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The Role of Probiotics in Cancer Treatment: Emphasis on their In Vivo and In Vitro Anti-metastatic Effects

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Probiotics are defined as live bacteria and yeasts that exert beneficial effects for health. Among their various effects, anti-cancer properties have been highlighted in recent years. Such effects include suppression of the growth of microbiota implicated in the production of mutagens and carcinogens, alteration in carcinogen metabolism and protection of DNA from oxidative damage as well as regulation of immune system. We performed a computerized search of the MEDLINE/PUBMED databases with key words: cancer, probiotics, lactobacilli, metastasis and invasion. Cell line studies as well as animal models and human studies have shown the therapeutic effects of probiotics in reduction of invasion and metastasis in cancer cells. These results support the beneficial effects of probiotics both *in vitro* and *in vivo*. However, pre-clinical or clinical studies are not enough to decide about their application.

Key words: Probiotics, lactobacilli, cancer, metastasis, invasion

Lactobacillus and Bifidobacterium have been shown to exert beneficial effects in human (1). Numerous lines of evidence have shown that changed gut microbiota is associated with several common disorders including cancer. Therefore, resuming the equilibrium using the beneficial bacteria (called "probiotics") for disease treatment and prevention has been regarded profitable (1).

Probiotic bacteria have recently become the focus of research because of their anti-cancer properties. The underlying mechanisms for their anti-cancer effects are versatile including suppression of the growth of microbiota implicated in the production of mutagens and carcinogens, alteration in carcinogen metabolism, and protection of DNA from oxide damage as well as regulation of immune system (2). In addition, they have been shown to

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change expression of different genes participating in cell death and apoptosis (3), invasion and metastasis (4), cancer stem cell maintenance (5) as well as cell cycle control (6). Further studies have shown their modulatory effects on the cancerrelated signaling pathways in a cell type specific manner (7-9). In addition, their anti- proliferative effects have been assessed in several cell line studies (10-12). Notably, a traditional fermented milk product has been shown to inhibit *in vitro*

proliferation of MCF-7 breast cancer cells but not normal mammary epithelial cells which implies that the bioactive substances prompt responses that are specifically detected in tumor cells (13). Special attention has been given to the effects of probiotics in reduction of invasion and metastasis in cancer cells in cell line studies as well as animal models and human studies. Invasion and metastasis have been regarded as important hallmarks of malignant cells which are endowed to them through diverse

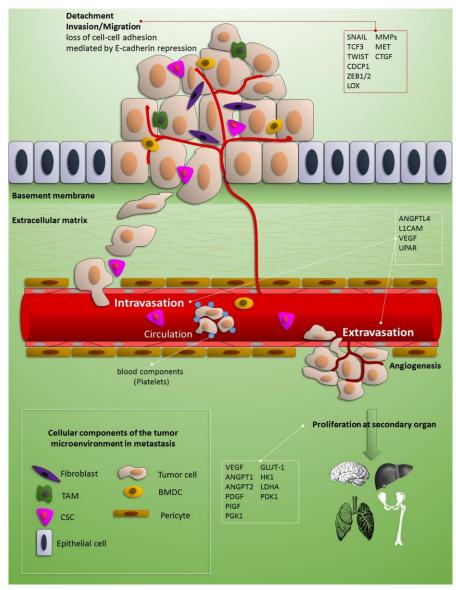


Fig 1. The schematic description of various molecules and cells involved in the metastasis. Metastasis cascade include loss of cell-cell adhesion, acquisition of the ability to interrupt the basement membrane, invasion into the stroma (local invasion), passing the blood circulation (intravasation), staying alive in the circulation before they can reach to a remote organ, extravasation and production of clinically evident metastases. Several molecules are involved in each step. TAM: tissue activated macrophage; CSC: cancer stem cell; BMDC: bone marrow derived cells

and complex genetic or epigenetic aberrations as well as extrinsic signals, such as those relayed from their microenvironment (14). The schematic description of various molecules and cells involved in metastasis are summarized in Figure 1. Metastasis cascade include acquisition of the ability to interrupt the basement membrane, invasion into the stroma (local invasion), passing the blood circulation (intravasation), staying alive in the circulation before they can reach to a remote organ, and production of clinically evident metastases. During this process, cancer cells recruit numerous stromal cells to support them in each step. Consequently, cancer microenvironment not only participates in the early steps of carcinogenesis but also contributes in metastasis cascade (15). Several studies have assessed the effects of probiotics on critical steps of invasion and metastasis such as interruption of cell-cell adhesion, epithelialmesenchymal transition, tumor microenvironment, and cancer stem cell maintenance. The results of these studies have been summarized in the following sections.

Evidence acquisition

We performed a computerized search of the MEDLINE/PUBMED, Web of Knowledge, Scopus, ProQuest and Google Scholar databases with key words: cancer, probiotics, lactobacilli, metastasis, and invasion within the maximal date range until 2017.

Cell-cell adhesion

Tight junction between epithelial and endothelial cells has a critical role in preserving cell to cell integrity. Defects in this structure underlie the invasion and thus metastasis process (16). Tight iunction structure has several molecular components including zona occludens-1 (ZO-1), claudin-1, and occludin. Effective assembly and preservation of this structure is carried out through the anchorage of the transmembrane proteins by the peripheral or plaque proteins such as ZO-1. Indeed, this protein provides a scaffold to fix a number of

tight junction molecules together (16). On the other hand, the matrix metalloproteinases (MMPs) are regarded as critical participants of cell invasion through their role in degradation of various extracellular matrix proteins which enables cancer cells to migrate and invade (17). Considerably, cellfree supernatants (CFS) from L. casei and L. rhamnosus GG have been shown to prevent colon cancer cell invasion suggesting that probiotic CFS has anti-metastatic bioactive substances that may participate in cell in vation decrease in vitro (18). Such decrease in cell invasion has been later found to be accompanied by a decrease in matrix metalloproteinase-9 (MMP-9) protein level in cultured metastatic human colorectal carcinoma cells and an increase in the level of the tight junction protein ZO-1 in cultured metastatic human colorectal carcinoma cells (19). In addition, perioperative probiotic treatment has been shown to maintain the liver barrier in patients undergoing colorectal liver metastases surgery (20). A more recent study has shown that L. rhamnosus and L. crispatus CFSc can decrease expression of matrix metalloproteinase-2 (MMP-2), MMP-9 in HeLa cells and increase expression of their inhibitors. L. rhamnosus showed this effect in HT-29 cells as well (4). Furthermore, L. acidophilus and L. rhamnosus GG have been shown to regulate MMP-9 expression by the up-regulation of tissue inhibitor of metalloproteinases (TIMP)-1 and downregulation of CD147 in phorbol 12-myristate 13acetate- differentiated human monocytes (21). CD147 is over-expressed in numerous tumor cells and enhances metastasis formation by induction of both angiogenesis and MMPs expression (22, 23). On the other hand, TIMP-1 is tissue inhibitor of MMPs and its up-regulation has resulted in the inhibition of MMP-2 and suppression of metastasis (24). Recently, it has also been reported that L. rhamnosus GG significantly down-regulates expression *GLUT1* in the MDA-MB-231 cells (8). This gene encodes an important rate-limiting protein in the transport of glucose into cancer cells. Its inhibition has been shown to decrease MMP-2 expression and c-Jun NH2-terminal kinase (JNK) activation, which controls numerous targets in the metastatic cascade (25). Lipoteichoic acid (LTA) deficient L. acidophilus (NCK2025) has been shown to increase ICAM5, RUNX3, TIMP2, RASSF1A expression in human colon carcinoma cell line HT-29 (26). ICAM5 codes for a type I transmembrane glycoprotein that is a member of the intercellular adhesion molecule family. It has been shown to be highly methylated in a fraction of colon cancer specimens. Its methylation diminishes the cell-to-cell adhesion in the cancer cells leading to enhancement of invasive potential (27). RUNX3 inhibits cancer cell migration and invasion through up-regulation of TIMP-2, which successively prevents MMP-2 expression and (28). RASSF1A is a genuine tumor suppressor protein that can enhance death receptor-dependent cell death through TNF-R1, TRAIL or Fas activation (29). Moreover, its methylation has been shown to be associated with colorectal cancer development (30). Considering the role of L. acidophilus (NCK2025) in restoration of expression of mentioned tumor suppressor genes, this probiotic might be efficient in suppression of metastasis. Another study has demonstrated that probiotic conditioned media treatment diminished the upregulation of genes in the NF-κB activation pathway, and down-regulated genes participating in extracellular matrix remodeling including MMPs, tissue-type plasminogen activator urokinase (PLAU) and its receptor (PLAUR) (31). Additionally, Kefir as a probiotic-containing fermented milk product has been shown to exert cytotoxic effects on 4T1 breast tumor cells. A notable decrease in tumor size and weight, a considerable enhancement in helper T cells and cytotoxic T cells as well as significant decreases in metastasis to lung and bone marrow were detected in the kefir water-treated BALB/c mice after 4T1

cancer cells transplantation (32). Kefir has been shown to exert an anti- proliferative effect on Caco- 2 and HT- 29 cells, and is accompanied by induction of cell cycle arrest at the G1 phase, induction of apoptosis, up-regulation in Bax:Bcl-2 ratio and an increase in p53 independent- p21 expression, while it does not influence either the motility and invasion of these cells in vitro or MMP expression (33). In an in vitro model of the human epithelium, L. plantarum prompted translocation of ZO-1 to the tight junction region. Besides, L. plantarum has been demonstrated to initiate Tolllike receptor 2 (TLR2) signaling, and treatment of Caco-2 monolayers with the TLR2 agonist enhanced translocation of occludin in the tight junction (34). Recently, L. rhamnosus GG has been shown to improve intestinal integrity by inhibition of miR122a leading to occludin restoration in Caco-2 colorectal cancer cells (35). Furthermore, viable L. rhamnosus GG could significantly up-regulate ZO-1, Claudin-1 and Occludin gene expression in Caco-2 cells leading to restoration of destroyed epithelial barrier (36). L. reuteri I5007 has been shown to exert similar effects in the expression of tight junction related proteins in newborn piglets (37). Another study has assessed the ability of Caco-2 cells to degrade collagen matrix and passing from membrane following treatment with different concentrations of probiotic bacteria. Notably, L. acidophilus and L. casei supernatants and cell extracts have decreased cell invasion capacity. Invasion inhibition effect of L. acidophilus was more than that of L. casei (38). As targeting tumor cell motility within the primary tumor is capable of prevention local invasion (39), colonization of lactobacilli in the site of the primary tumor may be beneficial in the prevention of metastases.

Epithelial-mesenchymal transition (EMT)

EMT is a biological process that permits a polarized epithelial cell, which typically interacts with basement membrane through its basal surface, to undertake numerous biochemical alterations

which result in acquisition of a mesenchymal cell phenotype. Such phenotype change is accompanied by increased migratory capacity and invasiveness (40). Among the different factors and pathways involved in EMT, stromal cell-derived factor 1 (SDF-1) and its receptor, CXCR4 have gained special attention. CXCR4 has been shown to enhance EMT through the Wnt/β-catenin signaling pathway. Thus, targeting of the SDF-1/CXCR4 axis has been suggested as a treatment strategy in cancer suppression (41). Anti-CXCR4 antibodies have been shown to inhibit CXCL12 mediated cancer cell adhesion, migration, and proliferation (42). Notably, L. acidophilus NCFM has been shown to exert anti-metastatic effects via down-regulation of CXCR4 expression in colon, mesenteric lymph nodes and spleen of tumor-bearing mice (43). Considering the role of MMPs in the maintenance of EMT (17), the observed role of lactobacilli in down-regulation of MMPs (4) implies a putative role for them in suppression of EMT.

Live L. casei has been demonstrated to induce apoptotic cell death in both murine (CT26) and human (HT29) colon carcinoma cell lines as well as an experimental tumor model. Tumor growth inhibition has been associated with up-regulation of the TNF-related apoptosis-inducing ligand TRAIL (10). Previously, it has been determined that soluble TRAIL gene and actinomycin D synergistically inhibit metastasis of TRAILresistant colon cancer in the liver (44). Also, trail resistance has been shown to trigger EMT and increase breast cancer cell invasiveness by modulation of PTEN and miR-221 expression (45). However, there is some contradictory evidence regarding the role of TRAIL in metastasis in other cancers such as pancreatic ductal adenocarcinoma. In this cancer, TRAIL prompted the expression of proinflammatory cytokines as well as urokinase-type plasminogen activator and increased the invasion cancer cells in vitro (46).

L. casei and L. rhamnosus GG have been

demonstrated to suppress NF- κ B activation by the inhibition of I κ B α destruction in intestinal epithelial cells (47-49). Besides, bacteria-free solution originating from *L. plantarum* has been shown to suppress various NF- κ B pathways (50). As NF- κ B activity is associated with EMT and metastatic potential in various cancers (51, 52), the modulation of this pathway by certain lactobacilli strains may be of practical value.

Tumor microenvironment

Tumor microenvironment is constructed via interactions between tumoral and nontransformed cells. The latter have an active and often tumor-promoting role at all stages of tumorigenesis. The major non-malignant cell types that are detected in this microenvironment are the cells of the immune system, the tumor vasculature and lymphatics, as well as the fibroblasts, pericytes and adipocytes (53). Many animal studies have shown that the beneficial anti-metastatic effects of lactobacilli are accompanied by or exerted via modulation of microenvironment. For instance, L. casei YIT9018 has been shown to suppress pulmonary and regional lymph node metastases in mice and guinea pigs (54). Intralesional injection of L. casei YIT9018 in highly metastatic melanoma bearing C57BL/6 mice has been shown to suppress tumor growth and improve the survival of affected animals. In addition, intravenous (I.V.) injection of this strain protects the mice against pulmonary metastasis after I.V. injection of melanoma cells. Injection of these lactobacilli exerts protective effects against both the axillary lymph node metastasis and lung metastases depending on the route and timing of injections. These effects are accompanied by augmentation of natural killer (NK) cell activity as well as cytolytic activity of axillary lymph node cells (55). Another study has shown that lymph node cells activated by the subcutaneous injection of these lactobacilli participate in the suppression of the metastasis (6). Matsuzaki et al. have reported that intralesional

injection of L. casei YIT9018 into Lewis lung carcinoma-bearing mice suppresses both the growth of the primary tumors and the development of lung metastases. In the L. casei YIT9018-primed mice, intraperitoneal administration of L. casei elicits a high level of IL-2 and IFN-y in the peritoneal cavity and enhances host immune response against tumor (56). Yazdi et al. have shown that selenium nanoparticle-enriched Lactobacillus brevis (L. brevis) elicits efficient immune responses in tumor bearing BALB/c mice, decreases the liver metastasis in metastatic form of mouse breast cancer and improves the life span of animals' life span. The immune responses include an increase in the level of IFN-y and IL-17 as T helper 1 cytokines and enhancement in the activity of NK cells (57). Aragon et al. have demonstrated that the administration of milk fermented by L. casei CRL 431 diminishes or inhibits tumor growth with less tumor vascularity, extravasation of tumor cells, and lung metastasis. These benefits are accompanied by alterations in the immune response such as decreasing the infiltration of macrophages in both the tumor and the lungs and an increased antitumor response associated to CD8+ and CD4+lymphocytes (58). Takagi et al. have detected antimetastatic effects of L. casei Shirota (LcS) in transplantable tumor cells which is mediated through augmentation of NK cells cytotoxicity (41). L. rhamnosus GG has been shown to exert effective antioxidative activity via diminishing reactive oxygen species production and phagocytic capacity of the neutrophils (59). Considering the role of neutrophils in almost all steps of cancer metastasis which is exerted in response to tumorderived incitements (60), the inhibition of their function by probiotics might be an efficient strategy impedes metastasis. Furthermore, a constituent of polysaccharide peptidoglycan complex on LcS has been shown to exert beneficiary effects in murine inflammatory bowel disease and colitis-associated

cancer through inhibition of IL-6/STAT3 signaling (61). Considering the constitutive activation of STAT3 in many cancers and its fundamental roles in different steps of metastasis cascade such as cell transformation and migration, angiogenesis, as well as modulation of tumor microenvironment (62), its down-regulation by lactobacilli might affect metastasis potential of cancer cells. Likewise, a recent study has shown that kefir water exerts antiangiogenic effects in breast cancer through down-regulation of the IL-1\beta angiogenic factor that promotes tumor invasiveness, as well as the vascular endothelial growth factor (VEGF) which is a crucial mediator for angiogenesis (32). Further, decrease of the proangiogenic factor IL-6 has been detected following treatment with probiotics in breast cancer models (58, 63-65). All data presented above support the role of probiotics in changing pro-tumoral microenvironment.

Cancer stem cells

The presence of a fraction of multipotent "cancer stem cells (CSC)" in solid tumors as well as hematological malignancies has resulted in suggestion of a new model for explanation of tumorigenesis process (42). These cells are thought to directly or indirectly participate in the induction of metastasis. Furthermore, the heterogeneity detected in CSCs has resulted to suggest a role for them in determination of complexity and organ specificity in metastases (66). Many transcription factors as well as signaling pathways are implicated in the maintenance of CSCs. Among them are the hypoxia inducible factors (HIFs) which facilitate transcriptional responses to regional hypoxia in normal tissues and in cancers. Also, they induce specific signaling pathways and transcription factors, such as Notch and Oct4, which are implicated in stem cell self-renewal multipotency (43). Notably, L. rhamnosus has been shown to down-regulate the expression of HIF-1α in MDA-MB-231 triple negative breast cancer cell lines (8). Considering the specific activation of

HIF-1α signaling in the stem cells of mouse lymphoma and human acute myeloid leukemia and the effect of their inhibitors in preferential eradication of CSCs in mouse models (38), modulation of HIF-1α signaling treatment with lactobacilli might be of therapeutic value. Another study has revealed that a combination of eight Gram-positive bacterial strains (Streptococcus thermophilus, Bifidobacterium longum, Bifidobacterium breve, Bifidobacterium infantis, L. acidophilus, L. plantarum, L. casei, and L. bulgaricus) could activate NK cells to provide enhanced differentiation of CSCs which finally has led to suppression of tumor growth, and decreased inflammatory cytokine release (40). In addition, we recently detected the over-expression of SFRP2, an antagonist of Wnt pathway in HT-29 colorectal cancer cells following L. rhamnosus treatment and in HeLa cells following L. rhamnosus and L. crispatus treatments. Takig into the account the involvement of Wnt-induced CSCs in colorectal cancer metastasis (67) as well as the role of SFRP1 in the inhibition of the transformation and invasion abilities of cervical cancer cells via modulation of Wnt signal pathway (68), lactobacilli can be considered as putative therapeutic modalities in these cancer types.

Discussion

Even with extensive work committed to the early diagnosis and prevention of cancer, micro- or macro- metastases exist in most diagnosed patients at the time of their referral to diagnostic settings. In particular, metastasis is regarded as a possible life span-dependent destiny for both the early and late stage cancer patients (55). Consequently, several studies have focused on finding substances with anti-metastatic properties. For this purpose, it is necessary to find tumor and host factors contributing in the metastasis cascade. The "seed and soil" hypothesis suggested by Paget in 1889 (69) is now extensively assented in the scientific literature (70). The progenitor cell, initiating cell,

cancer stem cell, or metastatic cell are now considered as the "seed", whereas host factors, stroma, or the organ microenvironment are regarded as the "soil" (70). The consequence of metastasis is reliant on the communication between tumor cells and receptive tissues (70). Probiotics have been shown to influence all cell types and pathways implicated in the metastasis. Previously, lactobacilli-based immunotherapy has been suggested to be used along with conventional therapeutics to overcome the failures of the traditional treatment options, especially in the treatment of cancer metastases (2). As discussed formerly, the beneficial effects of lactobacilli in the cancer therapy are not confined to their immunomodulatory effects. They have been shown to alter expression of several genes involved in cell transformation, migration and invasion. Besides, it should be emphasized that the antimetastatic properties of probiotics might be different in distinct species of these organisms. Future studies are needed to identify putative pathways or molecules that are target of strain-specific gene expression modulation. Additionally, identification of formulations with the best bioactivity and less side effects is another challenge in this regard. Probiotic lactobacilli have also been shown to protect against cyclophosphamide-caused myelosuppression in animal models which has led to the improvement of the resistance to Candida albicans. Consequently, probiotics have been suggested as a modality to decrease immunosu-ppression in cancer patients (71). Moreover, a randomized control study in critically diseased children has shown that the intake of probiotics decreases the occurrence of acute infectious, nosocomial and antibioticassociated diarrhea in numerous general pediatric situations (72). Nevertheless, in some immunocompromised patients, there have been occasional cases of sepsis following probiotics intake (73). In brief, the results of recent studies on evaluation of the effects of probiotics on cancer cell invasion and metastasis have supported their beneficial effects both *in vitro* and *in vivo*. Nonetheless, pre-clinical or clinical studies are not enough to decide about their application.

Consequently, to translate the results of basic studies to clinical application and to avoid unwanted side effects, the exact component of lactobacilli which is responsible for beneficial effects should be determined in pre-clinical animal studies. Although the possibility of synergic effects of different components should be considered as well, some studies have revealed contradictory effects for different lactobacillus-derived substances (19). Additional studies for the identification of the bioactive components and their mechanism of action could lead to the application of probiotics as a nutritional modality to prevent metastasis.

Conflict of interest

Authors declare no conflict of interest.

References

- Vyas U, Ranganathan N. Probiotics, prebiotics, and synbiotics: gut and beyond. Gastroenterol Res Pract 2012;2012:872716.
- 2. Abedin-Do A, Taherian-Esfahani Z, Ghafouri-Fard S, et al. Immunomodulatory effects of Lactobacillus strains: emphasis on their effects on cancer cells. Immunotherapy 2015;7:1307-29.
- 3. Motevaseli E, Shirzad M, Akrami SM, et al. Normal and tumour cervical cells respond differently to vaginal lactobacilli, independent of pH and lactate. J Med Microbiol 2013;62:1065-72.
- Nouri Z, Karami F, Neyazi N, et al. Dual Anti-Metastatic and Anti-Proliferative Activity Assessment of Two Probiotics on HeLa and HT-29 Cell Lines. Cell J 2016;18:127-34.
- 5. Azam R, Ghafouri-Fard S, Tabrizi M, et al. Lactobacillus acidophilus and Lactobacillus crispatus culture supernatants downregulate expression of cancer-testis genes in the MDA-MB-231 cell line. Asian Pac J Cancer Prev 2014;15:4255-9.
- 6. Matsuzaki T, Yokokura T, Mutai M. The role of lymph node cells in the inhibition of metastasis by subcutaneous injection of Lactobacillus casei in mice. Med Microbiol Immunol

1988;177:245-53.

- 7. Taherian-Esfahani Z, Abedin-Do A, Nouri Z, et al. Lactobacilli Differentially Modulate mTOR and Wnt/ beta-Catenin Pathways in Different Cancer Cell Lines. Iran J Cancer Prev 2016;9:e5369.
- 8. Esfandiary A, Taherian-Esfahani Z, Abedin-Do A, et al. Lactobacilli Modulate Hypoxia-Inducible Factor (HIF)-1 Regulatory Pathway in Triple Negative Breast Cancer Cell Line. Cell J 2016;18:237-44.
- 9. Esfandiary A, Abedin-Do A, Taherian-Esfahani Z, et al. Intact expression of hypoxia-inducible factor 1α (HIF- 1α) gene in HeLa cell line following treatment with lactobacilli supernatants. Iran J Cancer Prev 2017;10.
- 10. Tiptiri-Kourpeti A, Spyridopoulou K, Santarmaki V, et al. Lactobacillus casei exerts anti-proliferative effects accompanied by apoptotic cell death and up-regulation of TRAIL in colon carcinoma cells. PloS one 2016;11:e0147960.
- 11. Sadeghi-Aliabadi H, Mohammadi F, Fazeli H, et al. Effects of Lactobacillus plantarum A7 with probiotic potential on colon cancer and normal cells proliferation in comparison with a commercial strain. Iran J Basic Med Sci 2014;17:815-9.
- 12. Choi SS, Kim Y, Han KS, et al. Effects of Lactobacillus strains on cancer cell proliferation and oxidative stress in vitro. Lett Appl Microbiol 2006;42:452-8.
- 13. Chen C, Chan HM, Kubow S. Kefir extracts suppress in vitro proliferation of estrogen-dependent human breast cancer cells but not normal mammary epithelial cells. J Med Food 2007;10:416-22.
- Jiang WG, Sanders AJ, Katoh M, et al. Tissue invasion and metastasis: Molecular, biological and clinical perspectives.
 Semin Cancer Biol 2015;35 Suppl:S244-75.
- 15. Wan L, Pantel K, Kang Y. Tumor metastasis: moving new biological insights into the clinic. Nat Med 2013;19:1450-64.
- 16. Martin TA, Jiang WG. Loss of tight junction barrier function and its role in cancer metastasis. Biochim Biophys Acta 2009;1788:872-91.
- 17. Martin TA, Ye L, Sanders AJ, et al. Cancer invasion and metastasis: molecular and cellular perspective 2013.
- Escamilla J, Lane MA, Maitin V. Probiotic Lactobacilli Decrease Invasion of Metastatic Human Colon Cancer Cells In Vitro. FASEB J 2010;24:928.21-.21.
- 19. Escamilla J, Lane MA, Maitin V. Cell-free supernatants from

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probiotic Lactobacillus casei and Lactobacillus rhamnosus GG decrease colon cancer cell invasion in vitro. Nutr Cancer 2012;64:871-8.

- 20. Liu Z, Li C, Huang M, et al. Positive regulatory effects of perioperative probiotic treatment on postoperative liver complications after colorectal liver metastases surgery: a double-center and double-blind randomized clinical trial. BMC Gastroenterol 2015;15:34.
- 21. Maghsoud F, Mirshafiey A, Farahani M, et al. Dual effect of cell free supernatants from Lactobacillus. acidophilus and Lactobacillus. rhamnosus GG in regulation of MMP-9 by upregulating TIMP-1 and downregulating CD147 in PMA-differentiated THP-1 cells. Cell J 2018;19:76pages.
- 22. Lüke J, Vukoja V, Brandenbusch T, et al. CD147 and matrix-metalloproteinase-2 expression in metastatic and non-metastatic uveal melanomas. BMC ophthalmol 2016;16:74.
- 23. Voigt H, Vetter-Kauczok CS, Schrama D, et al. CD147 impacts angiogenesis and metastasis formation. Cancer Invest 2009;27:329-33.
- 24. Wang N, Zhu M, Tsao SW, et al. Up-regulation of TIMP-1 by genipin inhibits MMP-2 activities and suppresses the metastatic potential of human hepatocellular carcinoma. PLoS One 2012;7:e46318.
- 25. Koch A, Lang SA, Wild PJ, et al. Glucose transporter isoform 1 expression enhances metastasis of malignant melanoma cells. Oncotarget 2015;6:32748-60.
- 26. Lightfoot YL, Yang T, Sahay B, et al. Targeting aberrant colon cancer-specific DNA methylation with lipoteichoic aciddeficient Lactobacillus acidophilus. Gut Microbes 2013;4:84-8.
- 27. Mokarram P, Kumar K, Brim H, et al. Distinct high-profile methylated genes in colorectal cancer. PLoS One 2009;4:e7012.
- 28. Chen F, Wang M, Bai J, et al. Role of RUNX3 in Suppressing Metastasis and Angiogenesis of Human Prostate Cancer. PLoS ONE 2014;9:e86917.
- 29. Volodko N, Salla M, Zare A, et al. RASSF1A Site-Specific Methylation Hotspots in Cancer and Correlation with RASSF1C and MOAP-1. Cancers 2016;8:55.
- Fernandes MS, Carneiro F, Oliveira C, et al. Colorectal cancer and RASSF family—a special emphasis on RASSF1A.
 International journal of cancer 2013;132:251-8.
- 31. Guo S, Guo Y, Ergun A, et al. Secreted metabolites of Bifidobacterium infantis and Lactobacillus acidophilus protect

- immature human enterocytes from IL-1β-induced inflammation: A transcription profiling analysis. PloS one 2015;10:e0124549.
- 32. Zamberi NR, Abu N, Mohamed NE, et al. The Antimetastatic and Antiangiogenesis Effects of Kefir Water on Murine Breast Cancer Cells. Integr Cancer Ther 2016;15:Np53-np66.
- 33. Khoury N, El-Hayek S, Tarras O, et al. Kefir exhibits antiproliferative and proapoptotic effects on colon adenocarcinoma cells with no significant effects on cell migration and invasion. Int J Oncol 2014;45:2117-27.
- 34. Karczewski J, Troost FJ, Konings I, et al. Regulation of human epithelial tight junction proteins by Lactobacillus plantarum in vivo and protective effects on the epithelial barrier.

 Am J Physiol Gastrointest Liver Physiol 2010;298:G851-9.
- 35. Zhao H, Zhao C, Dong Y, et al. Inhibition of miR122a by Lactobacillus rhamnosus GG culture supernatant increases intestinal occludin expression and protects mice from alcoholic liver disease. Toxicol Lett 2015;234:194-200.
- 36. Orlando A, Linsalata M, Notarnicola M, et al. Lactobacillus GG restoration of the gliadin induced epithelial barrier disruption: the role of cellular polyamines. BMC Microbiol 2014;14:19.
- 37. Yang F, Wang A, Zeng X, et al. Lactobacillus reuteri I5007 modulates tight junction protein expression in IPEC-J2 cells with LPS stimulation and in newborn piglets under normal conditions. BMC Microbiol 2015;15:32.
- 38. Wang Y, Liu Y, Malek SN, et al. Targeting HIF1alpha eliminates cancer stem cells in hematological malignancies. Cell Stem Cell 2011;8:399-411.
- 39. Palmer TD, Ashby WJ, Lewis JD, et al. Targeting tumor cell motility to prevent metastasis. Adv Drug Deliv Rev 2011;63:568-81.
- 40. Bui VT, Tseng H-C, Kozlowska A, et al. Augmented IFN- γ and TNF- α induced by probiotic bacteria in NK cells mediate differentiation of stem-like tumors leading to inhibition of tumor growth and reduction in inflammatory cytokine release; regulation by IL-10. Front immunol 2015;6:576.
- 41. Takagi A, Matsuzaki T, Sato M, et al. Enhancement of natural killer cytotoxicity delayed murine carcinogenesis by a probiotic microorganism. Carcinogenesis 2001;22:599-605.
- 42. Tabarestani S, Ghafouri-Fard S. Cancer stem cells and response to therapy. Asian Pac J Cancer Prev 2012;13:5951-8.

- 43. Keith B, Simon M. Hypoxia-inducible factors, stem cells, and cancer. Cell 2007;129:465-72.
- 44. Ishii M, Iwai M, Harada Y, et al. Soluble TRAIL gene and actinomycin D synergistically suppressed multiple metastasis of TRAIL-resistant colon cancer in the liver. Cancer letters 2007;245:134-43.
- 45. Wang H, Xu C, Kong X, et al. Trail resistance induces epithelial-mesenchymal transition and enhances invasiveness by suppressing PTEN via miR-221 in breast cancer. PloS one 2014:9:e99067.
- 46. Trauzold A, Siegmund D, Schniewind B, et al. TRAIL promotes metastasis of human pancreatic ductal adenocarcinoma. Oncogene 2006;25:7434-9.
- 47. Tien M-T, Girardin SE, Regnault B, et al. Anti-inflammatory effect of Lactobacillus casei on Shigella-infected human intestinal epithelial cells. J Immunol 2006;176:1228-37.
- 48. Kumar A, Wu H, Collier- Hyams L, et al. Commensal bacteria modulate cullin- dependent signaling via generation of reactive oxygen species. EMBO J 2007;26:4457-66.
- 49. Lin PW, Myers LE, Ray L, et al. Lactobacillus rhamnosus blocks inflammatory signaling in vivo via reactive oxygen species generation. Free Radic Biol Med 2009;47:1205-11.
- 50. Petrof EO, Claud EC, Sun J, et al. Bacteria- free solution derived from Lactobacillus plantarum inhibits multiple NF- kappaB pathways and inhibits proteasome function. Inflamm Bowel Dis 2009;15:1537-47.
- 51. Yan M, Xu Q, Zhang P, et al. Correlation of NF-kappaB signal pathway with tumor metastasis of human head and neck squamous cell carcinoma. BMC Cancer 2010;10:437.
- 52. Huber MA, Azoitei N, Baumann B, et al. NF-κB is essential for epithelial-mesenchymal transition and metastasis in a model of breast cancer progression. J Clin Invest 2004;114:569-81.
- 53. Zhu H, Wang D, Zhang L, et al. Upregulation of autophagy by hypoxia-inducible factor-1alpha promotes EMT and metastatic ability of CD133+ pancreatic cancer stem-like cells during intermittent hypoxia. Oncol Rep 2014;32:935-42.
- 54. Matsuzaki T, Yokokura T, Azuma I. Anti-tumour activity of Lactobacillus casei on Lewis lung carcinoma and line-10 hepatoma in syngeneic mice and guinea pigs. Cancer Immunol Immunother 1985;20:18-22.
- Matsuzaki T, Yokokura T, Azuma I. Antimetastatic effect of Lactobacillus casei YIT9018 (LC 9018) on a highly metastatic

- variant of B16 melanoma in C57BL/6J mice. Cancer Immunol Immunother 1987;24:99-105.
- 56. Han M, Wang Y, Liu M, et al. MiR-21 regulates epithelial-mesenchymal transition phenotype and hypoxia-inducible factor-lalpha expression in third-sphere forming breast cancer stem cell-like cells. Cancer Sci 2012;103:1058-64.
- 57. Wang WJ, Sui H, Qi C, et al. Ursolic acid inhibits proliferation and reverses drug resistance of ovarian cancer stem cells by downregulating ABCG2 through suppressing the expression of hypoxia-inducible factor-1alpha in vitro. Oncol Rep 2016;36:428-40.
- 58. Aragon F, Carino S, Perdigon G, et al. Inhibition of Growth and Metastasis of Breast Cancer in Mice by Milk Fermented With Lactobacillus casei CRL 431. J Immunother 2015;38:185-96.
- 59. Vong L, Lorentz RJ, Assa A, et al. Probiotic Lactobacillus rhamnosus inhibits the formation of neutrophil extracellular traps. J Immunol 2014;192:1870-7.
- 60. Liang W, Ferrara N. The Complex Role of Neutrophils in Tumor Angiogenesis and Metastasis. Cancer Immunol Res 2016;4:83-91.
- 61. Matsumoto S, Hara T, Nagaoka M, et al. A component of polysaccharide peptidoglycan complex on Lactobacillus induced an improvement of murine model of inflammatory bowel disease and colitis-associated cancer. Immunology 2009;128:e170-80.
- 62. Kamran MZ, Patil P, Gude RP. Role of STAT3 in cancer metastasis and translational advances. Biomed Res Int 2013;2013:421821.
- 63. de Moreno de LeBlanc A, Matar C, Farnworth E, et al. Study of cytokines involved in the prevention of a murine experimental breast cancer by kefir. Cytokine 2006;34:1-8.
- 64. de Moreno de LeBlanc A, Matar C, LeBlanc N, et al. Effects of milk fermented by Lactobacillus helveticus R389 on a murine breast cancer model. Breast Cancer Res 2005;7:R477-R86.
- 65. Aragon F, Carino S, Perdigon G, et al. The administration of milk fermented by the probiotic Lactobacillus casei CRL 431 exerts an immunomodulatory effect against a breast tumour in a mouse model. Immunobiology 2014;219:457-64.
- 66. Shiozawa Y, Nie B, Pienta KJ, et al. Cancer stem cells and their role in metastasis. Pharmacol Ther 2013;138:285-93.
- 67. Basu S, Haase G, Ben-Ze'ev A. Wnt signaling in cancer stem cells and colon cancer metastasis. F1000Res 2016;5:F1000

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- 68. Chung M-T, Lai H-C, Sytwu H-K, et al. SFRP1 and SFRP2 suppress the transformation and invasion abilities of cervical cancer cells through Wnt signal pathway. Gynecol Oncol 2009;112:646-53.
- 69. Paget S. The distribution of secondary growths in cancer of the breast. The Lancet 1889;133:571-3.
- 70. Fidler IJ, Poste G. The "seed and soil" hypothesis revisited. Lancet Oncol 2008;9:808.
- 71. Salva S, Marranzino G, Villena J, et al. Probiotic Lactobacillus strains protect against myelosuppression and

- immunosuppression in cyclophosphamide-treated mice. Int Immunopharmacol 2014;22:209-21.
- 72. Srinivasan R, Meyer R, Padmanabhan R, et al. Clinical safety of Lactobacillus casei shirota as a probiotic in critically ill children. J Pediatr Gastroenterol Nutr 2006;42:171-3.
- 73. Mehta A, Rangarajan S, Borate U. A cautionary tale for probiotic use in hematopoietic SCT patients-Lactobacillus acidophilus sepsis in a patient with mantle cell lymphoma undergoing hematopoietic SCT. Bone Marrow Transplant 2013;48:461-2.