice and wheat bars.

The pooled estimates for beta-glucans and SBP and DBP respectively were -2.7 mmHg (95% CI, -4.7 to -0.7 mmHg) and -1.5 mmHg (95% CI, -2.7 to -0.2 mmHg) indicating that consumption of a high beta-glucan diets significantly reduces blood pressure. These results were significantly different from zero for both SBP (p<0.01) and DBP (p=0.02). Heterogeneity denoted by I2 was low for SBP (0%, p=0.65) and DBP (0%, p=0.89). A meta-regression did not indicate a significant dose response (table 3).

**Chitosan**

Data were extracted from one trial with four arms which assessed the impact of 1.2 g of microcrystalline chitosan (a product of chitin) on blood pressure and lipids of carriers and non-carriers of the Apolipoprotein E 4 gene. Carriers were reported to have slightly higher SBP and DBP on the higher fibre diet whereas non-carriers were reported as having a slightly lower BP on the higher fibre diet. The limited evidence from one trial indicated that there was not enough conclusive evidence to determine whether or not there is an association between blood pressure and chitosan consumption.

**Mannans**

Data were extracted from four trials supplementing diets with mannans which include different soluble fibres.[[28](#_ENREF_28), [30](#_ENREF_30), [49](#_ENREF_49), [50](#_ENREF_50)] Landin *et al* [[28](#_ENREF_28)] supplemented the participant’s normal daily diet with 3 daily drinks, each containing 10 g of guar gum and compared this with drinks containing granulated gelling starch. Wood *et al.* [[30](#_ENREF_30)] supplemented a hypo-energetic, low carbohydrate diet with 6 capsules containing a total of 3 g of Konjac-mannan, a viscous soluble fibre that is a constituent of Konjac root. Grube et al. [[49](#_ENREF_49)] supplemented the diet with 3 g of a fibre complex derived from *Opuntia ficus-indica* and enriched with soluble fibre or a placebo consisting of cellulose. Reimer et al. [[50](#_ENREF_50)] supplemented the diet with 15 g of a complex fibre powder or placebo mixed with yoghurt All four studies were double blind.

The pooled estimates for mannans and SBP and DBP respectively were 0.4 mmHg (95% CI, -4.3 to 5.0 mmHg) and 1.7 mmHg (95% CI, -4.3 to7.6 mmHg) indicating that consumption of a diet high in mannans has no significant effect on SBP or DBP . This estimate was not significantly different from zero for SBP (p=0.88) or DBP (p=0.58). Heterogeneity denoted by I2 was high at 81% for SBP (p<0.01) and 91% for DBP (p<0.01). A meta-regression did not indicate a significant dose response (table 3).

**Pectins**

Data were extracted from two trials supplementing diets with pectins, soluble fibres originating from the cell walls of plants. In the study conducted by Bell *et al.[*[*26*](#_ENREF_26)*]*, the intervention was given to participants in the form of a fibre enriched cereal. Participants were randomised to receive pectin-enriched cereal (11% soluble fibre) or a placebo (cornflakes). Cereals were administered as 57g portions and were consumed as part of breakfast. There was no difference in total fibre consumed between the intervention and control groups and blood pressure reduced in all groups. In the study by Schwab [[51](#_ENREF_51)], participants with impaired glucose metabolism were provided with two drinks enriched with a daily total of 16g of sugar beet pectin or polydextrose control. Systolic and diastolic blood pressure decreased to a larger degree in the intervention group. As there were fewer than three trials a pooled estimate was not generated.

**Xylans**

Data were extracted from three RCTs reporting results of interventions involving xylans, insoluble and soluble fibres originating from the cell walls of plants [[25](#_ENREF_25), [26](#_ENREF_26), [31](#_ENREF_31)]. These were administered in the form of fibre ‘tablets’ containing vegetable, citrus and cereal-derived fibre[[31](#_ENREF_31)] or psyllium [[25](#_ENREF_25)] or as a psyllium enriched cereal.[[26](#_ENREF_26)] Birketvedt et al reported that the high fibre diet participants had a lower SBP and DBP but the remaining two trials reported no difference in blood pressure.

 The pooled estimates for xylans and SBP and DBP were -1.4 mmHg (95% CI, -5.5 to 2.8 mmHg) and -0.8 mmHg (95% CI, -3.9 to2.3 mmHg indicating that consumption of a diet high in xylans has no significant effect on blood pressure. These estimates were not significantly different from zero for SBP (p=0.52) or DBP (p=0.61). Heterogeneity denoted by I2 was moderate at 51% for SBP (p=0.37) and 45% for DBP (p=0.16). A meta-regression did not identify a significant dose response (table 3).

## Discussion

*Summary of results*

The results from this systematic review provide little evidence that an increase of total fibre intake has an impact on blood pressure. However, higher doses of individual fibre types, in particular beta-glucans, significantly reduce systolic and diastolic blood pressure in healthy individuals. Higher total fibre was significantly associated with lower blood pressure with each 1g increase in total fibre associated with 0.2 mmHg reduction in SBP and 0.12 mmHg reduction in DBP, but this was largely driven by one study[[28](#_ENREF_28)] which reported substantial reductions in blood pressure with very high doses (30g) of fibre. Notably, the association between fibre dose and blood pressure was not significant when this study was excluded.

In general, the studies included in the review reported reductions in systolic and diastolic blood pressure in both groups but larger reductions were reported from participants with a higher beta-glucan intake. Systolic and diastolic blood pressure were 2.7 and 1.5 mmHg lower respectively in the higher beta-glucan group. Weight loss was 0.5kg higher, on average, for participants taking beta-glucans in the three studies where weight was reported and therefore some of the reduction in blood pressure may, partly, be due to weight loss. It is unlikely, however, that the improvements in blood pressure can be completely explained by weight loss as studies involving alternative types of fibre did not result in similar benefits in blood pressure.

For the trials reporting significant blood pressure reduction due to beta-glucans, the supplement dose provided to participants in the intervention varied from 4 g to 15 g, however, in studies with a larger supplement, participants reduced intake of fibre from other sources and therefore differences in soluble fibre over the whole day varied only from 4 to 7 g for studies where this was reported. There was no evidence that the difference in the dose of beta-glucans was important although the actual difference was not reported in all studies.

*Mechanisms*

The mechanisms for the effect of high beta-glucans and blood pressure are not clear. Beta-glucans are viscous soluble polysaccharides that occur in the endosperm cell walls of grains. They are composed of glucose molecules with mixed β-(1→4) and β-(1→3) bonds and oats and barley are recognised as particularly rich sources. Considerable variation in the amount of beta-glucans in oats and oat products exists which is due to varietal and processing influences. Commercial rolled oats may contain in the region of 3 to 5% beta-glucan and oat bran between 6 to 10%.[[52](#_ENREF_52)]. It has been suggested that viscous soluble fibres lower blood pressure due to effects on peripheral insulin sensitivity although this is controversial[[43](#_ENREF_43)] Various methods have shown that higher levels of fermentable fibre in the gut are associated with improved insulin sensitivity.[[53](#_ENREF_53)] It is also possible that high intakes of beta-glucans help promote weight loss and reduce blood pressure compared to other fibre types.

*Comparison with previous studies and reviews*

The results from this review have some similarities with previous reviews of trials [[13](#_ENREF_13)] [[14](#_ENREF_14)] and prospective studies of blood pressure and incident hypertension.[[54](#_ENREF_54)] More detailed information is obtained here on the effect of different types of fibre on blood pressure not previously reported. Streppel *et al.* concluded that there was some support for a larger effect of soluble fibre on BP but did not quantify this effect and treated different types of soluble fibre altogether in one group.[[14](#_ENREF_14)] If beta-glucan was the most common type of soluble fibre this could have driven the results.

Such changes in blood pressure seen here are clinically important. For example, a reduction in diastolic blood pressure of 5 mmHg is associated with a reduction in stroke of 34% and coronary heart disease of 21% respectively.[[55](#_ENREF_55)] Importantly, the reduction in systolic blood pressure of nearly 3 mmHg seen with beta-glucan rich diets is very similar to the effect of a low salt diet in a non-hypertensive population as reported in a large review by He *et al.*[[56](#_ENREF_56)] Diets high in beta-glucans may have the potential to reduce blood pressure comparable to a sizeable decrease in salt intake and consequently reduce CVD risk by approximately 10%.[[56](#_ENREF_56)] Beta-glucans also reduce LDL cholesterol - further reducing cardiovascular risk. Yet evidence from systematic reviews of prospective studies suggests that high total fibre consumption reduces risk of CVD.[[57](#_ENREF_57)]

Previous research has tended to group together all soluble fibres when assessing effects on risk markers of CVD. We found that an increase in daily intake of more than 10 g was needed in order to see a benefit in BP for some of these other fibre types such as xylans, pectins and mannans although there were not enough studies to formally test this hypothesis for each fibre type. This may be because some of the studies were designed to assess the impact of dietary fibre tablets (using quite small doses of fibre) compared to placebo tablets and the dose may have been insufficient to detect any benefits on blood pressure over and above any differences due to weight loss if participants were on a weight loss diet.

Although the aim of the review was to include healthy participants many of the studies included participants who had higher than average body weight or lipid profile. It is probable that younger healthy individuals will have an attenuated response to dietary factors such as fibre as was seen in a previous review of fibre and blood pressure[[13](#_ENREF_13)] as well as in a review of dietary salt and blood pressure.[[58](#_ENREF_58)]

*Strengths of this review*

This is the first systematic review that reports on the effect of different types of fibre distinguished by their chemical structure on blood pressure in non-diseased populations. It included only RCTs, of at least 6 weeks in duration. More than half of the trials included in this analysis were double blind trials and therefore of high quality. Traditionally, fibre types are categorised as soluble or insoluble however many types of fibre contain a mixture of both and therefore our categorisation based on chemical structure is a strength of this review. Finally, the pooling of data enabled the detection of clinically meaningful differences in blood pressure. The numbers needed to detect a 5 mmHg difference with sufficient power are estimated to be between 60 and 70 participants.[[59](#_ENREF_59)]

*Limitations*

The evidence presented here is most consistent and most convincing for beta-glucans where there were sufficient trials included. There are also enough data to provide evidence for additional fibre types including arabinoxylan rich, xylans and mannans. However there was a lack of data to enable us to come to any conclusions about alginates, chitosan or pectins or the five fibre types where no data were available. There may be other methods of categorising fibre type based on rheology and molecular weight that are also important in driving change in metabolic risk that we did not look at in this review.

Most of the studies in this review included predominantly overweight or obese participants and the primary aim of many of the studies was weight loss. As many markers of CVD, including blood pressure, are related to weight and weight loss, it was difficult to isolate the contribution of the diet, independently from changes in weight. However, in many of the studies weight loss was similar in both groups and therefore the difference between groups was relatively small. Although the aim of RCTs is to independently assess the contribution of fibre type on blood pressure it is possible that other aspects of the diet were changed in addition to fibre that could have had an impact on blood pressure. Information provided from individual studies indicated that most made a reasonable attempt to maintain the macro-nutrient content of the diet. In addition, some of the studies were double blind and used a fibre supplement which made it less likely that other aspects of the diet could have been altered to a great extent. Additional plant sources of fibre such as fruit, vegetables and legumes which contain large amounts of active compounds including protein, were excluded from the analysis in order to isolate fibre.

Although included in the search strategy, the review did not include any results from children and included only one trial recruiting adolescents and therefore the results from this review cannot be extrapolated to younger age groups. This was part of a larger review and, therefore, some studies which only reported results in figures were excluded, and we did not contact authors for their data.

*Further recommendations*

Many countries include recommended levels of total fibre as part of nutrition policy but specific types of fibre are rarely mentioned. In the UK 18 g of NSP daily are recommended.[[60](#_ENREF_60)] A third of this could come from beta-glucan rich food. Beta-glucans were provided to participants in the form of cereal (both hot and cold) as well as baked goods such as bread, muffins, biscuits and cereal bars. An increase in the region of 5 g of beta-glucans could be achieved with a daily bowl of porridge or oat bran cereal together with an enriched snack such as a cereal bar. The results from this review together with the results from previous reviews on fibre and blood lipids[[61](#_ENREF_61)] provide strong evidence of the multiple health benefits of beta-glucans. Blood pressure and blood lipids are both important markers of CVD and therefore encouraging a higher intake of beta-glucan rich food has the potential to improve the risk factors for heart disease and stroke.

More research is needed in normal weight, healthy individuals which may necessitate larger sample sizes and longer follow up times to improve power.

*Conclusion*

Beta-glucan rich foods containing oats appear to be particularly beneficial in terms of reducing systolic and diastolic blood pressure. There was limited evidence that other fibre types also have a beneficial effect on blood pressure even when consumed in large amounts.

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**Table 1: Trial characteristics**

| **First Author, year**  | **Characteristics of participants** | **Design & length of f/u** | **N of partici-pants** | **Intervention design** | **Diet characteristics** | **Difference in fibre (g)** | **Difference in weight loss in kg1** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Andersson, 2007[[44](#_ENREF_44)] | Sweden27% MaleMean age: (59)Mean BMI: (28) ≥ 1 CHD risk factor | Crossover 6 weeks | 34 | ArabinoxylansSubstitution with wholegrain foods (Bread, bread, muesli & pasta) Minimum 50% wholegrain in provided foods = 112g wholegrain/day. | Intervention. g/d: C 143 P 28 F 8, Energy: 3180kJ/d, Fibre g/d:18Control. g/d: C 145 P 23 F 14, Energy: 3340kJ/d, Fibre g/d:6 | 12 | Values not reported |
| Bell,1990[[26](#_ENREF_26)] | USA100% MaleAge range: 24-59Body weight >130% of ideal Free of chronic disease | Parallel 6 weeks | 60 | Pectins & XylansSubstitution with Pectin or psyllium enriched cereals compared with cornflakes50% total soluble fibre in cereal was from pectin. | Not reported | n/a | 0.6 (Pectins)0.1 (Xylans) |
| Birketvedt,2000[[31](#_ENREF_31)] | Norway100% FemaleMean age: (40)Mean BMI: (28) | Double blindParallel 24 weeks | 53 | XylansSupplementation with tablets containing 6g of grain/citrus fibre compared with placebo tablets. | Not reported  |  | Values not reported |
| \*Cairella,1995[[40](#_ENREF_40)](Cairella *et al.*, 1995) | Italy27% MaleMean age: (36)BMI: (37) | Double blindParallel 60 days | 30 | XylansSupplement of citrus fibre tablets containing 6g of fibre compared with placebo | Not reported | n/a | Values not reported |
| Charlton*.*, 2011[[48](#_ENREF_48)] | Australia48% maleMean age: (51)Mean BMI: (27) | Parallel 6 weeks | 90 | Beta-glucansSubstitution with oat porridge and oat based cereal bars (3g fibre) with puffed rice and wheat bars as control | Intervention:.%E C 46 P 20 F 29 Control:.%E C 47 P 19 F 31  | n/a | 0.7 |
| Davy,2002[[27](#_ENREF_27)] | USA100% MaleMean age: (59)Mean BMI: (29) DBP 85-99mm and/ or SBP 130-159 mmHgFibre <30g/d | Parallel 12 weeks | 36 | Beta-glucansSubstitution with 60g oatmeal and 76g oat bran ready-to-eat cold cereal (14g/day of fibre, 5.5g/d beta-glucan) compared with wheat based control. | Intervention1. g/d: C 112 P 14 F 3, Energy: 2008kJ/d, Fibre g/d:14Control:. g/d: C 95 P 21 F 8, Energy: 2146kJ/d, Fibre g/d:14 | 0 | 0.2 |
| De Bock, 2012[[25](#_ENREF_25)] | New Zealand100% male Age:15-16 yearsMean BMI: (26) | Crossover Participant blind6 weeks | 45 | XylansSupplementation with 6g/day psyllium supplement compared with 6g/day of potato starch control. | Not reported | n/a | Values not reported |
| Grube., 2013[[49](#_ENREF_49)] | Germany26% MaleMean age: (45)Mean BMI: (29) | Double blindParallel 12 weeks  | 123 | MannansSupplementation with two tablets of IQP fibre supplement taken 3 times per day after meals compared with cellulose tablet placebo. | Not reported | n/a | -2.5 |
| He,2004[[47](#_ENREF_47)] | USA40% MaleMean age: (48)Mean BMI: (29) | Double blindParallel 12 weeks | 110 | Beta-glucansSubstitution with 60g oat bran in a muffin and 84g of oatmeal squares cereal dailyfibre 7.7g/d compared with refined wheat and corn control. | Intervention:. g/d: C 113.3 P 24 F 13.7, Energy 652 kcal/d, Fibre g/d:16Control: 2. g/d: C 108.4 P 10.8 F 11, Energy 567 kcal/d, Fibre g/d:3 | 13 | 0.7 |
| Jensen, 2012[[62](#_ENREF_62)] | Denmark33% maleMean age: (43)Mean BMI: (34) | ParallelDouble blind 12 weeks | 80 | AlginatesSupplementation with Alginate supplement as a blackcurrant flavoured powder mix mixed with water 3 times per day compared with maltodextrin control. | Intervention:.Energy 1638kcal/dControl: .Energy 1608kcal/d | n/a | 1.2 |
| Kristensen*.*, 2011[[33](#_ENREF_33)] | Denmark100% female (post-menopausal)Mean age: (60)Mean BMI: (30) | Parallel 14 weeks  | 72 | ArabinoxylansSubstitution with 105g wholegrain foods daily compared with low fibre cereal foods. | Intervention: Energy 2MJ C 87g/d P 17g/d F 7g/d fibre 11 g/d Control: Energy 2MJ C 86 g/d P 16g/d F 7g/d Fibre 5g/d | 6 | 0.9 |
| Landin,1992[[28](#_ENREF_28)] | Sweden100% MaleMean age: (52)Mean BMI: (25) | Double blindCrossover 6 weeks | 25 | MannansSupplementation with 10g guar given in a glass of water, 3 times a day before meals compared with starch placebo. | Intervention:. g/d: C 445 P 14 F 92, Energy 2875 kcal/d Control: g/d: C 445 P 14 F 92, Energy 2875 kcal/d | n/a | Values not reported |
| Lehtimaki,2005[[63](#_ENREF_63)] | Finland42% MaleMean age: (44)Mean BMI: (26) Stratified by apolipoprotein E genotype | Double blindCrossover3 months | 130 | ChistosanSupplementation with 1.2 g chitosan twice daily (total 2.4g/d) compared with starch capsules. | Not reported  | n/a | 0 (carrier)0.2 (non carrier) |
| Maki,2007[[43](#_ENREF_43)] | USA55% MaleAge: >40 BMI: (32) SBP 130-179mmHg DBP 85-109mmHgFibre <20g/d | Parallel 12 weeks | 97 | Beta-glucansSubstitution with 90g/d oat bran cereal + 60g/d oatmeal + 20g/d powdered oat beta-glucan. 7.7g/d beta-glucan compared with wheat cereal and low fibre supplements. | Intervention:. g/d: C 124.3 P 20.3 F 8.9, Energy: 658 kcal/d, Fibre g/d:17Control: g/d: C 139.5 P 10 F 2.1Energy: 641 kcal/d, Fibre g/d:2 | 15 | Values not reported |
| \*Marett,2004[[35](#_ENREF_35)] | USA52% MaleMean age: (29)BMI: mean not reported | Double blindParallel 6 months | 54 | ArabinoxylansSupplementation with 8.4g/d Larch or Tamarack arabinogalactan added to food or drinks compared with rice starch placebo. | Not reported | n/a | Values not reported |
| \*Niv, 2012[[38](#_ENREF_38)] | Israel48% maleMean age: (36)Mean BMI: (25) | Parallel 8 weeks  | 48 | FructansSupplementation with 500ml Orange juice daily containing 11.5g Levan fibre compared with orange juice control. | Not reported | n/a | Values not reported |
| Olendzki,2009[[45](#_ENREF_45)] | USA16% MaleMean Age: (48)Mean BMI: (31) | Parallel 3 months | 31 | Arabinoxylans Substitution increasing fibre to 30g/day compared with low fibre control. Both diets low in saturated fat. | Intervention: %E: C 52.1 P F 26.2, Energy: 1511 kcal/d, Fibre g/d:24Control: %E: C 49.9 P F 27.5, Energy: 1523 kcal/d, Fibre g/d:17 | 7 | -1.4 |
| \*Pal, 2012[[42](#_ENREF_42)] | Australia51% MaleAge 18-65BMI 25-40 | Participant blindParallel 12 weeks  | 72 | XylansSupplementation with fibre supplement containing 7g of psyllium mixed with water and taken 3 times per day compared with low fibre control. | Intervention: Energy 7.8MJ, C 46%, P 19%, F 34%, fibre 40g/d Control: Energy 8.2MJ, C 45%, P 18%, F 37%, fibre 20g/d | 20 | Values not reported |
| \*Pasman,1997[[32](#_ENREF_32)] | The Netherlands100% femaleMean age: (41)Mean BMI: (33) | Double blindParallel 14 months | 39 | MannansSupplementation with 20g guar gum in 2x10g doses daily to be consumed in afternoon and evening. Dissolved in 200ml water/coffee/orange juice compared with no supplement.. | Not reported | n/a | Values not reported |
| Reimer, 2013[[50](#_ENREF_50)] | Japan44% MaleAge 20-65Mean BMI: (27) | Double blindParallel 14 weeks  | 64 | MannansSupplementation PGX supplement containing fibre in 5g packets mixed with yoghurt taken 3 times per day compared with placebo containing rice flour in 5g packets mixed with yoghurt. | Not reported | n/a | 0 |
| \*Rigaud,1990[[36](#_ENREF_36)] | France21% MaleMean age: (37)Mean BMI: (29) | Double blindParallel 6 months | 52 | PectinsSupplementation with a dietary fibre tablets (beet, barley, citrus fibre, 90% insoluble) providing 7g/day compared with placebo tablets containing 1g fibre/d. | Not reported | n/a | Values not reported |
| \*Salinardi, 2010[[39](#_ENREF_39)] | USA36% maleMean age : (46)Mean BMI: (30) | Double blindParallel 12 weeks  | 69 | MannansSupplementation with beverage twice daily with meals containing 4.4g of fibre per drink compared to placebo beverage twice daily with meals containing no fibre. | Not reported | n/a | Values not reported |
| Saltzman,2001[[46](#_ENREF_46)] | USA49% MaleMean age: (45)Mean BMI: (26) | Parallel 6 weeks | 43 | Beta-glucansSubstitution with 45g/1000 kcal of rolled oats compared to 45g/1000 kcal of wheat products. | Intervention: g/d: C 229 P 79 F 67, Energy: 7645kJ/d, Fibre g/d:16Control: g/d: C 234 P 82 F 69, Energy: 7833kJ/d, Fibre g/d:12.5 | 3 | Values not reported |
| Schwab,2006[[51](#_ENREF_51)] | Finland44% MaleMean age: (53)Mean BMI: (29) | Double blindParallel 12 weeks | 70 | PectinsSupplementation with Sugar-beet pectin, drinks. 400ml/day, containing 16g pectin, of which 76% soluble fibre compared to polydextrose control. | Not reported | n/a | 0.6 |
| \*Sciarrone,1993[[29](#_ENREF_29)] | Australia100% MaleMean age: (41)Mean BMI: (26) Normal BP only | Parallel 6 weeks | 21 | Arabinoxylan richSubstitution with 35% total energy complex carbohydrates, 20% sugar + fibre intake of approx 20g/1000kcal compared to 25% total energy complex carbohydrates, 20% sugar + fibre intake <8g/1000kcal. | Intervention: g/d: C 339 P 78 F 86, Energy: 2437 kcal/dFibre g/d:41Control: g/d: C 314 P 100 F 114, Energy: 2658 kcal/d, Fibre g/d:24 | 17 | Values not reported |
| \*Smith,2008[[41](#_ENREF_41)] | USA29% MaleAge 22-66yBMI <30 | Double blindParallel 6 weeks | 90 | B GlucansSupplementation with 6g high molecular weight beta-glucan per day was given as a dietary supplement powder, consumed as a beverage with morning and evening meals compared to low molecular weight beta-glucan. | Not reported | n/a | 0.7 |
| \*Swain,1990[[37](#_ENREF_37)] | USA20% MaleMean age: 30BMI: not reported | Double blindCrossover 6 weeks | 24 | Beta-glucansSupplementation with oat enriched muffins or entrees containing a total of 100g oat bran/d compared to low fibre wheat based foods. | Intervention: %E: Fat 35, 2429 kcal, fibre 39g/dControl: %E: Fat 30, 2315 kcal, fibre 18g/d | 21 | -0.1 |
| Wood,2007[[30](#_ENREF_30)] | USA100% MaleMean age: 39Mean BMI: 30 SBP <160mmHg DBP <90mmHg | Double blindParallel 12 weeks | 30 | MannansSupplementation with 3g/d Konjac-mannan compared to maltodextrin placebo supplement. | Intervention: %E: C 12.5 P 28.4 F 60.7, Energy: 6866kJ/d, Fibre g/d:13Control: %E: C 13.3 P 27.1 F 59.6, Energy: 7017kJ/d, Fibre g/d:10 | 3 | -0.1 |

Abbreviations: GI=glycaemic Index

GL=glycaemic load

%E= percent energy

g/d=grams per day

C =carbohydrate

P=protein

F=fat

\*Not included in meta-analysis

1Weight loss of control group-weight loss of intervention group (positive value indicates higher weight loss or less weight gain in intervention group)

Table 2: Assessment of bias for trials included in the meta-analysis

| First author, year | Allocation sequence generation | Allocation concealment | Participant blinding | Researcher Blinding | Incomplete outcome reporting | Selective outcome reporting | Any other bias |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Andersson, 2007 | Unclear | Unclear | Bias | Bias | No Bias | No Bias | No Bias |
| Bell, 1990 | Unclear | Unclear | No Bias | No Bias | No Bias | No Bias | No Bias |
| Birketvedt, 2000 | Unclear | Unclear | No Bias | No Bias | No Bias | No Bias | No Bias |
| Charlton*,* 2012 | No bias | No bias | No Bias | Bias | No bias | No bias | Unclear |
| Davy, 2002 | Unclear | Unclear | Bias | No Bias | No Bias | No Bias | No Bias |
| De Bock*,* 2012 | No bias | Unclear | No bias | Bias | No bias | No bias | No bias |
| Grube, 2013 | No bias | No bias | No bias | No bias | No bias | No bias | No bias |
| He, 2004 | Unclear | No Bias | No Bias | No Bias | No Bias | No Bias | No Bias |
| Jensen, 2012 | No bias | No bias | No bias | No bias | No bias | No bias | Unclear |
| Kristensen, 2011 | Unclear | Unclear | Bias | Bias | No bias | No bias | Unclear |
| Landin, 1992 | Unclear | Unclear | No Bias | No Bias | No Bias | No Bias | No Bias |
| Lehtimaki, 2005 | No Bias | No Bias | No Bias | No Bias | No Bias | No Bias | No Bias |
| Maki, 2007 | Unclear | Unclear | No Bias | No Bias | Bias | No Bias | No Bias |
| Olendzki, 2009 | No Bias | Unclear | Bias | Bias | Bias | Unclear | Unclear |
| Reimer, 2013 | Unclear | Unclear | No bias | No bias | No Bias | No bias | Unclear |
| Saltzman, 2001 | No Bias | Unclear | Unclear | Unclear | Bias | No Bias | No Bias |
| Schwab, 2006 | Unclear | Unclear | No Bias | No Bias | Unclear | No Bias | No Bias |
| Wood, 2007 | No Bias | Unclear | No Bias | No Bias | No Bias | No Bias | No Bias |

**Table 3: Meta-regression and subgroup analysis using random effects model indicating change in blood pressure in mmHg for each higher unit of variable**

| Variable | Outcome | No. studies | Coefficient(mmHg/unit)\* | 95% CI (mmHg/unit) | p value  | Residual I2 (%) |
| --- | --- | --- | --- | --- | --- | --- |
| Mean age at baseline (years) | SBPDBP | 1715 | -0.05-0.05 | -.24 to 0 .13-0.18 to -0.07 | 0.540.38 | 4354 |
| BMI at baseline (kg/m2) | SBPDBP | 1816 | 0.490.14 | -0.22 to-1.20-.42 to 0.69 | 0.170.61 | 3956 |
| Fibre dose for all fibre types (g) | SBPDBP | 2018 | -0.20-0.12 | -.39 to -.02-.19 to -.06 | 0.03<0.01 | 2520 |
| Fibre dose for beta-glucans (g) | SBPDBP | 54 | 0.05-0.07 | -0.76 to 0.86-0.85 to 0.71 | 0.850.74 | 00 |
| Fibre dose for Arabinoxylan rich (g) | SBPDBP | 33 | -0.190.23 | -12.98 to 12.61-6.12 to 6.57 | 0.880.73 | 00 |
| Fibre dose for Mannans (g) | SBPDBP | 43 | -0.29-0.36 | -1.13 to 0.55-1.34 to 0.61 | 0.280.13 | 740 |
| Fibre dose for Xylans (g) | SBPDBP | 33 | -0.57-0.43 | -4.13 to 3.00-3.34 to 2.47 | 0.290.31 | 00 |
| Baseline difference between groups (mmHg) | SBPDBP | 1514 | -0.290.08 | -1.08 to 0.50-.82 to 0.97 | 0.440.86 | 2934 |
| Difference in weight change between groups (kg) | SBPDBP | 1412 | 0.09-1.65 | -1.51 to 1.68-5.66 to 2.37 | 0.910.38 | 2338 |

**Captions**

Figure 1: PRISMA flow chart of included references

Figure 2: Systolic blood pressure and fibre type for all trials

Figure 3: Diastolic blood pressure and fibre type for all trials

Figure 4: Pooled estimates of systolic blood pressure for fibre categorised into low, medium and high dose

Figure 5: Pooled estimates of diastolic blood pressure for fibre categorised into low, medium and high dose

Supplemental Digital Content figure 1: Funnel plot for all trials of any fibre type reporting systolic blood pressure. Estimate is in mmHg.

Supplemental Digital Content figure 2: Funnel plot for all trials of any fibre type reporting diastolic blood pressure. Estimate is in mmHg.

Supplemental Digital Content figure 3: Pooled estimates of systolic blood pressure for double blind fibre trials only

Supplemental Digital Content figure 4: Pooled estimates of diastolic blood pressure for double blind fibre trials only

**Contributors**

VJB was the project lead for the main systematic review concerning dietary carbohydrates and cardio-metabolic health. VJB, DET, CLC searched databases. CPG helped develop search strategies. Article screening was undertaken by VJB, DET, CLC, CELE and CN. Data extraction was carried out by VJB, DET, DCG, CLC, CELE and CN. Quality of data extraction and checking was carried out by DET, CN, CLC and CEW. Statistical analysis was undertaken by CELE and overseen by DCG. CELE wrote the first draft of the manuscript. All authors reviewed the manuscript and contributed to manuscript revisions.