ANTI-INFLAMMATORY EFFECTS OF BIDARIA KHANDALENSE EXTRACT ON RAT ENDOTOXIN-INDUCED UVEITIS

Jasem Estakhr, Nasim Javdan

Science and Research Branch, Islamic Azad University, Fars, Iran.

Corresponding Address: Jasem Estakhr, j.estakhr@yahoo.com. Tel: +989179283966.

Summary

Bidaria khandalense extract (BKE) with high levels of polyphenol compounds has been reported to have antioxidative effects in vitro and in vivo. In this study, attention was focused on the antioxidant effect of BKE. The aim of the present study was to determine the effects of BKE on endotoxin-induced uveitis (EIU) in rats. In addition, the endotoxin-induced expression of the inducible nitric oxide synthase (iNOS) and cyclooxygenase (COX)-2 proteins was determined in a mouse macrophage cell line (RAW 264.7) treated with BKE in vitro, to clarify the anti-inflammatory properties. EIU was induced in male Wistar rats by a footpad injection of lipopolysaccharide (LPS). Immediately after the LPS injection, 1, 10, or 100 mg BKE or 10 mg prednisolone was injected intravenously. After 24 hours, the aqueous humor was collected from both eyes, and the number of infiltrating cells, protein concentration, nitric oxide (NO), prostaglandin (PG)-E2, and TNF−α levels in the aqueous humor were determined. RAW 264.7 cells treated with various concentrations of BKE were incubated with 10 µg/mL LPS for 24 hours. Levels of NO, PGE2, and TNF−α were determined. The expression of iNOS and COX-2 proteins was analyzed by Western blot analysis. The number of inflammatory cells, the protein concentrations, and the levels of NO, PGE2, and TNF−α in the aqueous humor in the groups treated with BKE were significantly decreased in a dose-dependent manner. In addition, the anti inflammatory effect of 100 mg BKE was as strong as that of 10 mg prednisolone. The anti-inflammatory action of BKE was stronger than that of either quercetin or anthocyanin administered alone. BKE also suppressed LPS-induced iNOS and COX-2 protein expressions in RAW 264.7 cells in vitro in a dosedependent manner. The results suggest that BKE has a dose-dependent anti– ocular inflammatory effect that is due to the direct blocking of the expression of the iNOS and COX-2 enzymes and leads to the suppression of the production of NO, PGE2, and TNF−α.

Key Words: Bidaria khandalense extract, Anti-inflammatory, NO, PGE2, TNF−α

Introduction

Nowadays, medicinal plants receive attention to research centers because of their special importance in safety of communities. The use of herbal medicine for the treatment of diseases and infections is as old as mankind. The curative properties of medicinal plants are due to the presence of various complex chemical substances of different composition which occur as secondary metabolites (1,2).

Bidaria khandalense belong to the family Asclepiadaceae is a gigantic climber reaching at the tops of tall trees in the dense forests of central and southern India (3). It is also found north of Iran. This medicinal plant is rich in phenolic compounds as well as many essential nutritional components, such as flavonoids and phenolic acids, which have a wide range of biological properties, including antioxidant (4-6), and anticarcinogenic properties (7). Studies evidence suggests that high intake of flavonoids may provide protection against coronary heart disease (8,9), stroke (10), and lung cancer (11). *Bidaria khandalenses'* Stems are yellowish-green, densely pubescent and terete, Leaves are broadly ovate and Flowers are borne in pedunculate cymes. Fruits are follicle and seeds are measuring about 10-12 mm long and 3-4 mm broad. The whole plant contains high levels of polyphenol compounds (3).

There have been no reports on the effects of BKE on lipopolysaccharide (LPS)-induced inflammation in vivo or in vitro. Endotoxin-induced uveitis (EIU) is an animal model of acute anterior segment intraocular inflammation that is induced by an injection of LPS or lipoteichoic acid (12-17). In this model, LPS may directly activate the vascular endothelium, macrophages, and other cells. Cellular infiltration and protein extravasations in the anterior part of the eye reaches a maximum 20 to 24 hours after LPS treatment. In the vitreous and retina, cellular infiltration reaches a maximum 48 hours after LPS treatment (18). Exposure to exogenous bacterial toxins, such as LPS, stimulates cellular inflammatory responses and releases factors such as nitric oxide (NO) (19,20), and prostaglandin (PG)-E2, (21–23); cytokines, including tumor necrosis factor TNF−α (24); and eicosanoid mediators, which promote inflammatory responses.

There are three types of nitric oxide synthase (NOS) isoforms in cells including; Endothelium NOS and neural NOS which are both constitutive NOS isoforms and act to maintain normal vasoactivity in an active state of vasodilation through a Ca^{+2} dependent pathway and acts as a neurotransmitter in neuron signal transmission. NOS in macrophages and hepatocytes is an inducible (i)NOS isoform, and it acts in a Ca^{+2} independent pathway. After exposure to endogenous and exogenous stimulators, iNOS is induced quantitatively in various cells, such as macrophages, smooth muscle cells, and hepatocytes, and triggers several disadvantageous cellular responses that can cause inflammation and stroke (25). The level of NO production induced by iNOS may reflect the level of inflammation, and therefore we might be able to evaluate the effect of an anti-inflammatory drug by measuring NO levels. Recently it has been reported that Ginkgo biloba extract prevents the inflammation of EIU by suppressing generation of NO (26). PGE2, thromboxane B2, and leukotriene B4, are as major inflammatory mediators. At an inflammation the major COX product is PGE2 which leads to local blood flow increases, edema, and pain sensitization. The common mechanism of action of nonsteroidal anti-inflammatory drugs is inhibition of cyclooxygenase (COX), and therefore prostaglandin production (27). As is now well appreciated, COX has two isoforms (28-30) including; COX-1 which exsits in places such as endothelium, stomach, and kidney, and COX-2 which is induced by endotoxins and proinflammatory cytokines in cells in vitro, and at inflammatory sites in vivo.

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n this study Bidaria khandalense was subjected to anti-inflammatory screening on EIU in rats. The anti-inflammatory properties of BKE in vivo was compared with that of prednisolone. In addition, to make clear the anti-inflammatory effects, we also investigated the expression of iNOS and COX-2 in a mouse macrophage cell line (RAW 264.7) treated with BKE in vitro.

Materialsa and Methods

Plant materials

Bidaria khandalense was collected from Guilan province in north of Iran, and then was identified by a botanist. Its leaves and fruits were dried under shade and powdered. The extract was prepared by the maceration method (80% ethanol in 300 g/lit for 48 hours), filtered with filter paper. After filtration ethanol was removed by rotary evaporator. The extract was stored in -4c° for more administration.

Animal treatment

Adult male albino rats of Wistar strain weighing 150 - 200 g used for the study were obtained from Razi Institute, (Karaj, Iran) and maintained according to the guidelines of Committee for the Purpose of Control and Supervision of Experiments on Animals, Razi Institute, Karaj, Iran. EIU was induced by a footpad injection of 200 µg LPS (100 µg each footpad) from *Salmonella typhimurium* (Sigma-Aldrich) that had been diluted in 0.1 mL phosphate-buffered saline (PBS, pH 7.4). Rats were injected intravenously with 1, 10, or 100 mg BKE or 10 mg prednisolone diluted in 0.1 mL PBS containing 0.1% dimethyl sulfoxide (DMSO; Sigma-Aldrich). Rats were killed, and the aqueous humor (15–20 µL/rat) was collected from both eyes by an anterior chamber puncture 24 hours after the LPS injection.

Cell Count and Protein Concentration

For cell counting, the aqueous humor sample was suspended in an equal amount of Turk stain solution, and the cells were counted with a hemocytometer under a light microscope. The number of cells per field was manually counted, and the number of cells per microliter was obtained by averaging the results of four fields from each sample.

To determine the total protein concentration in the aqueous humor, A BCA protein assay reagent kit (Pierce, Rockford, IL) was used.

Cell Culture and LPS Stimulation

The mouse macrophage cell line (RAW 264.7) was obtained from the American Type Culture Collection (Manassas, VA). Cells were cultured in RPMI-1640 medium supplemented with 2 mM glutamine, antibiotics (100 U/mL penicillin and 100 U/mL streptomycin) and 10% heatinactivated fetal bovine serum (Invitrogen-Gibco, Grand Island, NY) and maintained at 37°C in a incubator containing 5% CO2. The cells were seeded onto a 24-well plate (5×10^4 cells/well) for the experiments. The cells treated with 1, 10, or 100 µg/mL BKE for 24 hours were induced with 10 µg/mL of LPS for 24 hours. BKE was dissolved in 0.01% DMSO. For the control group, RAW cells were cultured with 0.01% DMSO alone.

Nitrite Concentration in the Aqueous Humor

NO was evaluated as its end product, nitrite, by using Griess reagent (Sigma-Aldrich). The culture supernatant (100 µL) was mixed with 100 µL of Griess reagent for 10 minutes, and the absorbance at 550 nm was measured in a microplate reader. The concentration of nitrite in the samples was determined from a sodium nitrite standard curve. The data represent the mean of eight determinations ± SD.

Levels of TNF−α, PGE2, and Monocyte Chemoattractant Protein-1 in the Aqueous Humor

The aqueous humor was collected and accurately diluted 10-fold with PBS. ELISA kits (R&D Systems) were used to measure the levels of TNF−α, PGE2, and monocyte chemoattractant protein (MCP)-1 in the aqueous humor.

Western Blot Analysis

Cells were washed with ice-cold PBS and then lysed in cold NP-40 lysis buffer (50 mM Tris-Cl [pH 7.6], 150 mM NaCl, 10% glycerol, 1% NP-40, 1 mM phenylmethylsulfonyl fluoride, and 1 mg/mL each of leupeptin, aprotinin, and pepstatin) for 10 minutes at 4°C. Plates were then scraped, and crude lysates were cleared by centrifugation at 14,000*g* for 10 minutes at 4°C. Aliquots of the cleared lysates were diluted with 2× SDS sample buffer, and SDS-polyacrylamide gel electrophoresis was performed. Protein expression was analyzed by Western blot analysis by the following standard procedures. The primary antibody (anti-NOS; Upstate Biotechnology) was developed with horseradish peroxidase– conjugated secondary antibody (Amersham Biosciences) and visualized by chemiluminescence (Amersham Biosciences).

Statistical Analysis

Data were expressed as mean ± standard deviation and were analyzed by analysis of variance (ANOVA). The Tukey-Kramer test was used to compare the two treatment groups. $P < 0.05$ was considered to be statistically significant.

Results

Effect of BKE on EIU

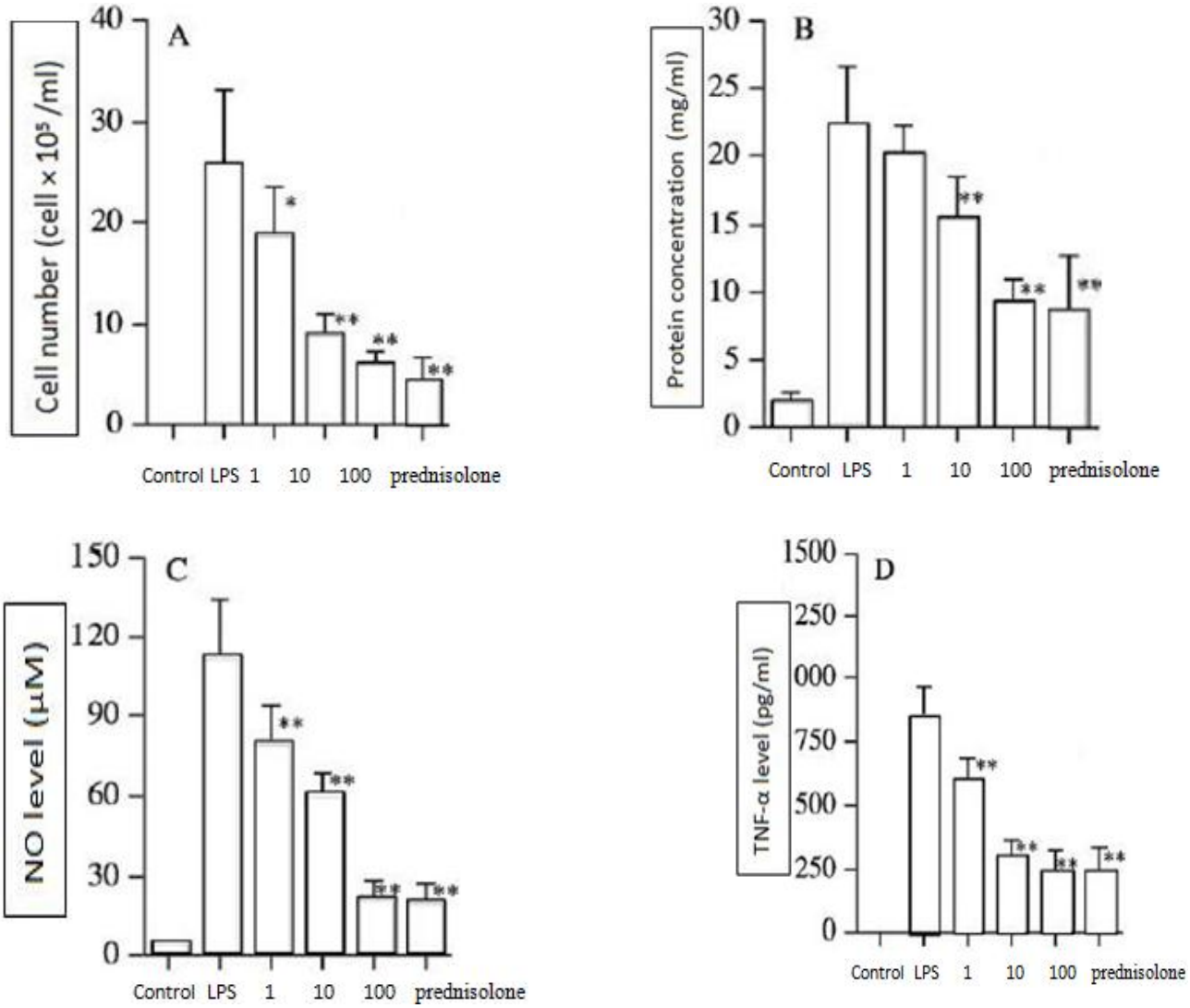
In the LPS group, 24 hours after LPS treatment the number of inflammatory cells that infiltrated the aqueous humor was 23.6 ± 8.7 × 10^5 cells/mL (mean ± SD, $n = 8$). In the groups treated with BKE the number of inflammatory cells was significantly lower than that in the LPS group, and the reduction was dose-dependent (Fig. 1A). The effect of the 100-mg dose of BKE on the number of cells in the aqueous humor was almost the same as that observed with the 10-mg prednisolone dose (Fig. 1A).There were no infiltrating cells in the aqueous humor from the control group (rats without LPS).

As it can be found from Fig. 1B, Fig. 1C, Fig. 1D, and Fig. 1E, the protein concentration and the levels of NO, TNF-α, and PGE2 in the BKE treated groups were significantly lower than that observed in the LPS group respectively. The reduction in these parameters in the 100-mg BKE group was almost the same as that in the prednisolone group (Figs. 1B–E). The MCP-1 level was 7.9 ± 2.6 pg/mL in the LPS group whereas there was not any MCP-1. The level of MCP-1 was significantly reduced by 100-mg BKE and prednisolone in the aqueous humor (Fig. 1F).

Expression of the iNOS and COX-2 Proteins

For clarification of the inhibitory property of BKE on LPS-induced NO and PGE2, the expression of the iNOS and COX-2 proteins was evaluated. Expression of the iNOS protein was high in LPS-stimulated RAW cells (Fig. 2A, lane 2). Clearly, it can be seen from figure 2A, lanes 3-5 that the expression of the iNOS protein significantly decreased in a dose-dependent manner within the concentration range from 1to 100µg/mL BKE. Although expression of COX-2 was detected in normal cells (Fig. 2B, lane 1), there was strong expression in LPS-stimulated cells (Fig. 2B, lane 2). Expression of the COX-2 protein decreased in a dose-dependent manner within the concentration range from 1 to 100µg/mL of BKE (Fig. 2B, lanes 3–5).

FIGURE 1. Effect of Bidaria khandalense extract on LPS-induced cell counts (**A**), protein concentration (**B**), NO production (**C**), TNF-α (**D**), PGE2 (**E**), and MCP-1 concentration (**F**) in aqueous humor. The aqueous humor was collected 24 hours after LPS treatment. Values are mean ± SEM (n=10). **P* _ 0.05 and ***P* _ 0.01 versus the LPS group. The dose of prednisolone (PSL) was 10 mg.



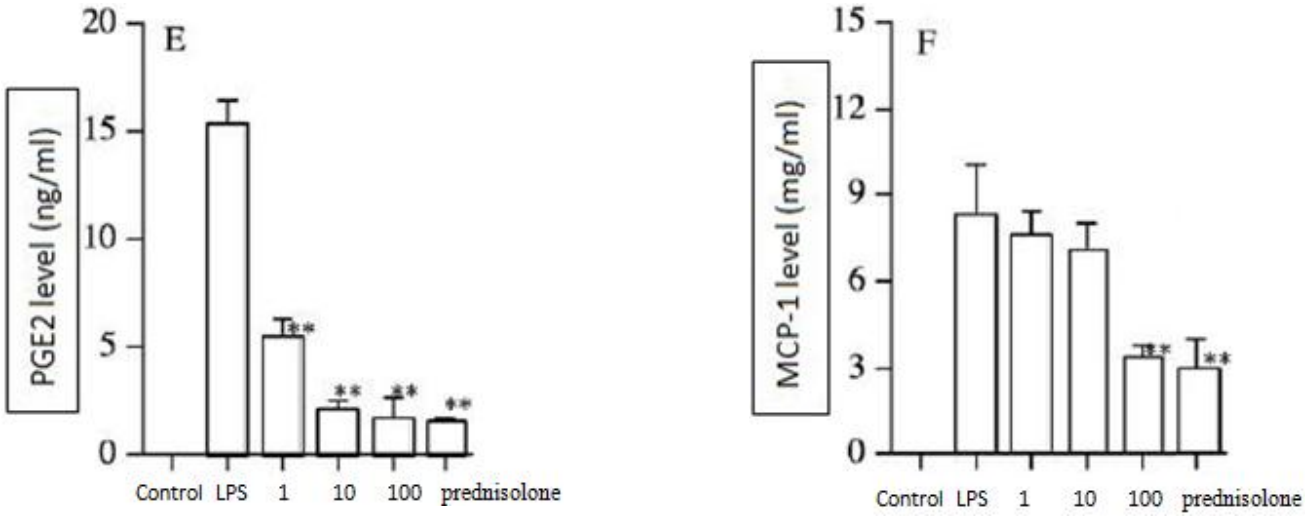
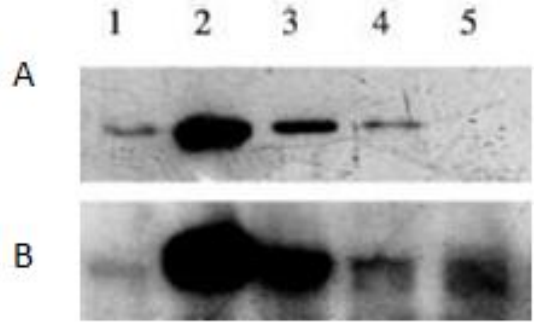


FIGURE 2. Western blot analysis of The effect of Bidaria khandalense extract on expression of LPS-induced iNOS protein (**A**) and COX-2 protein (**B**) in RAW 264.7 macrophages. *Lane 1*: control; *lane 2*: LPS; *lane 3*: 1 µg/mL of BKE; *lane 4*:10 µg/mL of BKE; *lane 5*: 100 µg/mL of BKE.



Discussion

The results of this study indicate that BKE suppresses the development of EIU in a dose-dependent manner. Particularly, the anti–inflammatory effect of 100 mg BKE was approximately as same as that observed with a 10-mg dose of prednisolone. Flavonoids and other phenolics have been suggested to play a preventive role in the development of cancer and heart disease (31). Antioxidant activity of some flavonoid compounds has been shown and given BKE with high levels of polyphenol compounds may has Antioxidant activity (32).

Oxidative stress has been known to be a major factor in triggering local inflammation and tissue damage during the inflammatory process, and BKE's antioxidant properties have been proposed to underlie its beneficial effects on inflammation. It is known that NO production plays an important role in endotoxemia and inflammatory conditions (21). To elucidate the anti-inflammatory mechanism of BKE, we focused our attention on BKE's antioxidant activity and measured the concentration of NO in the aqueous humor in vivo. Our results showed that BKE prevented NO production in the aqueous humor and the expression of the iNOS enzyme in a dose-dependent manner. These results are in agreement with those of our in vivo experiment. Large amounts of NO production induced by bacterial LPS or cytokines have been reported to play a central role in endotoxemia and inflammatory conditions (21). Therefore; we propose that BKE, which inhibits NO production through the inhibition of iNOS enzyme expression, could have a beneficial therapeutic effect with regard to the treatment of inflammation. In EIU, LPS stimulates inflammatory cells to upregulate iNOS mRNA (33, 34). Increased NO levels have been detected in the aqueous humor in patients with Behc¸et's disease (35). In this study, BKE inhibited the development of EIU and suppressed LPS-induced iNOS expression in a dose-dependent manner. Therefore, the present results support their hypothesis. TNF-α produce principally by activated macrophages and monocytes, and the most important role of TNF-α is in nonspecific resistance to various infectious agents (36, 37). The results show that the reduction in the TNf-α concentration has been occurred in a dose dependent manner by BKE. According to previous studies, EIU in mice has been worsened by decreasing TNF-α and it is not directly involved in the pathogenesis of EIUand may protect against inflammatory processes in EIU (38, 39). In this study, LPS significantly increased TNF-α level in the aqueous humor, and the different effects of TNF-α on EIU may be due to differences in species (rat and mouse) or animal strain. PGE2 may have an important role in suppression of TNF-α by NO. According to previous studies, NO activates COX enzymes and thereby leads to a marked increase in PGE2 production (40,41). The suppressive effect of PGE2 on TNF synthesis through elevated cAMP levels has been convincingly demonstrated (36, 41-43). Our results are in agreement with the previous studies, as we found that BKE suppressed the levels of LPS-induced PGE2 and TNF-α in a dose dependent manner in vivo. In addition, our results indicated that the BKE decreased the expression of the COX-2 enzyme in a dose-dependent manner. COX-2 is primarily responsible for increased PGE2 production during inflammation, and PGE2 is generally considered to be a proinflammatory agent. Results show that BKE suppressed the development of EIU and decreased LPS-induced COX-2 expression in vitro in a dose-dependent manner. Therefore, our findings are in agreement with the results of previous studies (17, 44-47) and suggested that blocking of COX-2 protein expression is one of the anti-inflammatory mechanisms of BKE. In conclusion, this study indicates that BKE has a dose-dependent anti– ocular-inflammatory effect on EIU. In particular, by increasing dose the effect of BKE was remarkable. It appears BKE performs its anti-inflammatory activity due to suppression of NO, PGE2, and TNF-_ production through the direct inhibition of the expression of the iNOS and COX-2 enzymes. These findings suggest that BKE may be useful for the treatment of ocular inflammation.

References

1. Karthikeyan A, Shanthi V, Nagasathaya A. Int J Green Pharm 2009; 3: 78-80.

2. Linuma M, Tsuchiya H, Sato M, Yokoyama J, Ohyama M, Ohkawa Y, et al. J Pharmacol 1994; 46(11): 892-895.
3. Sumy O, Ved DK, Krishna R. Tropical Indian medicinal plants propagation methods 2000; 194 -197.
4. Wang SY, Lin HS. Antioxidant activity in fruits and leaves of blackberry, raspberry, and strawberry varies with cultivar and developmental stage. *J Agric Food Chem*. 2000;48:140–146.
5. Kahkonen MP, Hopia AI, Heinonen M. Berry phenolics and their antioxidant activity. *J Agric Food Chem*. 2001;49:4076–4082.
6. Zheng W, Wang SY. Oxygen radical absorbing capacity of phenolics in blueberries, cranberries, chokeberries, and lingonberries. *J Agric Food Chem*. 2003;51:502–509.
7. Ames BN. Dietary carcinogens and anticarcinogens: oxygen radicals and degenerative diseases. *Science*. 1983;221:1256–1264.
8. Hertog MG, Feskens EJ, Hollman PC, Katan MB, Kromhout D. Dietary antioxidant flavonoids and risk of coronary heart disease: the Zutphen Elderly Study. *Lancet*. 1993;342:1007–1011.
9. Knekt P, Jarvinen R, Reunanen A, Maatela J. Flavonoid intake and coronary mortality in Finland: a cohort study. *BMJ*. 1996;312:478– 481.
10. Keli SO, Hertog MG, Feskens EJ, Kromhout D. Dietary flavonoids, antioxidant vitamins, and incidence of stroke: the Zutphen study. *Arch Intern Med*. 1996;156:637–642.
11. Knekt P, Jarvinen R, Seppanen R, et al. Dietary flavonoids and the risk of lung cancer and other malignant neoplasms. *Am J Epidemiol*. 1997;146:223–230.
12. Suzuma I, Mandai M, Suzuma K, Ishida K, Tojo SJ, Honda Y. Contribution of E-selectin to cellular infiltration during endotoxininduced uveitis. *Invest Ophthalmol Vis Sci*. 1998;39:1620 1630.
13. Hikita N, Chan CC, Whitcup SM, Nussenblatt RB, Mochizuki M. Effects of topical FK506 on endotoxin-induced uveitis (EIU) in the Lewis rat. *Curr Eye Res*. 1995;14:209–214.
14. Bhattacherjee P, Williams RN, Eakins KE. An evaluation of ocular inflammation following the injection of bacterial endotoxin into the rat foot pad. *Invest Ophthalmol Vis Sci*. 1983;24:196–202.
15. Baatz H, Tonessen B, Prada J, Pleyer U. Thalidomide inhibits leukocyte-endothelium interaction in endotoxin-induced uveitis. *Ophthalmic Res*. 2001;33:256–263.
16. Ohgami K, Shiratori K, Kotake S, et al. Effects of astaxanthin on lipopolysaccharide-induced inflammation in vitro and in vivo. *Invest Ophthalmol Vis Sci*. 2003;44:2694–2701.
17. Shiratori K, Ohgami K, Ilieva IB, Koyama Y, Yoshida K, Ohno S. Inhibition of endotoxin-induced uveitis and potentiation of cyclooxygenase- 2 protein expression by alpha-melanocyte-stimulating hormone. *Invest Ophthalmol Vis Sci*. 2004;45:159–164.

18. Rosenbaum JT, McDevitt HO, Guss RB, Egbert PR. Endotoxininduced uveitis in rats as a model for human disease. *Nature*. 1980;286:611–613.
19. Chen YC, Shen SC, Lee WR, Hou WC, Yang LL, Lee TJ. Inhibition of nitric oxide synthase inhibitors and lipopolysaccharide induced inducible NOS and cyclooxygenase-2 gene expressions by rutin, quercetin, and quercetin pentaacetate in RAW 264.7 macrophages. *J Cell Biochem*. 2001;82:537–548.
20. Boujedaini N, Liu J, Thuillez C, Cazin L, Mensah-Nyagan AG. In vivo regulation of vasomotricity by nitric oxide and prostanoids during gestation. *Eur J Pharmacol*. 2001;427:143 149.
21. Bellot JL, Palmero M, Garcia-Cabanes C, Espi R, Hariton C, Orts A. Additive effect of nitric oxide and prostaglandin-E2 synthesis inhibitors in endotoxin-induced uveitis in the rabbit. *Inflamm Res*. 1996;45:203–208.
22. Murakami A, Nakamura Y, Tanaka T, et al. Suppression by citrus auraptene of phorbol ester-and endotoxin-induced inflammatory responses: role of attenuation of leukocyte activation. *Carcinogenesis*. 2000;21:1843–1850.
23. Hoekzema R, Verhagen C, van Haren M, Kijlstra A. Endotoxininduced uveitis in the rat: the significance of intraocular interleukin- 6. *Invest Ophthalmol Vis Sci*. 1992;33:532–539.
24. Tracey KJ, Cerami A. Tumor necrosis factor: a pleiotropic cytokine and therapeutic target. *Annu Rev Med*. 1994;45:491–503.
25. Wadsworth TL, Koop DR. Effects of Ginkgo biloba extract (EGb 761) and quercetin on lipopolysaccharide-induced release of nitric oxide. *Chem Biol Interact*. 2001;137:43–58.
26. Ilieva IB Ohgami K, Shiratori K, et al. The effects of Ginkgo biloba extract on lipopolysaccharide-induced inflammation in vitro and in vivo. *Exp Eye Res*. 2004;79:181–187.
27. Vane JR. Inhibition of prostaglandin synthesis as a mechanism of action for aspirin-like drugs. *Nat New Biol*. 1971;231:232–235.
28. Xie WL, Chipman JG, Robertson DL, Erikson RL, Simmons DL. Expression of a mitogen-responsive gene encoding prostaglandin synthase is regulated by mRNA splicing. *Proc Natl Acad Sci USA*. 1991;88:2692–2696.
29. Kujubu DA, Fletcher BS, Varnum BC, Lim RW, Herschman HR. TIS10, a phorbol ester tumor promoter-inducible mRNA from Swiss 3T3 cells, encodes a novel prostaglandin synthase/cyclooxygenase homologue. *J Biol Chem*. 1991;266:12866–12872.
30. Vane JR, Bakhle YS, Botting RM. Cyclooxygenases 1 and 2. *Annu Rev Pharmacol Toxicol*. 1998; 38:97–120.
31. Serafini M, Maiani G, Ferro-Luzzi A. Alcohol-free red wine enhances plasma antioxidant capacity in humans. *J Nutr*. 1998;128: 1003–1007.
32. Cao G, Sofic E, Prior RL. Antioxidant and prooxidant behavior of flavonoids: structure-activity relationships. *Free Radic Biol Med*. 1997;22:749–760.
33. Jacquemin E, de Kozak Y, Thillaye B, Courtois Y, Goureau O. Expression of inducible nitric oxide synthase in the eye from endotoxin-induced uveitis rats. *Invest Ophthalmol Vis Sci*. 1996; 37:1187–1196.

34. Ohta K, Nakayama K, Kurokawa T, Kikuchi T, Yoshimura N. Inhibitory effects of pyrrolidine dithiocarbamate on endotoxininduced uveitis in Lewis rats. *Invest Ophthalmol Vis Sci*. 2002;43: 744–750.
35. Yilmaz G, Sizmaz S, Yilmaz ED, Duman S, Aydin P. Aqueous humor nitric oxide levels in patients with Behcet disease. *Retina*. 2002; 22:330–335.
36. Eigler A, Moeller J, Endres S. Exogenous and endogenous nitric oxide attenuates tumor necrosis factor synthesis in the murine macrophage cell line RAW 264.7. *J Immunol*. 1995;154:4048– 4054.
37. Friden BE, Runesson E, Hahlin M, Brannstrom M. Evidence for nitric oxide acting as a luteolytic factor in the human corpus luteum. *Mol Hum Reprod*. 2000;6:397–403.
38. Zhang M, Hung L, Gery I. Vasoactive intestinal peptide (VIP) exacerbates endotoxin-induced uveitis (EIU) in mice. *Curr Eye Res*. 2000;21:913–917.
39. Kasner L, Chan CC, Whitcup SM, Gery I. The paradoxical effect of tumor necrosis factor alpha (TNF-alpha) in endotoxin-induced uveitis. *Invest Ophthalmol Vis Sci*. 1993;34:2911–2917.
40. Salvemini D, Misko TP, Masferrer JL, Seibert K, Currie MG, Needleman P. Nitric oxide activates cyclooxygenase enzymes. *Proc Natl Acad Sci USA*. 1993;90:7240–7244.
41. Endres S, Fulle HJ, Sinha B, et al. Cyclic nucleotides differentially regulate the synthesis of tumour necrosis factor-alpha and interleukin- 1 beta by human mononuclear cells. *Immunology*. 1991; 72:56–60.
42. Eisenhut T, Sinha B, Grottrup-Wolfers E, Semmler J, Siess W, Endres S. Prostacyclin analogs suppress the synthesis of tumor necrosis factor-alpha in LPS-stimulated human peripheral blood mononuclear cells. *Immunopharmacology*. 1993;26:259–264.
43. Spengler RN, Spengler ML, Lincoln P, Remick DG, Strieter RM, Kunkel SL. Dynamics of dibutyryl cyclic AMP- and prostaglandin E2-mediated suppression of lipopolysaccharide-induced tumor necrosis factor alpha gene expression. *Infect Immun*. 1989;57:2837– 2841.
44. van der Pouw Kraan TC, Boeije LC, Smeenk RJ, Wijdenes J, Aarden LA. Prostaglandin-E2 is a potent inhibitor of human interleukin 12 production. *J Exp Med*. 1995;181:775–779.
45. Nataraj C, Thomas DW, Tilley SL, et al. Receptors for prostaglandin E(2) that regulate cellular immune responses in the mouse. *J Clin Invest*. 2001;108:1229–1235.
46. Gilroy DW, Colville-Nash PR, Willis D, Chivers J, Paul-Clark MJ, Willoughby DA. Inducible cyclooxygenase may have anti-inflammatory properties. *Nat Med*. 1999;5:698 –701.
47. Tuo J, Tuaillon N, Shen D, Chan CC. Endotoxin-induced uveitis in cyclooxygenase-2-deficient mice. *Invest Ophthalmol Vis Sci*. 2004; 45:2306–2313.