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Revisiones

Dietary fibre: influence on body weight, glycemic control and plasma cholesterol profile

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Abstract

There have been several studies on the effects of dietary fibre on the metabolism. Epidemiologic studies have consistently reported an inverse relationship between dietary fibre and type 2 diabetes mellitus or cardiovascular mortality. This review focuses on observational and experimental studies that examine the effect of different types and sources of dietary fibre on body weight, glucose metabolism and lipid profile.

From the available evidence, we conclude that clinical studies consistently show that the intake of viscous dietary fibre decreases the low density lipoprotein cholesterol and postprandial glucose levels, and induces short term satiety. However, few clinical trials have demonstrated that the intake of dietary fibre has a positive effect on the control of diabetes and body weight.

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Key words: *Dietary fibre. Body weight. Overweight. Obesity. Diabetes. Cholesterol.*

FIBRA DIETÉTICA: INFLUENCIA SOBRE EL PESO CORPORAL, EL CONTROL GLICÉMICO Y EL PERFIL DEL COLESTEROL PLASMÁTICO

Resumen

Existen diversos estudios que han evaluado el efecto del consumo de fibra dietética sobre el metabolismo. Diversos estudios epidemiológicos observaron una relación inversa entre la fibra dietética y la diabetes mellitas tipo 2 o la mortalidad cardiovascular. Esta revisión se basa sobre estudios observacionales y experimentales que han valorado los efectos de diferentes tipos y fuentes de fibra dietética sobre el peso corporal, el metabolismo de la glucosa y el perfil lipídico.

De la evidencia disponible, concluimos que los estudios clínicos consistentemente muestran que la ingesta de alimentos fuentes de fibra viscosa disminuye el colesterol de las lipoproteínas de baja densidad y los niveles de glucosa postprandial e induce la saciedad a corto plazo. Sin embargo, pocos ensayos clínicos han demostrado un efecto positivo sobre el control de la diabetes y el peso corporal.

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Palabras clave: *Fibra dietética. Peso corporal. Sobrepeso. Obesidad. Diabetes. Colesterol.*

Introduction

Dietary fibre is a complex of non-digestible carbohydrates and lignin that are intrinsic and intact in plants and are resistant to digestion and absorption in the small intestine. Dietary fibre promotes beneficial physiological effects such as laxation, reduction in blood cholesterol and postprandial blood glucose modulation. Traditionally dietary fibre has been classified on the basis of its solubility in water (soluble or insoluble). However, the *National Academy of Sciences Panel* for the definition of dietary fibre recommended that the terms soluble and insoluble should be gradually replaced by terms referring to the specific beneficial physiological effects associated with the fibre: viscosity and fermentability.[1]

Dietary fibre is one of the most studied dietary components associated with a good cardiovascular health. Three decades ago it was suggested that a diet rich in non-refined carbohydrates and fibre is associated with

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a lower prevalence of chronic diseases,[2,3] and the role of dietary fibre in human health and bodily mechanisms continues to be a subject of discussion within the scientific community.

Several longitudinal observational studies have shown a significant inverse relationship between fibre intake and cardiovascular and total mortality.[4-8] A combined analysis of 10 prospective cohort studies conducted in the USA and Europe showed a 25% decrease in the risk of coronary disease for each 10 gram increase in fibre intake, after adjusting for several dietary and cardiovascular confounding factors.[9] However, other studies suggest that cardiovascular benefits are, to a great extent, a direct consequence of eating whole-grain bread, green-leafy vegetables, fruit and vegetables, more than dietary fibre itself.[10,11] Recently, Streppel et al.[12] also observed that coronary heart disease mortality and all-cause mortality were reduced by 17% and 9% respectively for every additional 10 g of dietary fibre per day, with no clear associations for different types of dietary fibre.

Epidemiologic studies show that cereals, which are especially rich in insoluble fibre, protect the body from cardiovascular diseases and mortality. However, in clinical studies, only soluble viscous fibre has been demonstrated to have metabolic advantages. This paradox can be explained by the fact that food rich in fibre contains other phytochemical compounds that have been demonstrated to modulate inflammation, oxidation, insulin resistance and cholesterol metabolism. Likewise, it is possible that the effects attributed to fibre intake may instead be an indicator of lifestyle and of a healthy dietary pattern.

This review has focused on observational and experimental studies that have examined the effects of different types and sources (natural and synthetic) of dietary fibre on body weight, glucose metabolism, lipid profile and the prevention of cardiovascular diseases. Controversial issues, as well as limitations and clinical applications, are also discussed.

Fibre and body weight

Proposed mechanism of action

There are several epidemiological studies suggesting an association between fibre intake and obesity or coronary heart disease. However, whether these associations are due to dietary fibre intake alone or to other possible dietary confounders is still a matter of some controversy. Dietary fibre can modulate body weight by various mechanisms. Fibre-rich foods usually have lower energy content, which contributes to a decrease into the energy density of the diet.[13] Foods rich in fibre need to be chewed longer, leading to an increase in the time needed to eat the food and in the feeling of satiety. The fibres which make up viscous solutions also delay the passage of food from the stomach to duodenum and

contribute to an increase in satiety and a decrease in energy consumption.[14] In the intestine, the incorporation of fibre may complicate the union between digestive enzymes and their substrate, thus slowing down the absorption of nutrients.[13] It is also important to note that the effects of dietary fibre consumption on body weight may be related to different gut hormones which regulate satiety, energy intake and/or pancreatic functions.[15]

Observational and epidemiological studies

Observational studies show that the obesity is less frequent in developing countries where there is high fibre consumption. In contrast, in recent decades the increased prevalence of obesity in developed countries has been accompanied by a decrease in the consumption of fibre and complex carbohydrates.[16-19] In addition, it has been reported that vegetarian populations have a low risk of being overweight and obese, which suggests that dietary fibre consumption could play an important role in the prevention and development of obesity.[20]

A cross-cultural study of 16 cohorts in seven countries show that the BMI and subscapular skin fold thickness were inversely associated with total dietary fibre intake, suggesting that a reduced intake of fibre was an important determinant of body fat stores.[18] A cross-sectional study (see table I) also showed that total soluble fibre intake was negatively associated with the energy intake and total body fat content.[16] Alfieri et al.[21] assessed the total fibre intake by means of 3-day food records in 3 population groups (one normal weight group, with a BMI between 20 and 27.0 kg/m^2; one moderately obese group, with a BMI between 27.1 and 40 g/m^2; and one severely obese group, with a BMI > 40.0 kg/m^2). These authors showed that fibre intake was significantly higher in the normal weight group and was inversely associated with BMI after adjusting for several potential confounders (sex, age, education level and income). Recently, new research conducted as part of the PREDIMED study has also shown a significant inverse relationship between total dietary fibre consumption and body mass index or abdominal circumference.[22]

Prospective epidemiologic studies also support the relationship between the high consumption of fibre and a lower increase in weight.[23-25] The *CARDIA (The Coronary Artery Risk Development in Young Adults)* study, a multicenter population-based cohort study carried out over 10 years, examined 2909 young individuals to determine the relationship between total dietary fibre intake and plasma insulin concentrations, weight and other cardiovascular diseases risk factors. After adjusting for BMI and multiple dietary (total energy, fat, alcohol intake) and potential non-dietary confounders (gender, education, physical activity, basal body weight, tobacco use), the study reported an inverse

association between total fibre intake, plasma insulin concentrations and body weight gain[23] (see table I) suggesting that fibre may play an important role in the prevention of insulin resistance and obesity. Individuals consuming higher amounts of fibre have a lower weight gain compared to those consuming lower amounts, independently of the level of total fat consumed. However, it has yet to be established whether body weight gain can be modulated by fibre intake or whether such observations are a consequence of a reverse causation bias or other uncontrolled factors. Controlled trials analyzing the effects of fibre on body weight change are required. Likewise, Liu et al.,[24] in 2003 showed in the *Nurses Health Study* cohort that women in the highest quintile of dietary fibre intake had 49% lower risk of major weight gain than did women in the highest quintile. However, it is important to emphasize that these findings may reflect a healthy dietary pattern rather than fibre intake per se.

Experimental and clinical studies

Epidemiological data and mechanistic studies support the contention that fibre has beneficial effects on body weight regulation; however, there has been inconsistent data from randomized controlled clinical trials that have evaluated how body weight is affected by supplementing Fibre in the diet.[26-29] In a systematic review, Howarth et al.[19] analyzed several clinical trials conducted in small and heterogeneous population samples over relatively short periods of time (from 1 to 12 months). The findings were that the intake of 12 g fibre/day resulted in a decrease of 10% in energy intake and a body weight loss of 1.9 kg over 3.8 months.[19] These authors indicated that this effect on body weight loss was greater in obese subjects.

The literature contains several reports of the effect of fibre supplements on body weight.[19,29] However, only a few of the randomized placebo-controlled clinical trials used body weight (see table II) as the primary variable in the analysis.[13] In addition, long-term (≥ 4 months) trials are rare[30-33] and have only been conducted in small samples of heterogeneous populations (healthy controls, obese or diabetic patients) while using different types and doses of fibre.[19]

One of the best-studied fibre supplements in terms of its effects on body weight is *guar gum*. A meta-analysis of the randomized placebo controlled trials identified 34 *guar gum* trials of which only 11 could be analysed[29] and only 2 were for a period > 14 weeks.[30,33] The meta-analysis concluded that *guar gum* is not efficacious in

Table I
Observational and epidemiological studies examining the association between dietary fibre and body weight

Reference	Participants	Duration of the study	Type of fibre used	Outcomes
Miller et al., 1994[16]	78 participants (23 lean and 23 obese men; 17 lean and 15 obese women)	Cross-sectional	Total dietary fibre intake	Obesity is maintained by a diet rich in fat, added sugar and relatively low in fibre. Dietary fibre consumption was lower for obese men and women than lean men and women.
Alfieri et al., 1995[21]	150 subjects (normal, severely obese and moderately obese)	Cross-sectional	Total dietary fibre intake	Total fibre consumption was significantly higher in the lean group (P < 0.05). Total dietary fibre intake was inversely associated with BMI after adjusting with confounders.
Nelson & Tucker 1996[17]	203 healthy men	Cross-sectional	Total dietary fibre intake	Reported intakes of carbohydrate, complex carbohydrate and dietary fibre were inversely associated with body fat (P= 0.002). The highest-body fat group reported significantly more dietary fibre consumption (P = 0.005) than the leanest subjects.
Ludwig et al., 1999[23]	2909 healthy black and white adults	10 years of follow-up	Total dietary fibre intake	Dietary fibre shower linear associations from lowest to highest quintiles of dietary fibre intake with the body weight and waist-to-hip ratio, after adjusting by confounders.
Kromhout et al., 2001[18]	12763 men	Cross-cultural	Total dietary fibre intake	The average dietary fibre intake was inversely related to population average subscapular skinfold thickness and body mass index.
Tucker & Thomas 2009[25]	252 women free from serious disease, premenopausal and non-smokers,	20 months of follow-up	Total dietary fibre intake	Increasing dietary fibre significantly reduces the risk of women gaining weight and fat. For each 1 g increase in total fibre consumed, weight decreased by 0.25 kg (P = 0.0061) and fat by 0.25 percentage point (P = 0.0052).

Table II
Experimental and clinical studies examining the effect between dietary fibre and body weight

Reference	Participants	Duration and type of the study	Type of fibre used	Outcomes
Tuomilehto et al., 1980[30]	32 women hipercholesterolemic females	Double-blind controlled trial. Patients taking *guar gum* (15 g) or placebo or no medication at all for 4 months.	*Guar gum*	Significantly higher decrease in body weight was seen in subjects taking *guar gum* compared to other two groups.
Hylander & Rossner, 1983[34]	135 members of a weight loss club	100 participants were randomly given one sachet of either bran or *ispaghula* granulate before meals for 2 weeks. 35 controls rated hunger.	Bran or *ispaghula* granulate	No significant differences in weight reductions were observed between the groups. Only when extra dietary fibre was given immediately before meals were reduced hunger feelings observed.
Walsh et al., 1984[35]	20 obese women	Double-blind trial for 8 weeks was conducted. Participants were given two 500 mg *Glucomannan* capsules with 240 ml water, 1h prior to each of three meals per day, or placebo.	*Glucomannan* (from konjac root)	The weight loss was significantly higher in the *Glucomannan* group.
Rösner et al., 1988[26]	62 moderately obese women	Randomized, double-blind, parallel group design for 12 weeks. Participants were treated with a hypocaloric diet and 6.5 g fibre supplement, or placebo.	Dietary fibre supplement	After 12 weeks of treatment, weight loss was similar in both groups.
Ryttig et al., 1989[31]	97 obese women	Randomized, double-blind, parallel controlled trial of 52 weeks duration. Intervention group was treated by a 1200 kcal diet and a dietary fibre supplement of 7 g/d for 11 weeks (Part I), followed by a 1600 kcal diet and a dietary fibre supplement of 6 g/d for 16 weeks (Part II). The placebo group was given a dietary fibre supplement of 6 g/d (Part I) and *ad libitum* diet for the rest of the period.	Dietary fibre supplement	During part I and part II, weight loss was significantly higher in the intervention group than placebo group.
Rigaud et al., 1990[32]	52 overweight patients	Randomized, double-blind, placebo-controlled, parallel group for 6 months of treatment with a hypocaloric diet and a dietary fibre supplement (7g/d) or placebo.	Dietary fibre supplement	After treatment, weight loss in the fibre group was significantly higher than placebo group.
Vita et al., 1992[38]	50 severely obese patients	Parallel trial. Two groups were treated with hypocaloric diet alone or supplemented with 4 g/day of *Glucomannan* for a 3-month period.	*Glucomannan*	The group treated with diet plus *Glucomannan* supplement showed a significantly higher weight loss in relation to the fatty mass alone.
Makkonen et al., 1993[33]	30 menopausal women	Double-blind placebo-controlled parallel-group trial. Intervention group was treated 15 g/d *guar gum* or placebo for a 6-month period.	*Guar gum*	Body weight did not change in either group.
Cairella et al., 1995[39]	30 obese patients	Parallel trial. The patients were treated with a hypocaloric diet supplemented with *Glucomannan* or placebo.	*Glucomannan*	The diet supplement was more effective with *Glucomannan* with placebo.
Rodríguez-Morán et al., 1998[27]	125 women and men with T2DM	Double-blind placebo-controlled study. A period of 6 weeks of diet counselling followed by a 6-week treatment period with *Plantago Psyllium* or placebo in combination a low fat diet were given.	*Plantago Psyllium*	No significant changes were observed in weight between groups.
Birketvedt et al., 2005[36]	176 overweight or obese men and women	Randomized placebo-controlled studies. 5 group treated with a 1200 kcal diet plus a) *Glucomannan*, b) *Glucomannan*, and *guar gum*;, c) *Glucomannan*, *guar gum* and alginat; d) Placebo or e) Alone diet during a 5 weeks period.	*Glucomannan*, *guar gum*, alginat	The hypocaloric diet supplemented with fibres induced significantly the weight loss more than placebo or diet alone.
Salas-Salvadó et al., 2008[40]	200 overweight or obese patients	Parallel, double-blind, placebo controlled clinical trial. The patients were randomized to receive a hypocaloric diet plus 3 g of a mixed fibre dose, twice (b.i.d. group) or three times (t.i.d. group) or placebo for 16 weeks.	*Plantago ovate husk* and *glucomannan*	Weight loss tended to be higher after both doses of fibre than placebo; the differences in changes between groups were not statistically significant. Postprandial satiety increased in both fibre groups compared to the placebo.
Estruch et al., 2009[22]	772 cardiovascular high-risk subjects	Randomized were assigned to a low-fat diet or two recommendations for increasing the vegetables, fruits and legumes intake.	Total dietary fibre intake from natural food	Body weight, waist circumference and mean systolic and diastolic blood pressure significantly decreased across quintiles of fibre intake. Plasma concentrations of C-reactive protein decreased in parallel with increasing dietary fibre (P=0.04).

T2DM: Types 2 Diabetes Mellitus.

reducing body weight and that it is frequently associated with gastrointestinal complaints such as flatulence, diarrhea, abdominal pain, and cramps.[29]

Other types of fibre supplements have been studied, also with inconclusive results with respect to weight control.[34-36] Among these fibres, *Plantago ovata* and *glucomannan* are the most important. A large-scale study performed with *ispaghula husk* showed no significant short-term (3 weeks) differences in loss of body weight when comparing *ispaghula*, bran and control groups.[34] Also, Rodriguez-Morán and coworkers[27] analyzed *Plantago psyllium* to determine the lipid- and glucose-lowering efficacy of this type of fibre. They found that administering 5 g of *Plantago psyllium* had no significant short-term effects (6 weeks) on body weight in type II diabetic patients.[27] In contrast, several studies have demonstrated that *glucomannan* supplements have a significant effect on appetite and body weight. However, only some of these studies were randomized placebo-controlled trials, and all were short-term and performed in small study populations.[35,37-39]

Recently, we evaluated the effect of a mixed fibre supplement on body-weight loss, satiety, tolerability, lipid profile and glucose metabolism in a large sample of overweight or obese patients.[40] We studied 166 overweight or obese patients in a parallel, double-blind, placebo-controlled clinical trial. These patients were randomized to receive a mixed fibre dose *(Plantago ovata husk and glucomannan)* or a placebo twice or 3 times a day in the context of a calorie restricted diet for a period of 16 weeks. Weight-loss tended to be higher for both fibre supplements (-4.52 ± 0.56 and -4.60 ± 0.55 kg) than for the placebo (-3.79 ± 0.58); however, the differences in changes between groups were not statistically significant.[40]

To conclude, there is sufficient evidence that body weight can be controlled by a high intake of fibre in the context of a diet that is high in fruit, vegetables, nuts, legumes, and whole grains. However, fibre supplementation cannot be systematically recommended for weight control because long-term adherence to a fibre supplemented diet is poor in adults[41] and because there is still controversy surrounding the effects of fibre supplements on body weight.

Fibre and glycemic control

Proposed mechanism of action

Slavin and coworkers[42] have shown that viscous soluble fibre plays an important role in controlling postprandial glycemic and insulin responses because of its effect on gastric emptying and macronutrient absorption from the gut.[42] Surprisingly, the most prospective studies have found that insoluble fibre but not soluble fibre is inversely related to the incidence of type 2 diabetes mellitus (T2DM).[43-47] To date, the physiopathology mechanisms that explain
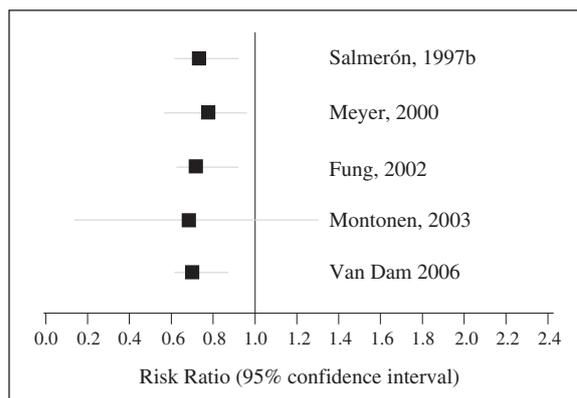
Fig. 1.—*Low versus high whole-grain intake and relative risk (95% IC) of type 2 diabetes incidence.*

the beneficial effects of insoluble fibre have still not been clearly delimited.

Observational and epidemiological studies

The results of prospective cohort studies (table III) were homogenous and consistently show that the risk for T2DM decreased between 21% and 82% (see fig. 1) across quintiles or quartiles (mean intake of 16 g/day to 302 g/day) of whole grain intake[45,46,48-50] and between 21% and 30% (see fig. 2) across quintiles (mean intake of 2.3 g/day to 7.5 g/day) of total cereal fibre intake.[43-47,51,52] This association was observed in both women and men and was statistically significant in all but one of the studies.[46] However, it is important to emphasize that no analysis was carried out to determine whether this association differs according to the type of grain consumed or to determine the extent to which the structure of the grain or its constituents such as magnesium or vitamin E may explain its protective effect.

All the studies reviewed have analyzed large cohorts from 4316 to 91,249 participants from 6 to 12 years of follow-up. However, because all of these studies were performed in American individuals (except for that of
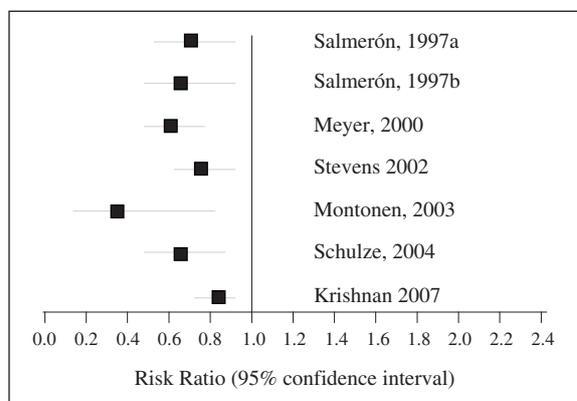
Fig. 2.—*Low versus high cereal fiber intake and relative risk (95% IC) of type 2 diabetes incidence.*

Table III
Observational and epidemiological sudies examining the association between dietary fibre and glycaemic control

Reference	Participants	Duration of the study	Type of fibre used	Outcomes
Salmerón et al., 1997[43]	42759 men without T2DM or CVD	6 years of follow-up	Cereal fibre	523 incident cases of T2DM were reported. Cereal fibre was inversely associated with risk of T2DM (RR = 0.70; 95% CI, 0.51-0.96). The combination of a high glycaemic load and low cereal fibre intake increased the risk of T2DM (RR = 2.17, 95% CI, 1.04-4.54) compared with a low glycaemic load and high cereal fibre intake.
Salmerón et al., 1997[44]	65173 women without T2DM or CVD or cancer	6 years of follow-up	Cereal fibre	915 incident cases of T2DM were reported. Cereal fibre was inversely associated with risk of T2DM (RR = 0.72; 95% CI, 0.58-0.90). The combination of a high glycaemic load and low cereal fibre intake further increased the risk of T2DM (RR = 2.50, 95% CI, 1.14-5.51) compared with a low glycaemic load and high cereal fibre intake.
Meyer et al., 2000[45]	35988 older Iowa women free initially from T2DM	6 years of follow-up	Whole grain and and total dietary fibre intake	1141 incident cases of T2DM were reported. Multivariable-adjusted relative risks of diabetes were 1.0, 0.99, 0.98, 0.92 and 0.79 (P for trend: 0.0089) across quintiles of whole grain intake; and 1.0, 1.09, 1.0, 0.94 and 0.78 (P for trend = 0.005) across quintiles of total dietary fibre intake.
Fung et al., 2002[49]	42898 men without T2DM o CVD	≤ 12 years of follow-up	Whole grain	1197 incident cases of T2DM were reported. The RR between the highest and lowest quintiles of whole grain intake was 0.58 (95% CI: 0.47, 0.70; P for trend < 0.0001).
Stevens et al., 2002[51]	12251 African Americans and whites, adults free initially from T2DM	9 years of follow-up	Total dietary fibre, fruit fibre, legumes fibre, cereals fibre intake	1147 incident cases of T2DM were reported. The hazard ratio for the fifth compared with the first quintile of cereal fibre was 0.75 (95% CI 0.60-0.92) in whites and 0.86 (0.65-1.15) in African Americans.
Montonen et al., 2003[46]	2286 men and 2030 women free initially from T2DM	10 years of followed	Whole grain and cereal fibre	54 men and 102 women incident cases of T2DM were reported. Whole grain and cereal fibre consumption was associated with a reduced risk of T2DM. The RR between the highest and lowest quartiles of whole grain and cereal fibre consumption was 0.65 (95% CI: 0.36, 1.18; P for trend = 0.02) and 0.39 (95% CI: 0.20, 0.77; P for trend = 0.01).
Liu et al., 2003[48]	75521 women without T2DM or CVD	10 years of follow-up	Whole grain	The RR between the highest and lowest quartiles of whole grain and cereal fibre consumption was 0.62 (95% CI: 0.53, 0.71; P for trend < 0.003).
Schulze et al., 2004[52]	91249 women without T2DM or CVD	8 years of follow-up	Cereal fibre	1964 incident cases of T2DM were reported. Multivariable-adjusted relative risks of diabetes were 1.0, 0.85, 0.87, 0.82 and 0.64 (P for trend = 0.004) across quintiles of cereal fibre intake.
Van Dam et al., 2006[50]	41186 women without T2DM or CVD	8 years of follow-up	Whole grain	1964 incident cases of T2DM were reported. Daily consumption of whole grain was associated with a lower risk of T2DM compared with consumption less than once a week. After mutual adjustment, the hazard ratio was 0.73 (0.63-0.85; P for trend = 0.0001) for whole grains.
Krishnan et al., 2007[47]	59000 black women with T2DM, CVD or cancer	8 years of follow-up	Cereal fibre	1938 incident cases of T2DM were reported. Cereal fibre intake was inversely associated with risk of T2DM with an RR of 0.82 (95% CI, 0.70-0.96) for the highest *vs* lowest quintiles of intake.

T2DM: Types 2 Diabetes Mellitus; CVD: Cardiovascular Disease; RR : Relative risk.

Table IV
Experimental and clinical studies that have examined the effect between dietary fibre and glycemic control

Reference	Participants	Duration and type of the study	Type of fibre used	Outcomes
Giacco et al., 2000[55]	63 patients with type 1 diabetes	Randomized parallel groups. 32 patients (intervention group) and 31 (control group) were randomized to follow a high-fibre or low-fibre diet for a 24-week period.	Total dietary fibre intake from natural foodstuff	After 24 weeks, the patients that followed the high-fibre diet decreased both mean daily blood glucose concentrations ($p < 0.001$), HbA1c ($p < 0.05$), and a number of hypoglycaemic events compared with those that followed the low-fibre diet.
Chandalia et al., 2000[56]	13 patients with T2DM	Randomized, crossover study. The patients were assigned to follow 2 diets, each for 6 weeks: a moderate dietary fibre diet (24g: 8g of soluble and 16 g of insoluble fibre) and a high-fibre diet (50 g: 25g of soluble and 25 g of insoluble fibre).	Food not fortified with fibre	To 6 weeks, the mean daily preprandial plasma glucose concentrations were 13 mg/dl lower during the high-fibre diet period compared with the low-fibre diet period. The high-fibre diet also significantly lowered the area under the curve for 24-hour plasma glucose and insulin concentrations by 10% and 12% respectively, which were measured every two hours.
Pereira et al., 2002[53]	11 overweight or obese subjects, hiperinsulinemic,	Randomized, nonblinded, crossover controlled trial. 2 periods, each of 6 weeks, with a diet including 6-10 servings/d breakfast cereal, bread, rice, pasta, muffins, cookies and snacks of either whole or refined grains were assigned.	Whole grain	Fasting insulin was, significantly, 10% lower during the consumption of the whole grain than during consumption of the refined-grain. After the whole grain diet, the area under the 2h insulin curve tended to be lower than after the refined-grain diet.
Weiker et al., 2006[54]	17 overweight or obese subjects with normal glucose metabolism	Randomized, single-blinded crossover controlled trial. Subjects ingested three macronutrient-matched portions of control (white bread) or oat fibre-enriched white bread (enriched with 10.4 g insoluble fibre per portion) per day for a 3-day period.	Oat-fibre	Increased insoluble dietary fibre intake for 3 days significantly improved whole-body insulin sensitivity.

T2DM: Types 2 Diabetes Mellitus; CVD: Cardiovascular Disease; RR : Relative Risk.

Montonen et al.[46] which was conducted in Finland), the generalizability of these findings is uncertain. Furthermore, the evidence from the prospective cohort studies is considered too weak to establish a definitive conclusion regarding the preventive effect of whole grain or cereal fibre consumption on the development of T2DM.

Experimental and clinical studies

Several randomized controlled trials (table IV) have been performed to determine the effect of dietary fibre from natural food on insulin sensitivity;[53,54] blood glucose control;[55-57] and hypoglycemic episodes[55] or HbA1c levels.[55,57,58] However, all of them were short term studies.

Several studies conducted during the last decade regarding the effect of dietary fibre on insulin sensitivity provide controversial results. In a randomized cross-over study, Pereira and co-workers used a euglycemic-hyperinsulinemic clamp test to measure

insulin sensitivity in 11 obese hyperinsulinaemic participants. Their results showed that a whole grain diet led to a postprandial improvement in insulin sensitivity when compared to a refined grain diet.[53] Likewise, Weicker and co-workers[54] used the same method to measure insulin sensitivity in overweight and obese women and found that this increased after 3 days of a diet containing bread enriched with insoluble fibre compared to another diet containing white bread. Giacco and co-workers[55] carried out a 6-months randomized parallel study comparing a diet containing 50 g/d of soluble fibre with a diet containing only 15 g/d of fibre. They found an improvement in the daily blood glucose profile and the HbA1c levels and a marked reduction in the number of hypoglycemic events.

Chandalia et al.[56] also demonstrated that high-fibre diets contributed to better metabolic control in thirteen T2DM diabetic patients. In a cross-over study, patients were randomized to a diet containing a moderate amount of fibre (8 g of soluble fibre and 16 g insoluble fibre) or to a diet containing a high amount of fibre (25 g of soluble fibre and 25 g insoluble fibre). Plasma glu-

cose concentrations were significantly lower for the high fibre diet than for the low-fibre diet[56]. In contrast, Jenkins et al.[57] used a cross-over design to study the effects of a diet high in cereal fibre in T2DM patients and found no improvement in conventional markers of glycemic control after 3 months of intervention.

In clinical studies using fibre supplements, it appears that only the viscous variety of soluble fibre plays a significant role in reducing postprandial glycemia. This is in contrast to the findings from prospective studies where insoluble fibre, but not soluble fibre, from both of natural food source was inversely related to the risk of diabetes.[45,46] However, a recent meta-analysis of prospective studies showed no major difference in the relative risk of diabetes for either soluble or insoluble fibre. This could be because the amount of soluble fibre consumed in an average diet is not sufficient to cause a significant effect.[59]

The most commonly studied fibre supplements in terms of their effect on the postprandial glucose and insulin response are *Psyllium* or *Plantago ovata*,[60,61] *glucomannan*,[62,63] *guar gum*[64,65] and *pectin*.[66,67] In almost all cases the intake of this type of fibre was associated with a better postprandial metabolic response, although this was not in case of Glore's study.[64]

Currently, the *American Diabetes Association* recommends that diabetic patients consume 14 g/1000 kcal/day of fibre because a high amount of fibre is necessary to improve glycemic control. This amount is between 2 and 3 times higher than that consumed by individuals in many developed countries.[68]

High fibre diets, in general, are well accepted and palatable for the majority of the population, as is observed in several prospective studies and clinical trials. However, long-term compliance with fibre supplemented diets is poor in adults. In addition, soluble fibre supplements are frequently associated with gastrointestinal complaints. If fibre is to be considered a long-term therapeutic option for diabetic patients in the future, an effective and well-tolerated source needs to be found.

In summary, the short term beneficial effects of fibre on the glycemic profile have been widely documented; however, there have not been enough trials to prove categorically that soluble fibre supplements would be an effective tool for ameliorating glycemic control in the long term. Although prospective studies have shown that fibre in the diet protects the individual from diabetes, clinical trials are necessary in the future to corroborate the beneficial effects of fibre in monitoring the incidence of diabetes.

Influence of fibre on the serum levels of cholesterol

Proposed mechanism of action

Several mechanisms have been described in order to explain the effect of dietary fibre on blood lipid profile.

In this sense, the hypocholesterolaemic action of fibre is partly mediated by a lower absorption of intestinal bile acid because the interruption of the enterohepatic bile acid circulation,[69] thus increasing faecal bile acid loss· and its de novo synthesis in liver.[70] Moreover, Fernández[71] and Trautwein and co-workers[72] suggested that the physicochemical properties of soluble fibre result in important modifications in volume, bulk and viscosity in the intestinal lumen, which will alter metabolic pathways of hepatic cholesterol and lipoprotein metabolism, also resulting in lowering of plasma LDL-cholesterol. Other studies suggest that dietary fibre increases the enzymatic activity of cholesterol-7-α-hydroxylase, the major regulatory enzyme in the hepatic conversion of cholesterol to bile acids[73] contributing to a higher depletion of hepatic cholesterol. Secondarily, this depletion leads to a stimulatory effect on the enzymatic activity of HMG-CoA reductase increasing the endogenous cholesterol synthesis. However, at the same time, there is an increase in the number of LDL-c receptors and in the recruitment of the esterified cholesterol from the circulating LDL-c particles.[74] Jenkins[75] and Jones and coworkers[76] described a reduction in the hepatic lipogenesis stimulated by insulin. It has also been suggested that the fermentation of dietary fibre by the intestinal microflora could modify the short chain fatty acids production thus reducing the acetate and increasing the propionate synthesis. This in turn reduces the endogenous synthesis of cholesterol, fatty acids and very low density lipoproteins.[77,78]

Traditional dietary patterns, characterized by high fibre content, have been associated with lower rates of coronary disease. However, it should be taken into account that foods rich in fibre are also usually rich in a wide range of other bioactive substances which have a clear role in the prevention of cardiovascular disease.[79-81] Likewise, the beneficial effect of diets enriched in fibre on the lipid profile could also be because these diets are traditional low in fat (especially saturated fat) or because they promote satiety and therefore help to protect against overweight and obesity.[82]

Observational and epidemiological studies

Cross-sectional studies have shown that a higher intake of dietary fibre is related to a best lipid profile (table V). Thus, for example, in an analysis of dietary factors and cardiovascular risk performed in a sample of 3,452 Swiss adults, it was observed that a healthy diet characterized by high consumption of dietary fibre was associated with lower rates of serum triglycerides and higher HDL-c.[83] An improvement in lipid profiles associated to a high fibre consumption has also been observed in epidemiologic studies (see table V) carried out on adults in Germany,[84] China,[85] Denmark,[86] France,[87,88] Greece,[89] Italy[90] and Maryland.[91] However, it is well known that can not be established any causal

Table V

Observational and epidemiological studies that have examined the association between dietary fibre and cholesterol profile

Reference	Participants	Duration of the study	Type of fibre used	Outcomes
Van Dam et al., 2003[84]	19750 men and women from 3 Dutch municipalities	Cross-sectional dietary patterns were identified by factor analysis	Total dietary fibre intake	3 dietary factors were identified: Cosmopolitan pattern (rich in fried vegetables, salad); traditional pattern (rich red meat) and refined pattern (rich sugar-beverages and white bread). A higher adherence to Cosmopolitan pattern was significantly associated with higher HDL-c concentrations; the traditional dietary pattern was associated with higher HDL-c and total cholesterol concentrations; and the refined dietary pattern was associated with higher total cholesterol concentrations.
Wu et al., 2003[93]	573 subjects without heart disease	2 years of follow-up	Total dietary fibre intake (viscous and pectin)	The ratio of total cholesterol:HDL-c was inversely related to the intake of total fibre (P = 0.001), viscous fibre (P = 0.05) and pectin.
Lairon et al., 2003[87]	4080 men and women	Cross-sectional	Total dietary fibre intake	The highest dietary fibre intake was associated with a lower body mass index, plasma triglycerides in men. Soluble dietary fibre was less effective.
Lairon et al., 2005[88]	2532 men and 3429 women	Cross-sectional	Total dietary fibre intake (soluble and insoluble)	The highest total dietary fibre and non-soluble dietary fibre intakes were associated with a significantly lower risk of plasma Apo B, Apo B: Apo A-I, cholesterol and triglycerides.
De Castro et al., 2006[92]	316 subjects	7 years of follow-up	Total dietary fibre intake	Changes in serum total cholesterol were inversely associated with changes in total dietary fibre, fruit/fruit juices and vegetables. Each increase of 10 g in the consumption of total dietary fibre was associated with a reduction of 12.5mg/dl in the serum total cholesterol.
Newby et al., 2007[91]	1516 community-dwelling volunteers	Cross-sectional	Whole grain	Whole grain was also inversely associated with a total cholesterol and LDL-c.
Ruixing et al., 2008[85]	986 with hyperlipidemia from two Chinese cities	Cross-sectional	Total dietary fibre intake	Hyperlipidemia was negatively correlated with total dietary fibre intake in both cities.
Berg et al., 2008[83]	3452 participants	Cross-sectional dietary patterns were identified by cluster analysis	Total dietary fibre intake from natural food	A healthy dietary pattern characterized by consumption of dietary fibre was associated with lower rates of serum triglycerides and higher HDL-c.

HDL-c: High Density Lipoprotein cholesterol; LDL-c: Low Density Lipoprotein cholesterol; Apo: Apolipoprotein.

relationship through the results obtained in cross-sectional studies.

A ten year study of a cohort of 2,909 healthy adults aged between 18 and 30 showed a strong negative association between fibre intake and blood pressure and levels of triglyceride, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, and fibrinogen even after adjusting for confounding factors. However these associations were substantially attenuated by adjustment for fasting insulin level suggesting that the effect of fibre on insulin metabolism could also explain the relationship between fibre dyslipidemia or cardiovascular disease.[23] A similar study observed a decrease of 12.5 mg/dl in the serum total cholesterol levels (P < 0.05) for each increase of 10 g in the con-

sumption of dietary fibre intake in a 7- year of follow-up in a cohort of 316 of Japanese-Brazilians subjects.[92] Wu et al.[93] studied a cohort of 573 adults aged between 40 and 60 and found and inverse relationship between the ratio of TC/HDL-c and the total intake of dietary fibre (P = 0.01). This is important because the ratio of TC/HDL-c has been proposed as a good indicator of cardiovascular risk.[94,95]

Experimental and clinical studies

In relation to controlled and randomized clinical trials, since Keys and coworkers[96] established for first time that some types of dietary fibre can decrease

Table VI
Experimental and clinical studies that have examined the effect between dietary fibre and cholesterol profile

Reference	Participants	Duration and type of the study	Type of fibre used	Outcomes
García et al., 2006[100]	11 adults	Randomized, single-blind, and controlled, cross-over intervention. The participants consumed white bread rolls as either placebo or supplemented with 15 g *arabinoxylan* for a 6 week period, with 6 week washout period.	*Arabinoxylan*	Serum triglycerides and Apo A-1 were significantly lower during *arabinoxylan* consumption compared to the placebo.
Naumann et al., 2006[101]	47 healthy subjects	Parallel trial. 22 subjects were assigned to consume a fruit drink control with 5g rice starch (placebo, control group) and 25 subjects with *β-glucan* from oats for a 5-week period.	*β-glucan*	Higher decrease in serum concentrations of total and LDL-c was observed in the *β-glucan* group compared to the control group.
Pittaway et al., 2006[105]	47 free-living adults	Randomized crossover. The subjects were assigned to follow a diet supplemented with *chickpeas* or wheat, each for a 5-week period.	*Chickpea*	The serum total and LDL-c levels were significantly lower after the *chickpea*-supplemented period compared to the wheat-supplemented diet.
Chen et al., 2006[111]	110 participants	Randomized controlled trial. Subjects were randomly assigned to receive 8 g/day of oat bran or control intervention for 3 months.	Oat bran	The results of this study did not support the hypothesis that water soluble fibre intake from oat bran reduces total and LDL-c in subjects with normal serum cholesterol levels.
Cicero et al., 2007[102]	141 hypertensive, overweight patients	Open-label clinical trial. The patients were randomized to the oral ingestion of *psyllium* powder or *guar gum* 3.5 g t.i.d, to be consumed 20 minutes before main two mails or to standard diet.	*Psyllium and guar gum*	Both fibres improved significantly HbA1c, LDL-c and ApoB. *Psylliun* fibre only improved in plasma triglycerides concentration.
Keenan et al., 2007[103]	155 dyslipidemic	Randomized, blind controlled study for a 10-week period. Subjects were randomized to one of 4 treatment groups or control. Treatment groups included either high molecular weight or low molecular weight concentrated barley *β-glucan* at both 3 and 5g doses for a 6-week period.	Concentrated barley *β-glucan*	The mean LDL-c levels decreased in the 5 high molecular weight or low molecular weight concentrated barley *β-glucan by 15% and 13%*, respectively, whereas in both the 3 g/d groups by 9% versus baseline.
Queenan et al., 2007[104]	75 subjects hypercholesterolemic men and women	Parallel, clinical trial. Subjects were randomized to receive 6 g/day concentrated oat *β-glucan* or 6 g/day dextrose (control) for a 6-week period.	Oat *β-glucan*	Total and LDL-c significantly decreased in the oat *β-glucan* group from baseline and the reduction in the LDL-c was higher in the *β-glucan* group than control group.
Maki et al., 2007[106]	27 healthy men	Randomized crossover compared the effects of consuming high fibre oat and wheat cereals on postprandial metabolic profiles.	*β-glucan* o wheat cereal	Peak triglycerides concentration was lower after oat *vs* wheat cereal consumption. Similar tendency was observed with mean area under the triglyceride curve.
Jenkins et al., 2008[108]	28 hyperlipidemic subjects	Randomized crossover. The subjects followed were randomized to receive supplements of strawberries or additional oat bran breads each for a 1-month period with 2 weeks of washout.	Supplement of strawberries or oat bran	Strawberry supplementation reduced damage oxidative to LDL while maintaining reductions in blood lipids.

HDL-c: High Density Lipoprotein cholesterol; LDL-c: Low Density Lipoprotein cholesterol; Apo: Apolipoprotein.

plasma total cholesterol in humans, several studies have shown that a high consumption of dietary fibre, particularly soluble fibre *(pectin, guar gumm, β-glucans, glucomannan, psyllium),* significantly decrease serum levels of TC and LDL-c.[97,98] However, a meta-analysis carried out by Brown et al.[99] indicates that the effects of different types of viscous fibres on TC concentrations are modest. These results were obtained from 67 experimental metabolic studies carried out on 2,990 subjects showing that for each gram of soluble fibre added to the diet, the TC and the LDL-c concentration decreased by 1.7 mg/dL and 2.2 mg/dL respectively.[99]

Epidemiological evidences showed a stronger association with cardiovascular protection of insoluble fibre than soluble fibre.[7] In a recent parallel, double-blind, placebo-controlled clinical trial, 200 overweight or obese patients were randomized to receive a mixed dose of soluble fibre (3 g *Plantago ovata husk* and 1 g *glucomannan)* or a placebo twice or three times daily in the context of an energy-restricted diet for a period of 16 weeks. Differences in plasma LDL-c changes between the groups were significant with greater reductions in the two fibre supplemented groups in comparison to the placebo. A similar pattern was observed for changes in TC: HDL-c and HDL-c: LDL-c ratios.[40] Others clinical trials support the hypocholesterolemic effects of soluble fibre derived both from supplements[100-104] or fibre derived from foods[105-110] (see table VI) on patients at high risk of cardiovascular disease. However, the efficacy of water-soluble fibre intake from oat bran in lowering serum lipid and glucose levels in a free-living population of healthy persons was not demonstrated.[111] In a meta-analysis of 8 controlled trials, it was observed that the hypolipidemic effects of *physillium* in hypocholesterolemic individuals already consuming a low-fat diet beyond reductions achieved with diet only. Results confirm that *psyllium* significantly lowers an additional 4% of serum total and cholesterol and an additional 7% relative of LDL-c concentrations in comparisons to placebo group consuming a low fat diet.[112] In relation to the effect of soluble fibre on HDL-c levels, there is some controversy in the literature. Thus while some studies shown a reduction of plasma HDL-c levels,[113] and others report that it has little, no or an inconsistent effect on HDL-c.[114]

Insoluble fibre such as that from wheat or cellulose has not been reported to have any significant effect on blood cholesterol,[115,116] although as has been mentioned, various epidemiological studies show that the consumption of insoluble fibre is associated with a reduction in the risk of coronary diseases and T2DM, possibly because of the presence, along with dietary fibre, of several bioactive and antioxidant phytochemical substances in foodstuffs[117] or because of the effect that fibre has on blood pressure, body weight and postprandial glycemia or insulin levels.[93]

In clinical practices, diets rich in fibre and dietary fibre supplements have been used to decrease plasma cholesterol and thus prevent cardiovascular diseases. The latest recommendations from the panel of American experts on cholesterol control *(National Cholesterol Education Program*-III, 2002) highlight the benefits of adding a variable quantity of soluble fibre (10-25 g/day) and phytosterols (2 g/day) to the diet as a primary or secondary prevention strategy to delay pharmacological treatment or to avoid unnecessary increases in the doses of hypolipidemic agents. The *American Heart Association* recommends a total dietary fibre intake of 25 g/day to 30 g/day from foods (not supplements) to ensure nutrient adequacy and maximize the cholesterol-lowering impact of a fat-modified diet.[118] Finally, as has been mentioned, both the *American Dietetic Association* and the *Institute of Medicine* advise an intake of 14 g of dietary fibre per 1,000 kcal, or 25 g/day for adult women and 38 g/day for adult men, to protect against cardiovascular disease, and that this fibre should come from high-fibre foods.[1,119]

To conclude, the evidence available shows that the intake of foods that are high in fibre has clear benefits regarding the lipid profile and cardiovascular risk. Although some studies of fibre supplements have shown positive effects regarding the control of blood lipids, the number of adults who adhere to the use of fibre supplements tends to be low. Likewise, these effects are modest when compared with a whole foods approach that encourages the consumption of fibre-rich foods.[119-122] As was concluded at the last World Health Organization workshop on carbohydrates and human nutrition, the best sources of dietary fibre are intact fruits, vegetables, whole grains, nuts and pulses, all of which are rich in potentially cardioprotective components.[82] Consequently, a Mediterranean-style diet rich in those foods should be recommended to improve the lipid profile and to reduce the risk of cardiovascular disease.[123-124]

Acknowledgments

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