Effect of Camphor on the Behavior of Leukocytes In vitro and In vivo in Acute Inflammatory Response

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Abstract

**Purpose:** To evaluate the effect of camphor on acute inflammatory response by leukocytes on chemotaxis, antiedematogenic and phagocytic activities.

**Methods:** The effect of camphor in acute inflammatory response evaluated by neutrophil chemotaxis, ear edema induced by croton oil, activity of the enzyme myeloperoxidase (MPO) and phagocytic activity of macrophages in Swiss mice.

**Results:** Camphor treatment did not show any cytotoxicity. Camphor at 3, 10, and 30 µg/ml doses exhibited significant (p < 0.01) reduction on leukocyte migration toward N-formyl methionyl leucyl phenylalanine fMLP. Topical treatment with camphor did not reduce significant ear edema or MPO activity at any of the doses tested. However, in contrast, oral treatment with 100 and 200 mg/kg camphor significantly (p < 0.01) reduced ear edema and myeloperoxidase (MPO) activity. Additionally, the phagocytic activity of macrophages was not affected by camphor.

**Conclusions:** These results indicate that the anti-inflammatory activity of camphor may be related to the inhibition of leukocyte migration and antiedematogenic activity.

**Keywords:** Camphor, Inflammatory response, Chemotaxis, Macrophages, Phagocytic, Leukocytes, Edema

INTRODUCTION

Acute inflammation is characterized by swelling, heat, redness, and pain and is an important defense mechanism against invading pathogens. The mediators that arise from the cyclooxygenase (COX) cascade and role of biologically active prostaglandins in the inflammatory process and body homeostasis have been extensively studied. Cyclooxygenase inhibitors prevent prostaglandin biosynthesis and are effective anti-inflammatory compounds that reduce the levels of prostaglandins and cardinal signs of inflammation. Neutrophil chemotaxis to sites of inflammation is an essential process during normal immune responses to tissue injury and infection. Phagocytes form an important front-line defense against infection and are a major part of innate immunity and the process of removing pathogens from the blood and tissue fluids [1].

Anti-inflammatory drugs, such as steroids and nonsteroidal anti-inflammatory drugs, cause adverse effects, including gastric damage. The use of these drugs for their anti-inflammatory
effects has not been successful in all cases. Hence, the search for natural products has increased.

Camphor (C_{10}H_{16}O) is a natural and synthetic terpenoid ketone compound that is present in *Cinnamomum camphora* and other plant species [2]. It is a popular household remedy that is believed to act as an aphrodisiac, contraceptive, abortifacient, and lactation suppressor [3]. Camphor has been used topically to relieve pain and treat warts, cold sores, hemorrhoids, and osteoarthritis. It is a common ingredient in a wide variety of over-the-counter topical products [4]. The human lethal dose has been reported to be 50 - 500 mg/kg [3]. However, the toxicity of camphor in rats is not considered to be high, with an LD_{50} of 3000 mg/kg [5].

Several studies have been performed with extracts of plants that contain camphor, demonstrating anti-inflammatory, antioxidative, and antimicrobial effects [6,7]. However, very few studies have specifically evaluated the effects of camphor on the acute inflammatory response, hence the need for this study.

**EXPERIMENTAL**

**Chemicals**

Camphor, Dexamethasone, Zymosan, LPS (lipopolysaccharides from *Salmonella enterica* serotype *typhimurium*), fMLP (N-formyl methionyl leucyl phenylalanine) and Cróton oil were purchased from Sigma-Aldrich (St. Louis, MO, USA).

**Animals**

Male Swiss mice, weighing 25 - 30 g, were provided by the Central Animal House of the State University of Maringá, Maringá, Brazil. The animals were housed at 22 ± 2 °C under a 12/12 h light/dark cycle. Prior to the experiments, the animals were fasted overnight, with water provided *ad libitum*. The experimental protocols were approved by the Ethical Committee on Animal Experimentation of the State University of Maringá (CEAE/UEM 070/2012). The animals were handled according to the standard protocols for the use of laboratory animals [8].

**Cell viability analysis**

The MTT (3-[4,5-dimethylthiazol-2-yl]-2,5-diphenyl-2H-tetrazolium bromide; Sigma) assay is based on the mitochondrial enzyme reduction of tetrazolium dye to detect and determine cell viability. Neutrophils were obtained from the peritoneal cavity of mice 4 h after zymosan injection (1 mg/cavity, i.p.). Briefly, the cells were plated at a density of 5 × 10^5 cells/well in a volume of 100 μl RPMI 1640 medium supplemented with 10 % fetal bovine serum (FBS) and 100 U/ml penicillin + 100 μg/ml streptomycin in 96-well plates. The cells were incubated with varying concentrations of camphor (3, 10, 30, and 90 μg/ml) at 37 °C in 5 % CO₂ for 90 min followed by the addition of 10 μl MTT (5 mg/ml) stock solution to each well. After 2 h of incubation at 37 °C, 150 μl of the supernatant was removed, and 100 μl dimethyl sulfoxide (DMSO) was added to each well. The cells were incubated at 25 °C for a further 10 min, and absorbance was measured using a Biochrom Asys Expert plus microplate reader at a wavelength of 540 nm. The values of the blank wells were subtracted from each well of treated and control cells. Viability was determined using Eq 1.

\[
\text{Viability} = \frac{(\text{At} - \text{Ab})}{(\text{Ac} - \text{Ab})} \times 100
\]

where At, Ab and Ac are the absorbance of treated cells, blank and control, respectively

**Evaluation of in vitro neutrophil chemotaxis**

To evaluate the effect of camphor on chemotaxis, neutrophils were obtained from the peritoneal cavity of mice by peritoneal wasing with 3 ml of phosphate-buffered saline (PBS) that contained ethylene-diaminetetraacetic acid (EDTA) 4 h after zymosan injection (1 mg/cavity, i.p.). The cell suspension was centrifuged at 1000 rpm for 10 min at 4 °C and resuspended in RPMI1640 medium [9]. The cell number was adjusted to 1 × 10^6 cells/ml in RPMI 1640 medium that contained 0.1 % bovine serum albumin (BSA). A chemotaxis assay was performed using a 48-well microchemotaxis plate (Neuro Probe), in which the chambers were separated by a polycarbonate membrane (5 μm pore size). The chemoattractant, N-formyl methionyl leucyl phenylalanine (fMLP; 10⁻⁶ M), and vehicle (RPMI 1640) were placed in the lower chamber. A neutrophil suspension (1 × 10^6 cells/ml) was pretreated for 30 min with camphor (1, 3, 10, 30, 60, and 90 μg/ml) and then placed in the upper chamber. The chambers were incubated at 37 °C with 5 % CO₂ for 1 h. Following incubation, the membrane was washed in phosphate-buffered saline (PBS), fixed in methanol, and stained with Instant Prov. The membrane area of each well was scored using light microscopy to count the cells present in five random fields. The results are expressed as the mean number of
neutrophils per field and are representative of triplicate measurements from three separate experiments.

**Evaluation of camphor in topical ear edema inflammation model**

Cutaneous inflammation was induced by the application of 5 % croton oil (10 µl) in acetone (vehicle) in the inner surface of the mouse right ear [9]. The left ear received an equal volume of vehicle. Camphor (0.5, 1, 2.5, and 5 mg/ear), dexamethasone (0.1 mg/ear, anti-inflammatory drug reference), or vehicle was applied topically to the right ear 1 h before croton oil application. The effect of oral camphor treatment was also studied. For oral treatment, the mice received camphor (100, 200, or 400 mg/kg) or dexamethasone (1 mg/kg, anti-inflammatory drug reference), diluted in hydroalcoholic vehicle that contained 2 % ethyl alcohol and 1 % Tween. Four hours after application of the inflammatory stimulus, the mice were euthanized with an anaesthetic overdose of ketamine/xylazine [10], intraperitoneally. Phosphate-buffered saline that contained peritoneal exudate cells was recollected and kept on ice. The suspended cells were centrifuged at 1500 rotations per minute for 10 min and resuspended with complete RPMI-1640. Peritoneal exudate cells were then isolated on 24-well culture plates and allowed to adhere for 1 h at 37 °C in 5 % CO₂. After nonadherent cells were removed, the remaining adherent cells were designated as peritoneal macrophages. Cell viability, evaluated by the exclusion test with Trypan blue, was ≥ 90 % in all of the experiments. The cells were incubated for 24 h at 37 °C in 5 % CO₂ with different concentrations of camphor (3, 10, 30, or 90 µg/ml) in complete RPMI-1640 medium. Lipopolysaccharide (LPS; 20 µg/ml) was used as a positive control, and RPMI-1640 medium was used as a negative control. After incubation, 100 µl of a 3 % suspension of chicken red blood cells (CRBCs) was added to each well. CRBCs were used to assess macrophage phagocytosis. After 1 h, the macrophages were fixed and stained. Phagocytosis index was measured by counting the number of phagocytosed CRBCs per 100 macrophages [11].

**Statistical analysis**

The data are expressed as mean ± SEM for each experimental group. The results were statistically analyzed using one-way analysis of variance (ANOVA) followed by Tukey’s test. The software used was GraphPad Prism version 5.01, GraphPad Software, Inc. Differences were considered significant at p < 0.05.

**RESULTS**

**Cell viability**

In the cell viability assay, camphor was tested at different concentrations. Concentrations of 3, 10, 30, and 90 µg/ml presented cell viability of 82.5, 76, 85.8, and 88 %, respectively, indicating that camphor did not induce cell death when compared with the untreated cells.

**Effect of camphor on in vitro neutrophil chemotaxis**

To investigate the direct effect of camphor on leukocyte chemotaxis, different concentrations of camphor were tested (1, 3, 10, 30, 60, and 90 µg/ml) in the in vitro chemotaxis assay. fMLP was the chemotactic agent used to promote migration of neutrophils. The results obtained are...
shown in Figure 1. MLP induced significant leukocyte migration compared to the vehicle (RPMI1640). Camphor at doses of 3, 10, and 30 µg/ml significantly reduced (p < 0.01) neutrophil migration toward fMLP (10^(-6) M; 25.09 ± 0.89, 36.42 ± 1.07, and 23.53 ± 2.18 %, respectively), as illustrated in Figure 1. Additionally, the results demonstrated that oral treatment with camphor significantly reduced MPO activity by 51.5 and 60.6 % at doses of 100 and 200 mg/kg, respectively (p < 0.01), dexamethasone (1 mg/kg) significantly inhibited MPO activity by 57.6 % (p < 0.01). Camphor, at a dose of 400 mg/kg, increased MPO activity by 21 % (Figure 2D).

Effect of camphor on the phagocytic activity of macrophages

Camphor did not exert any influence on the phagocytic activity of macrophages (Figure 3).

**DISCUSSION**

Polymorphonuclear leukocyte recruitment is known to be an essential factor in the acute inflammatory process by acting as first-line defense cells in the initiation and resolution phases of this process, involving the participation of many inflammatory mediators, such as prostanoids.

In vitro treatment with camphor did not affect the viability of neutrophils at any of the concentrations tested, indicating that the direct effect of camphor on leukocyte chemotaxis inhibition did not occur because of toxic effects that induce cell death.

Studies performed with extracts and essential oils of *Artemisia fukudo* and *Cinnamomum camphora* that contain camphor as a major constituent found that they inhibited
Figure 2: Effect of Camphor on the ear edema and myeloperoxidase activity. Effect of topical treatment with camphor on ear edema (A) and myeloperoxidase activity (MPO) (B) induced by croton oil in ear tissues from mice. The animals were treated topically with camphor or dexamethasone (Dex) 1 h before croton oil application (10 µl/ear). Effect of oral treatment with camphor on ear edema (C) and MPO activity (D) induced by croton oil in ear tissues from mice. The animals were treated oral with camphor or Dex 1 h before croton oil application (10 µl/ear). Dex was used as anti-inflammatory drug (positive control). The right ears received only the vehicle (Basal). Ear edema and MPO activity were determined 4 hours after application of croton oil. Data are mean ± S.E.M., *p < 0.05, compared to the control group (croton oil) (ANOVA, Tukey’s test)

proinflammatory cytokines, such as interleukin-1β (IL-1β), interleukin-6 (IL-6), tumor necrosis factor-α (TNF-α), and prostaglandin E2 (PGE2) in macrophage cultures [13,14]. Indeed, camphor as an isolated compound inhibited the production of IL-1β, IL-4, and TNF-α [12]. Our data suggest that camphor may act by inhibiting pro-inflammatory cytokines induced by chemotactic agents. fMLP is a chemotactic agent involved in the release of many cytokines upon binding to its G-protein-coupled receptor, activating multiple signaling cascades [13]. These pathways include the mitogen-activated protein kinase (MAPK) and phosphatidylinositol 3-kinase (PI-3K) cascades, which are important for the development of the functional responses of neutrophils in inflammation. Further studies should be performed to elucidate the anti-inflammatory mechanism of action of camphor.

To demonstrate the topical effect of camphor in vivo, we evaluated inflammatory ear edema induced by croton oil. This oil is an irritant that induces an inflammatory response by activating phospholipase A2 and initiating arachidonic acid metabolites [14], followed by COX-1- and COX-2-induced prostaglandin production and 5-lipoxygenase-induced leukotriene production. Prostaglandins and leukotrienes are inflammatory mediators involved in edema and leukocyte migration.

MPO enzyme is found in the azurophilic granules of neutrophils and other cells of myeloid origin. It
catalyzes the production of hypochlorous acid (which has toxic effects on microorganisms) from hydrogen peroxide and chloride, but it is harmful to tissue cells [15]. Myeloperoxidase is an indirect marker of neutrophil infiltration into tissue. Decreases in MPO activity suggest less neutrophil infiltration. Our data suggest that camphor exerts anti-inflammatory effects only when administered systemically. At higher doses (e.g., 400 mg/kg), camphor has irritative effects. Oral dexamethasone administration inhibited phospholipase A2, consequently reducing eicosanoid production. Based on our results, we suggest that camphor inhibits chemotactic mediators that are released through different metabolic pathways. Our data showed that camphor effectively inhibited in vitro chemotaxis and leukocyte infiltration and had antiedematogenic activity when administered systemically.

Macrophages are phagocytic cells that play a central role in the immune response to inflammatory and infectious diseases. Lipopolysaccharide (LPS) is a major component of the outer membrane of Gram-negative bacteria and acts as one of the most powerful activators of resident macrophages by binding the CD14/toll-like receptor 4 (TLR-4)/MD2 receptor complex, leading to the activation of nuclear factor κB (NF-κB) and MAPKs, which not only promote the overproduction of cytokines, pro-inflammatory mediators, and phagocytosis but also induce the differentiation and maturation of monocytes/macrophages [16,17]. As an activator of macrophages, LPS is one of the most potent microbial initiators of inflammation, which can increase the secretion of NO in mouse peritoneal macrophages [16]. The stimulation of TLR-4 receptors by LPS results in a significant increase in the production of pro-inflammatory cytokines, such as IL-6 and TNF-α [18]. The rate and index of CRBC phagocytosis were positively correlated with the expression of TLR-4 [19].

NO is an inflammatory mediator secreted by macrophages that also increases macrophage activity [16,20]. Cinnamomum camphora and Ocotea odorifera extracts and their essential oils, which contain camphor, exhibit antioxidant activity [6], inhibiting free radical formation, such as NO and reactive oxygen species, and likely contributing to anti-inflammatory activity. Since camphor did not significantly alter the phagocytosis index at any of the concentrations tested, we suggest that camphor, as an isolated compound, is unlikely to be involved in the production of free radicals (e.g., NO) or pathways involved in the activation of TLR-4.

CONCLUSION

The results obtained show that camphor affects inflammatory response, inhibits neutrophil migration in vitro, has antiedematogenic activity, and decreases neutrophil infiltration in inflamed tissue. Camphor affects inflammatory response only after oral administration. It exerts anti-inflammatory effects at low doses but has an irritant effect at higher doses. Further studies are needed to elucidate the mechanism of the action of camphor.

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