Integrated Blood Pressure Control

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REVIEW

# Probiotics and blood pressure: current insights

This article was published in the following Dove Press journal:
Integrated Blood Pressure Control
25 February 2016
Number of times this article has been viewed

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**Abstract:** Gut microbiota play a significant role in host metabolic processes, and recent metagenomic surveys have revealed that they are involved in host immune modulation and influence host development and physiology (organ development). Initially, probiotics are identified as potential therapeutics to treat gastrointestinal disorders and to revitalize the disturbed gut ecosystem. Currently, studies are exploring the potential for expanded uses of probiotics for improving the health conditions in metabolic disorders that increase the risk of developing cardiovascular diseases such as hypertension. Further investigations are required to evaluate targeted and effective use of the wide variety of probiotic strains in various metabolic disorders to improve the overall health status of the host. This review addresses the causes of hypertension and the hypotensive effect of probiotics, with a focus on their mechanistic action.

**Keywords:** probiotics, hypertension, ACE, gut microbiota, metabolic disorders, metagenomics

## Introduction

Probiotics have gained significant importance in the last few decades for their health promoting roles in the prevention and prophylaxis of various gut associated disorders, urogenital, and respiratory infections.[1] They have also been shown to positively affect the host immune system through immunoglobulin production, and trigger cell-mediated immune responses as a frontline of defense.[2,3] Probiotics are described as "live microorganisms which when administered in adequate amounts confer a health benefit on the host".[4] The therapeutic potential and antimicrobial spectra of probiotics is a complex and a multifactorial process which involves the production of organic acids, hydrogen peroxide,[5,6] bacteriocins, bacteriocin-like inhibitory substances,[7,8] short-chain fatty acids (SCFAs), conjugated linoleic acid (CLA), and γ-amino butyric acid (GABA)[9–12] (Figure 1).

Many studies have elucidated the health benefits and clinical effects of probiotics in gastrointestinal abnormalities including irritable bowel syndrome, irritable bowel disease, gastric ulcers, rotavirus, traveler's and antibiotic-associated diarrhea, colorectal cancer, and in the alleviation of lactose malabsorption.[13,14] Recently, probiotics have undergone scientific scrutiny for their potential in reducing the risk of cardiovascular diseases (CVDs) and they have been shown to be effective in improving the health conditions among the tested subjects with cardio-associated diseases.[15–19] The estimated total number of adults with hypertension worldwide during the year 2000 was 1 billion and predicted to rise to 1.58 billion by the year 2025.[20]

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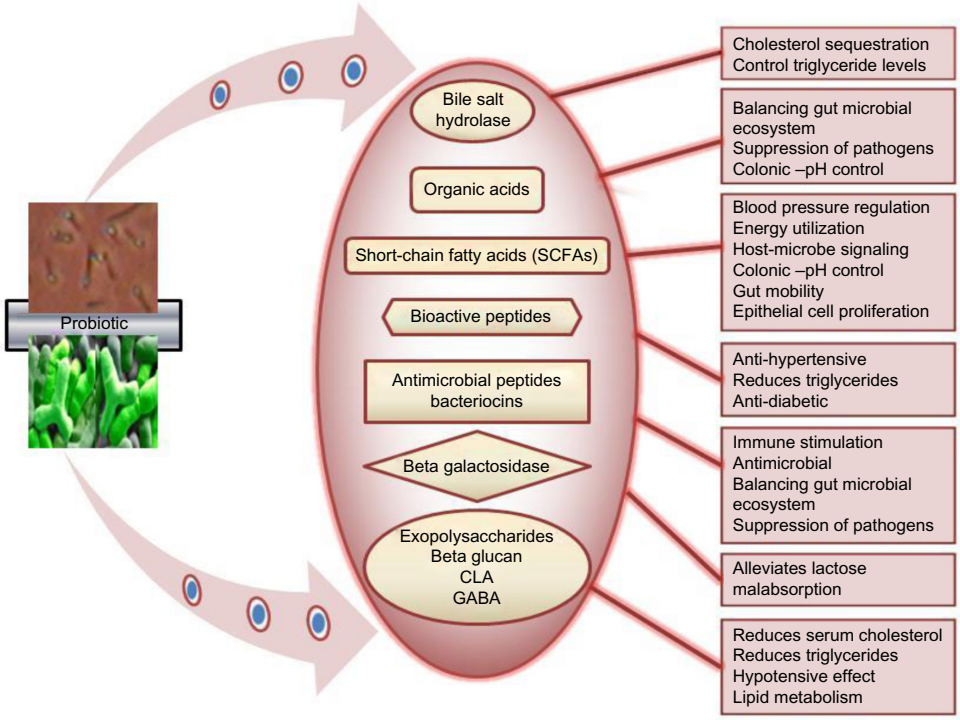


**Figure 1** Probiotics and their metabolite-related health promoting functions.
**Abbreviations:** CLA, conjugated linoleic acid; GABA, γ-amino butyric acid.

Certain probiotic strains such as lactobacilli and bifidobacteria can effectively produce SCFAs, CLA, GABA,[12,21–23] and ACE inhibitory peptides, which have shown potential hypotensive effects.[24–26] Growing public awareness of diet-associated health issues has fueled the functional foods concept, foods that provide specific health benefits over and above their nutritional value,[10] which can be produced under controlled fermentation conditions or enriched with added nutrients. Functional foods enhance the overall nutritional status with added vitamins and minerals including probiotics and their biogenic metabolites.[27] Many studies have shown the health benefits associated with the consumption of functional foods incorporated with probiotics, such as cheese,[28] milk, fermented milk products,[21,29,30] and non-dairy beverages.[31]

In this review we emphasize the biochemistry of hypertension, diet associated disorders, and the role of probiotics in controlling elevated blood pressure (BP) levels, nutritional programming, and the application of probiotic cultures in reducing the onset and development of CVD.

## Gut microbiology and human health

Metagenomics has revolutionized the field of microbiology by paving the way for culture-independent assessment and exploration of microbial communities residing in complex ecosystems. The mammalian gastrointestinal tract (GIT) is among the most densely populated with complex microbial communities and the colon merely harbors a load of ~$10^{14}$ cells/host.[32] The human intestinal microbiota plays a pivotal role in the host's digestive process, gut maturation, epithelial cell development, and a regulatory switch to innate immunity, thereby contributing to host health[33] and many more functions yet to be revealed which are associated with the gut microbiota. The metabolic capacity of the core gut microbiome is so prodigious that it has been considered as the "virtual organ" of the GIT,[34,35] and it is known to influence human health and disease susceptibility in different ways.

Microbial colonization of the host starts during birth, and the composition of the microbiota widely varies throughout host development.[36,37] A variety of factors during and after birth, such as mode of birth (vaginal versus cesarean-section), feeding (breastfed or bottle fed), and antibiotics play a significant role in shaping the gut microbiota,[38] which reflects their proximity in the health-disease state equilibrium during the growth and development of their host.[39] Furthermore, the possible role of early colonizers during infancy and changes in their relative composition of the gut microbiota during childhood that can lead to the accumulation of body weight and obesity has been elucidated.[40] A recent study revealed the presence of unique microbiome in the human placenta and its resemblance to their oral microbiome,[41] suggesting that it is

imperative to map the microbial networks residing at different niches to understand their role in health and disease.

## Intestinal dysbiosis, diet, and metabolic disorders

Recent studies have revealed that many health maladies are as a result of significant perturbation in core gut microbial communities, and many parameters such as host-microbe crosstalk which are intrinsically linked to the microbial ecology and gut functionality. The influence of GIT microbiota composition and their possible link to obesity,[42] diabetes,[43,44] neural disorders,[45,46] brain development,[47] insulin resistance, and other metabolic disorders[48] have been well documented. Furthermore, an aberration in the core-gut microbiota in TLR-5 deficient mice leads to the development of metabolic syndrome.[49] Recently, more evidence has been accumulated by deciphering the role of gut microbiota in developing CVD. For example, gut microbiota metabolizes specific dietary nutrients which belong to the trimethylamine group (eg, choline, phosphatidylcholine, and L-carnitine) resulting in the formation of the pro-atherogenic compound called trimethylamine-N-oxide (TMAO),[50,51] and the carnitine metabolic-pathway associated gene clusters are identified in the genomes of human microbiota.[52] Altogether, compositional sequencing approaches coupled with transcriptomics studies extrapolated the microbe-host interaction and their interplay among various metabolic and biochemical pathways at the molecular level. However, information on the key role-players is still unclear and yet to be determined for modulation or to reprogram the microbial territories to overcome the health ailments.

There are many factors in developing hypertension, such as sedentary lifestyle, lipid and cholesterol metabolism (obesity), sodium sensitivity, personal habits (alcohol consumption, smoking), anxiety, stress, and vitamin D deficiency.[22] There is direct evidence of the factors that control BP such as: a well programmed nutritional strategy and lifestyle, maintaining recommended body mass index (weight loss), reduced salt intake, "dietary approaches to stop hypertension"-type dietary pattern (vegetarian diet, more fruits, vegetables, and low-fat dairy products), increased potassium intake, and moderation of alcohol intake.[53,54]

It has been demonstrated that the risk of developing CVD was significantly lower in vegetarians when compared to omnivores.[55–57] In this context, vegetarians had a significantly higher abundance of *Bacteroides* species and lower abundance of *Prevotella* species in their core gut microbiomes when compared to omnivores, and a reduced risk of developing CVDs.[58] Similarly, a study in men (aged between 41–57 years), whose diet intake chiefly includes vegetables and fruits showed a reduced risk of developing high BP.[59] These studies indicate the importance of dietary habits and their influence on overall health status and GIT microbiota.

One way of modulating the gut microbiota is by the consumption of probiotics, in particular, products containing lactic acid bacteria. In this context, *Lactobacillus* spp. and *Bifidobacterium* spp. have been extensively studied as probiotic microorganisms, while other groups such as *Enterococcus*, *Oenococcus*, *Propionibacterium*, *Bacillus*, *Escherichia coli*, *Clostridium butyricum*, and some yeast strains, such as *Saccharomyces boulardii*, have also been used. In recent years, functional foods containing probiotics have become popular within the food industry due to the heightened awareness of consumers toward these health-promoting foods.[60] Nutritional programming to manipulate the composition of the intestinal microbiota through the administration of probiotics, prebiotics, and or synbiotics (a combination of probiotic and prebiotic) continues to receive much attention for preventing or attenuating the symptoms of metabolic-related diseases.

## Biochemistry of BP

The maintenance of BP homeostasis is a complex process which is carefully regulated by a variety of inputs. Hypertension or BP, defined as systolic blood pressure (SBP) above 140 mmHg and diastolic blood pressure (DBP) above 90 mmHg, is one of the key risk factors for an individual prone to many diseases including coronary heart disease, cerebral hemorrhage, renal and cardiac failure.[22,61,62] BP is controlled by a number of complex biochemical pathways. Typically, the renin-angiotensin system (RAS) is known to play a key role in BP regulation and sodium metabolism. In addition to RAS, the kinin-nitric oxide system, the neutral endopeptidase system, and the endothelin-converting enzyme systems have been shown to produce additional vaso-regulatory peptides.[63] However, RAS has been identified as one of the major controllers of BP among the others identified; which play a central role in controlling the level of other key vasoactive peptides.[63] ACE is a carboxypeptidase responsible for the generation of the potent vasoconstrictor angiotensin II by releasing the C-terminal dipeptide His-Leu from angiotensin I, and is also responsible for the inactivation of the vasodilator bradykinin, which gives rise to a net hypertensive effect.[63] Together these systems produce a wide array of peptides that collectively regulate BP, electrolyte balance, and fluid equilibrium via membrane bound receptors located in

different tissues.[64] RAS comprises of: i) AGT – a globular protein which serves as a substrate for ii) renin – an enzyme that catalyzes the proteolytic conversion of AGT to angiotensin I; iii) ACE (EC 3.4.15.1), a key enzyme of the RAS which controls the arterial BP and water-salt equilibrium in the body;[65] and iv) angiotensin II receptor.[66] The inhibition of ACE could lead to antihypertension. Recently, the influence of two sensory receptors for SCFAs (Olfr78 and GPR41) in BP regulation has been identified.[67] BP is a multifactorial trait which is regulated by multiple biochemical pathways and all the networks are firmly interlinked.

## Gut microbiota, probiotics, and BP homeostasis

Genomes of lactic acid bacteria (LAB) encode an array of proteolytic cassettes and peptide transporters.[68] In general, LAB are cell factories for many proteolytic enzymes (present on cell envelope and intracellular peptidases) which are involved in the hydrolysis of peptide bonds generating short oligopeptides.[69,70] Probiotics have been reported to exert ACE-inhibitory activity by producing antihypertensive bioactive peptides which are released during protein hydrolysis.[10,71] Similar to ACE-inhibitory peptides, other peptides, casokinins and lactokinins, are also being released during enzymatic proteolysis of milk proteins and microbial fermentations.[72] Hence, fermented milk products that are rich in bioactive peptides are considered as natural dietary sources to control hypertension. In addition to that, probiotic cultures with certain traits such as exopolysaccharides,[73] CLA,[74] and GABA production[22,75] positively influence the host lipid metabolism and gut microbial compositions (Figure 1). The SCFAs produced by gut microbes, in particular propionate modulates BP levels via Gpr41 and Olfr78 receptors. Furthermore, *Olfr78* knockout mice with reduced gut microbial biomass upon antibiotic treatment showed elevated BP levels.[76] Similarly, reduced microbial richness and diversity has been observed in spontaneously hypertensive rats, with an increase in Firmicutes/Bacteroidetes ratio and decrease in acetate, butyrate-producing microbes,[77] clearly indicating that our gut microbiota are master regulators of hypertension.

## Vitamins, minerals, and BP

Deficiency in vitamin and mineral levels are also involved in developing BP. Vitamin D has been identified as one of the key role-players, among others (vitamin C and E). An insufficient vitamin D level has been observed in 50% of the world's population and hypovitaminosis D leads to the development of hypertension. Furthermore, the antihypertensive effects of vitamin D are mediated by renoprotection, prevention of secondary hyperparathyroidism, vasodilation, suppression of the renin-angiotensin-aldosterone system, and anti-inflammatory effects have also been validated.[78,79] Studies have shown the association between vitamin D deficiency and elevated BP levels among the individuals tested.[78]

Oral administration of probiotic *Lactobacillus reuteri* National Collections of Industrial, Marine and Food Bacteria (NCIMB) 30242 (Cardioviva) increased serum vitamin D levels by 14.9 nmol/L and the levels of other vitamins (A, E and β-carotene) were unaffected.[80] Intensive research is required to understand the vitamin biosynthesis pathways of probiotic bacteria in vivo. Such studies aid us in developing live vitamin delivering cultures to combat vitamin deficiencies in the gut microenviroments. Furthermore, probiotic cultures are known to produce B vitamins such as folate (vitamin $B_9$)[81] and vitamin $B_{12}$,[82,83] which could be interesting in cases of vitamin deficiency. Until now only one study had shown the improvement of vitamin D levels upon probiotic administration in human subjects, therefore, there is a need for more clinical trials to support this hypothesis. The beneficial role of probiotics in improving cardiovascular health and in the reduction of BP cannot be ruled out; in order to confirm this role, more extensive studies are needed to understand the mechanisms underlying probiotic action. In a review by Ness et al, some studies have shown an inverse association between plasma vitamin C levels and BP, and a few reported an inverse association with vitamin C intake.[84]

In a recent meta-analysis, it has been found that a daily dose of vitamin C (500 mg) for a period of 8 weeks significantly reduced DBP by 1.67±0.72 mmHg.[85] In contrast, administration of 500 mg of vitamin C for 5 years had no effect on BP.[86] In conclusion, the association between vitamin C and controlling BP remains unclear due to the inconsistent results observed among research studies. Many minerals are involved in controlling BP levels; among them the major minerals positively involved in BP regulation are potassium, magnesium, and calcium.[87] A study has shown that consumption of yogurt containing probiotic strains (*Lactobacillus casei*, *L. reuteri*, and *Lactobacillus gasseri*) containing yogurt increased apparent calcium absorption in growing rats.[88] The ability of probiotics and prebiotics to increase micronutrient absorption has been examined in different studies. Although the obtained results were not uniform, an increased rate of mineral absorption was noticed in probiotic groups.[89] In summary, due to the lack of a large

number of studies on probiotics and their associative link with increased vitamin levels and mineral absorption, this area is still unclear and a solid conclusion cannot be drawn regarding the role of probiotics with respect to vitamins and minerals. Therefore, it is advisable to monitor the key vitamin and mineral levels in probiotic clinical trials to extrapolate the link between them.

## Probiotics as antihypertensive agents

A substantial body of evidence firmly supports the health benefits and clinical effects associated with probiotics and probiotic fermented foods based on in vitro and in vivo studies. In recent years probiotics and their potential role in maintaining cardiovascular and renal health has received much attention among the scientific communities. Numerous studies have shown either moderate or significant reduction in the ratios of SBP/DBP (Table 1). For example, administration of sour milk fermented with *Lactobacillus helveticus* LBK-16H containing bioactive tripeptides (commercialized as Evolus®; Valio Dairy, Helsinki, Finland) for 21 weeks reduced the mean SBP to 6.7 (±3.0) mmHg in 36 hypertensive subjects when compared to the control groups.[26] Similarly, a mean reduction of SBP 5.2 (±8.1) mmHg and DBP 1.7 mmHg has been recorded in borderline hypertensive men (aged 23–59 years) given sour milk fermented with *L. helveticus* and *Saccharomyces cerevisiae* containing tripeptides (commercialized as Ameal S; Calpis Food Industry, Tokyo, Japan).[90] It has been shown that administration of *L. casei* (LEx) cell lysate reduced BP, triglycerides, plasma cholesterol, and glucose levels when compared with the control group.[91] In a study, oral administration of probiotic cultures *Lactobacillus rhamnosus* GG and *Streptococcus thermophilus* containing milk along with vegan food significantly improved lipid profiles and controlled the coliforms in the colon of rats.[92] *L. helveticus* (LBK-16H strain) fermented sour milk containing ACE-inhibitory tripeptides attenuated the development of hypertension in spontaneously hypertensive rats.[93] In a study, milk fermented with *L. casei* strain Shirota and *Lactococcus lactis* YIT 2027 and enriched with GABA (1 mg/mL) significantly reduced the mean SBP (17.4±4.3 mmHg) and DBP (7.5±5.7 mmHg) in mildly hypertensive patients.[22] Furthermore, a meta-analysis based on 14 randomized placebo-controlled clinical trials has shown that probiotic fermented milk significantly reduced both SBP and DBP in pre-hypertensive and hypertensive subjects.[94] Tanida et al showed that intraduodenal injection of *Lactobacillus johnsonii* La1 ($1\times10^{8-9}$ CFU/day), or its metabolites, reduced hypertension and renal sympathetic nerve activity in urethane-anesthetized rats. This study suggests that La1 or its metabolites might lower BP by changing autonomic neurotransmission via the central histaminergic nerves and the suprachiasmatic nucleus in rats.[95] In a double-blind, randomized placebo-controlled trial, consumption of a *Lactobacillus plantarum* 299v ($2\times10^{10}$/CFU/mL/day) fermented food product by 36 smokers for 6 weeks significantly reduced SBP (13±4 mmHg, $P<0.001$). Moreover, significant reductions were also observed in fibrinogen and low-density lipoprotein cholesterol, leptin, IL-6, and F2-isoprostane concentrations, which serve as biochemical markers for lipid peroxidation and oxidative stress.[96] Lactic acid bacteria are able to metabolize the complex milk protein and aid in the release of short bioactive peptides which have ACE-inhibitory activity, thereby contributing to the modulation of hypertension.[71,97,98] In another study, fermented soy milk probiotic cocktail (*L. casei*, *Lactobacillus acidophilus*, *Lactobacillus bulgaricus*, *S. thermophilus,* and *Bifidobacterium longum*) enriched with whey-separated bioactive peptides with high ACE-inhibitory activity positively reduced SBP in rats after 8 weeks of oral application.[99] Earlier studies have shown the link between gut microbiota and TMAO levels in developing CVD. In a recent study, subjects who received probiotic *L. casei* Shirota (dose of $6.5\times10^{9}$ CFU thrice a day) for 12 weeks showed reduced levels of TMAO when compared to the control group.[100] Even though the level of reduction is not significant, it is noteworthy to explore the beneficial role of probiotics in multiple aspects of improving the overall health status.

Altogether these studies support the antihypertensive activity of probiotics and consumption of probiotic fermented foods for improving overall health status and reducing the risk of developing CVDs. It is noteworthy that regulation of hypertension via administration of probiotics is cross-linked with several different mechanisms, such as improving lipid levels, triglyceride levels, bile acid deconjugation, and controlling body mass index (Figure 2). In addition, an increase in absorption of nutrients, phytoestrogens (act as vasodilatory factors), and reduction in plasma glucose levels may also influence the probiotic effect in BP regulation.[17,65] Furthermore, this area of research needs to be examined thoroughly in more clinical studies to postulate the effect of probiotics in the regulation of hypertension.

## Conclusion

An increasing number of clinical trials supporting the probiotic-dependent attenuation of hypertension and hypercholesterolemia could provide immense support for

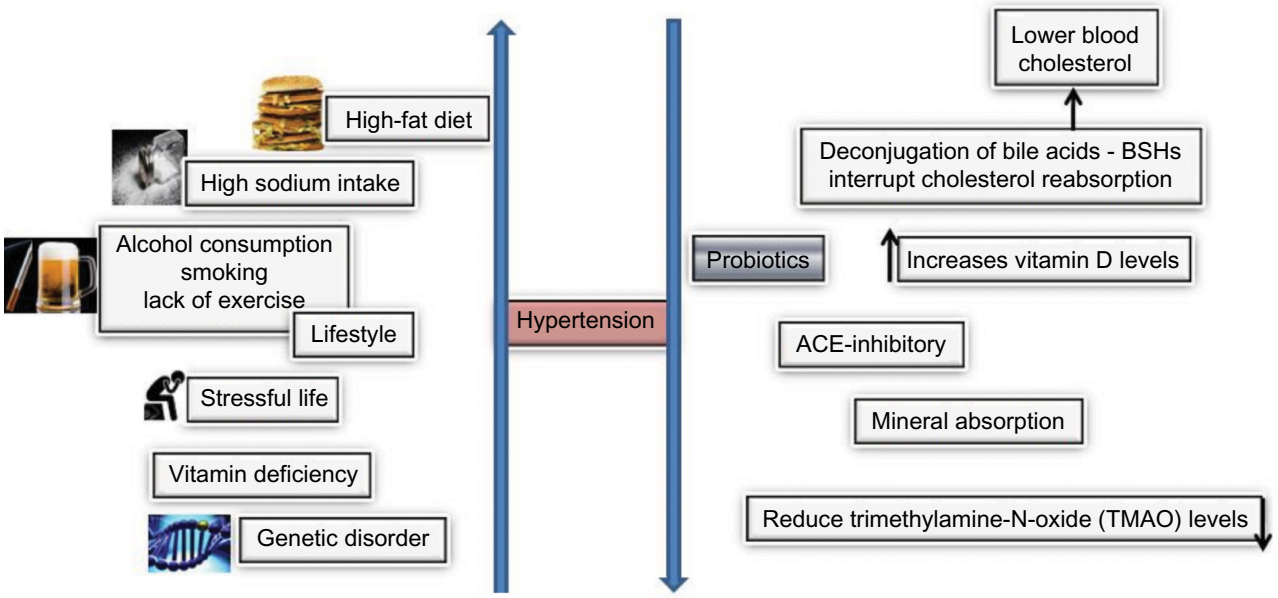


**Figure 2** Causative agents of hypertension and potential modes of probiotic action on hypertension.
**Abbreviation:** BSHs, bile salt hydrolases.

**Table 1** Anti-hypertensive effect of probiotics or probiotic fermented foods: in vivo studies

| Beneficial effect | Tested strains | Subjects | Dose (CFU) | Form | Result | Reference |
|---|---|---|---|---|---|---|
| Reduced systolic blood pressure (SBP) | *Lactobacillus casei*<br>*Lactobacillus acidophilus*<br>*Lactobacillus rhamnosus*<br>*Lactobacillus bulgaricus*<br>*Bifidobacterium breve*<br>*Bifidobacterium longum*<br>*Streptococcus thermophilus* | 60 pre-diabetic patients (25–65 years old) | $7\times10^9$<br>$2\times10^9$<br>$1.5\times10^9$<br>$2\times10^8$<br>$2\times10^{10}$<br>$7\times10^9$<br>$1.5\times10^{10}$ | Capsule (500 mg)<br>Prebiotic<br>Fructooligosaccharide | SBP 3.10±2.2 mmHg | 89 |
| Hypotensive effect | *S. thermophilus*<br>*Lactobacillus delbrueckii* ssp. *bulgaricus*<br>*L. acidophilus*<br>*Lactobacillus kefiri* | Meta-analysis<br>702 human subjects | NA | NA | SBP 3.1±1.56 mmHg<br>DBP 1.09±0.06 mmHg | 88 |
| Anti-hypertensive effect | *Lactobacillus helveticus*<br>*Saccharomyces cerevisiae* | 46 hypertensive men (aged 23–59 years) | 160 g/day | Sour milk (Ameal S) | SBP 5.2±8.1 mmHg<br>DBP 1.7 mmHg | 84 |
| Reduced blood pressure | *L. casei* | 28 hypertensive patients<br>(14 males and 14 females) | NA | 400 mg<br>cell lysate (LEx) | SBP 9±2 mmHg<br>DBP 6±2 mmHg | 85 |
| Reduced blood pressure levels | *L. helveticus*<br>*S. cerevisiae* | 36 hypertensive subjects<br>aged 40–80 years | 95 mL/day | Fermented milk (Ameal S) | 4 weeks<br>SBP 9.4±3.6 mmHg<br>8 weeks<br>SBP 14.1±3.1 mmHg<br>DBP 6.9±2.2 mmHg | 90 |
| | *L. helveticus* LBK-16H | 39 hypertensive subjects | 150 mL/day | Fermented milk (Evolus®) | SBP 6.7±3.0 mmHg<br>DBP 3.6±1.9 mmHg | 91 |
| Reduction in high blood pressure levels | *L. helveticus* CM4 | Total 80 subjects<br>40 – high–normal BP<br>40 – mild hypertension (MH) | 12 g/day | Tablet | High–normal group<br>SBP – no significant change<br>DBP 5.0±0.1 mmHg<br>MH group<br>SBP 11.2±4.0 mmHg<br>DBP 6.5±0.1 mmHg | 92 |

(*Continued*)

**Table 1** (*Continued*)

| Beneficial effect | Tested strains | Subjects | Dose (CFU) | Form | Result | Reference |
|---|---|---|---|---|---|---|
| Reduced blood pressure levels | *L. helveticus* LBK-16H | 17 mild-hypertensive subjects | 150 mL/day | Fermented milk (Evolus®) containing Ile-Pro-Pro and Val-Pro-Pro tripeptides | 7.3% reduction | 26 |
| Lowering blood pressure | *L. casei* Strain Shirota *Lactococcus lactis* YIT 2027 | 39 MH patients 16 women and 23 men (aged between 28–81 years) Mean age 54.2 years | 100 mL/day | Fermented milk containing GABA | SBP 17.4±4.3 mmHg DBP 7.2±5.7 mmHg | 22 |
| Lowers blood pressure | *L. helveticus* LBK-16H | 60 subjects (36 men, 24 women) | 150 mL/day | Fermented milk containing 2.5–2.7 mg/150 mL Ile-Pro-Pro and Val-Pro-Pro tripeptides | 10 weeks (mean) SBP 2.3 mmHg DBP ±0.5 mmHg | 93 |
| Reduces blood pressure, triglyceride, and cholesterol levels | **Group 1** *S. thermophilus* (2 cultures) + *L. acidophilus* (2 cultures) **Group 2** *S. thermophilus* (2 cultures) + *Enterococcus faecium* (Causido®) GAIO **Group 3** *S. thermophiles* (2 cultures) + *L. rhamnosus* | 70 healthy, overweight, and obese subjects 20 males 50 females 18–55 years old | 450 mL/day | Fermented milk (yogurt) | 8 weeks mean **Group 1** ΔSBP 4.4±1.8 mmHg ΔDBP 3.4±1.5 mmHg **Group 2** ΔSBP 8.0±2.3 mmHg ΔDBP 4.0±2.3 mmHg **Group 3** ΔSBP 2.6±3.1 mmHg ΔDBP 0.8±2.0 mmHg | 94 |
| Significant reduction in SBP, cholesterol, and triglyceride levels | *S. thermophilus* TMC1543 *L. casei* TMC0409 | 20 healthy adults | 200 mL/day $6.8\times10^8$/mL and $2.6\times10^7$ respectively | Fermented milk containing whey protein concentrate | Significant reduction in SBP ($P<0.05$) | 101 |
| Reduced blood pressure and body mass indexes | *Lactobacillus plantarum* TENSIA | 40 subjects | 50 g/day | Probiotic cheese | Morning ΔSBP 12.2±1.5 mmHg ΔDBP 4.0±0.9 Evening ΔSBP 8.8±0.9 mmHg ΔDBP 1.6±1.2 mmHg | 102 |

**Abbreviations:** DBP, diastolic blood pressure; SBP, systolic blood pressure; NA, not available.

the application of such cultures to improve cardiovascular health. Hence, dietary intervention to correct gut microbiota could be an innovative nutritional therapeutic strategy for hypertension. The knowledge obtained on probiotic potential against CVDs is still at infancy stage and current findings suggest that hypotensive effects of probiotics are very promising and worth exploring to promote cardiovascular health.

However, more studies are required for a better understanding of gut microbiota-host crosstalk and biochemical networks underlying control of hypertension. As BP is interlinked with other metabolic disorders, it is necessary to examine the outcomes in a meticulous manner to get a clear picture of probiotic action against CVDs.

## Disclosure

The authors have no conflicts of interest to disclose.

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