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RETRACTED: Fatty Acids Dietary Supplements Exert Anti-Inflammatory Action and Limit Ganglion Cell Degeneration in the Retina of the EAE Mouse Model of Multiple Sclerosis

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Abstract: Optic neuritis is an acute inflammatory demyelinating disorder of the optic nerve (ON) and is an initial symptom of multiple sclerosis (MS). Optic neuritis is characterized by ON degeneration and retinal ganglion cell (RGC) loss that contributes to permanent visual disability and lacks a reliable treatment. Here, we used the experimental autoimmune encephalomyelitis (EAE) mouse model of MS, a well-established model also for optic neuritis. In this model, C57BL6 mice, intraperitoneally injected with a fragment of the myelin oligodendrocyte glycoprotein (MOG), were found to develop inflammation, Müller cell gliosis, and infiltration of macrophages with increased production of oncomodulin (OCM), a calcium binding protein that acts as an atypical trophic factor for neurons enabling RGC axon regeneration. Immunolabeling of retinal whole mounts with a Brn3a antibody demonstrated drastic RGC loss. Dietary supplementation with Neuro-FAG (nFAG®), a balanced mixture of fatty acids (FAs), counteracted inflammatory and gliotic processes in the retina. In contrast, infiltration of macrophages and their production of OCM remained at elevated levels thus eventually preserving OCM trophic activity. In addition, the diet supplement with nFAG exerted a neuroprotective effect preventing MOG-induced RGC death. In conclusion, these data suggest that the balanced mixture of FAs may represent a useful form of diet supplementation to limit inflammatory events and death of RGCs associated to optic neuritis. This would occur without affecting macrophage infiltration and the release of OCM thus favoring the maintenance of OCM neuroprotective role.

Keywords: optic neuritis; myelin oligodendrocyte glycoprotein; neuroinflammation; macrophage infiltration; oncomodulin; neuroprotection

1. Introduction

Experimental autoimmune encephalomyelitis (EAE) is an extensively used animal model for multiple sclerosis (MS). Although there is no a single animal model that completely mirrors the human disease, the EAE model plays a pivotal role as a first-line model to study novel therapeutic interventions against MS and to shed light on mechanistic aspects of these treatments [1]. In both EAE and MS, symptomatic lesions typically involve the optic nerve (ON) and spinal cord.

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Traditionally, MS is considered a primary disorder of demyelination that is mediated by a neuroinflammatory state, which is established by activated microglia that triggers proinflammatory responses thus promoting macrophages influx, which is the main cause of ON fiber loss [2] and retinal ganglion cell (RGC) degeneration that contribute to permanent visual disability [3]. On the other hand, infiltrated inflammatory cells have been found to play an important role as sources of oncomodulin (OCM), a calcium-binding protein from the parvalbumin family that is secreted by macrophages and neutrophils and has been proposed to play an important role as an atypical trophic factor in axonal regeneration after lens injury or ON crush [4]. Whether the EAE model is characterized by altered OCM production remained to be established.

From the clinical point of view, about 20% of people who develop MS show optic neuritis as the first symptom [5]. Current therapies used for optic neuritis include the intravenous administration of corticosteroids that, however, show limited effect in preventing damages to RGC axons [6]. In fact, although corticosteroids may reduce inflammation and stimulate acute visual recovery, up to 60% of patients fail to normalize visual function (see [7]). Additional newer candidates to improve ON function have been recently established, although their benefit and harm remain to be determined (see [8]).

Nutritional approaches may contribute to counteract inflammatory processes in the eye as an increasing amount of scientific data highlight the ability of specific nutrients to cross the blood retinal barrier, and to modulate inflammatory pathways that account for neurodegeneration. For instance, in the retina, antioxidant compounds exert a neuroprotective effect through several mechanisms including the inhibition of inflammatory processes [9,10]. Among diet supplements, fatty acids (FAs) are, at present, extensively investigated for their benefits and potential harms, although data relative to their beneficial effects are often controversial. In this respect, there is evidence that omega-3 FAs reduce the risks associated with neuronal loss after traumatic spinal cord or brain injuries [11–13]. In addition, several studies in the mouse EAE model demonstrate that FAs can be effective in reducing axon demyelination in the ON or in the white matter of the spinal cord [14,15]. In the retina, clinical and experimental studies show that dietary supplementation with omega-3 FAs inhibits metabolic processes implicated in the pathogenesis of neurodegenerative diseases [16].

Neuroprotective effects of omega-3 FAs appear to involve decreased neuroinflammation [9] through the modulation of signaling pathways which are not completely clarified. In ocular pathologies, for instance, there is indication that long chain FA supplementation may prevent or delay neurodegenerative disorders, possibly involving an inhibitory effect on the production of inflammatory cytokines, although clinical trials are far from being conclusive [17–19].

Recently, a patented mixture of long-chain FAs, referred as FA Group (FAG®), has been found to be involved in cell protection from oxidative stress and inflammation. In cultured human monocytes, FAG is non-toxic up to 1 mg/mL and has been shown to inhibit the release of inflammatory cytokines induced by a lipopolysaccharide challenge [20]. The acronym FAG includes a number of different mixtures obtained by a calibrated mixing of long and short chain FAs given to sustain the metabolism of macrophages involved in the inflammatory reaction with the aim of facilitating its resolution and the shift of macrophages to the non-pro-inflammatory phase. Different mixtures have been studied and proposed in relation to different pathologies in different body districts and the specific inflammatory reaction elicited in the pathology. Among the different mixtures, an orally-administered compound based on FAG with the addition of lycopene and spirulina, designated as Macular-FAG (mFAG®), is commercialized by Sooft Italia SpA (Montegiorgio, Italy) with a main recommendation for patients with early signs of atrophic macular degeneration. Indeed, a recent study demonstrated that mFAG is able to limit the acute inflammatory reaction and macrophage infiltration triggered by a drusen-like insult in a mouse model of dry AMD [21] thus opening the way for further investigations using FAG in inflammatory diseases of the eye. An additional FAG-based compound, designated as Neuro-FAG (nFAG®), contains a different mix of FAs in different proportions, plus lycopene, and has been developed to specifically treat inflammatory events damaging RGCs and their axons.

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In the present study, we used the mouse model of myelin oligodendrocyte glycoprotein (MOG) immunization that results in EAE with a high incidence of optic neuritis (see [22]) in order to determine whether nFAG may counteract neuroinflammation with the final aim to address a possible role of this diet supplement in counteracting RGC degeneration. To this aim, nFAG was given daily to animals fed with a standard diet, starting on the day of MOG administration and continuing until their sacrifice, 16 days later. The effects of this diet supplement were investigated by evaluating markers of inflammation, gliosis and macrophage infiltration. OCM production was also determined. Molecular and biochemical data were further correlated with immunohistochemical evaluation of RGC number in retinal whole mounts in order to evaluate whether the diet supplement may reduce RGC loss that characterizes EAE mice.

2. Materials and Methods

2.1. Animals

This study was carried out in strict accordance with the recommendations in the Guide for the Care and Use of Laboratory Animals of the National Institutes of Health and adheres to the ARVO Statement for the Use of Animals in Ophthalmic and Vision Research. Procedures were carried in compliance with the Italian guidelines for animal care (DL 26/14) and the European Communities Council Directive (2010/63/UE), and are approved by the Commission for Animal Wellbeing of the University of Pisa (Permit Number: 0009069/2014). All efforts were made to reduce both animal suffering and the number of animals used.

C57BL/6J mice were originally purchased from Charles River Laboratories Italy (Calco, Italy) and mated in-house to a breeding colony. Mice were housed in a regulated environment (23 ± 1 °C, 50 ± 5% humidity) with a 12 h light/dark cycle (lights on at 08.00 a.m.), and provided with a standard diet and water ad libitum. Fifty-two female mice (8 week-old) were used for this study as females are more susceptible to develop MS than male mice [23].

2.2. Induction and Scoring of EAE

Of the fifty-two mice, twenty-six were immunized for EAE induction as described previously [24]. Briefly, mice were anesthetized by isoflurane, and a total of 200 µg MOG peptide ($MOG_{35–55}$; Anaspec, Freemont, CA, USA) emulsified in Complete Freund's Adjuvant (CFA; Sigma-Aldrich, St. Louis, MO, USA), containing 2.5 mg/mL mycobacterium tuberculosis, was injected subcutaneously at two sites on the back. Twenty-six mice (from now on referred as controls) were injected with an equal volume of phosphate-buffered saline (PBS) and CFA. All animals received 200 ng pertussis toxin (Sigma-Aldrich, St. Louis, MO, USA) in 0.1 mL PBS by intraperitoneal injection at 0 and 48 h post immunization. Clinical EAE scores were graded blindly and daily using the established standard scoring from 1 to 5 as follows: 0, no signs; 1, loss of tail tonicity; 2, loss of tail tonicity and mild paralysis of hindlimbs; 3, paralysis of hindlimbs; 4, hindlimb paralysis and mild paralysis of forelimbs; 5, complete paralysis or death [24].

2.3. Dietary Supplementation

The diet supplement used in this study and referred as nFAG is marketed in capsules by Sooft Italia SpA (Montegiorgio, Italy). Each capsule contains 500 mg of a patented mixture of saturated and unsaturated FAs that is referred as FAG (Again Life Italia s.r.l., Schio, Italy; for details see [25]) with addition of 2.5 mg of lycopene (from *Solanum lycopersicum* L., fructus). FAG composition was as follows: palmitic acid (10% by weight), oleic acid (10% by weight), stearic acid (10% by weight), linoleic acid (1% by weight), α-linolenic acid (1% by weight), γ-linolenic acid (0.5% by weight), eicosapentaenoic acid (3% by weight) and docosahexaenoic acid (2% by weight), with *N*-(2-hydroxyethyl)hexadecanamide added as an excipient. One-hundred mg of nFAG was suspended in 2 mL of 10% sucrose in water. Two-hundred µL of the suspension, containing 10 mg of nFAG, was administered daily to thirteen

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MOG-treated mice and thirteen control mice by oral gavage starting from the day of immunization until the day of sacrifice (day 16 post immunization). This dose corresponds to that recommended in humans (1–2 capsules/70 kg daily), normalized by the body surface area method for interspecies' drug dosage translation [26].

2.4. Isolation of Total RNA and Proteins

Mice were deeply anesthetized and euthanized by cervical dislocation. Retinas were rapidly dissected and stored at −80 °C until use for molecular analyses. Molecular analyses were performed using nine independent samples, each containing two retinas from two mice, per experimental condition. Total RNA and proteins were extracted using the AllPrep RNA/Protein Kit (Qiagen, Valencia, CA, USA) according to the manufacturer instructions.

2.5. Quantitative Real Time PCR

First-strand cDNA was generated from 1 μg of total RNA (QuantiTect Reverse Transcription Kit, Qiagen, Valencia, CA, USA). Real-time PCR amplification was performed with SsoAdvanced Universal SYBR Green Supermix (Bio-Rad Laboratories, Hercules, CA, USA) on a CFX Connect Real-Time PCR detection system and software CFX manager (Bio-Rad Laboratories, Hercules, CA, USA). qPCR primer sets for tumor necrosis factor-α (TNF-α), interleukin (IL)-1β, IL-6, IL-8, intercellular adhesion molecule-1 (ICAM-1), glial fibrillary acidic protein (GFAP), the inducible form of nitric oxide synthase (iNOS), cluster of differentiation 68 (CD68), endothelial growth factor-like module-containing mucin-like hormone receptor-like 1 (F4/80) and OCM were chosen to hybridize to unique regions of the appropriate gene sequence (see Table S1 for a complete list of assayed genes and primers). Amplification efficiency was near 100% for each primer pair (Opticon Monitor 3 software, Bio-Rad Laboratories, Hercules, CA, USA). Target genes were assayed concurrently with Rpl13a, a gene encoding for ribosomal protein L13A. Samples were compared using the relative threshold cycle (Ct Method). The increase or decrease (fold change) was determined relative to control mice after normalization to Rpl13a. All reactions were performed in triplicate.

2.6. Enzyme-Linked Immunosorbent Assays

Quantification of TNF-α, IL-1β, IL-6, IL-8, CD68, F4/80 and OCM protein levels was performed using commercially available kits (LifeSpan Biosciences, Inc., Seattle, WA, USA for CD68, F4/80 and OCM; R&D Systems, Minneapolis, MN, USA for TNF-α, IL-1β, and IL-6; MyBioSource, San Diego, CA, USA for IL-8). Proteins, purified as described above, were supplemented with a protease inhibitor cocktail (Roche Applied Science, Indianapolis, IN, USA). Protein content was quantified by the Micro BCA Protein Assay (Thermo Fisher Scientific, Waltham, MA, USA). ELISA plates were evaluated spectrophotometrically (Microplate Reader 680 XR, Bio-Rad Laboratories, Hercules, CA, USA) according to the manufacturers' instructions. Data were expressed as picograms of targets per milligram of protein. All experiments were performed in duplicate.

2.7. Western Blot

Western blot analysis was performed using the protein samples from ELISA quantifications. Aliquots of each sample containing equal amounts of protein (30 μg) were subjected to SDS-PAGE, and β-actin was used as loading control. Gels were transblotted onto a PVDF membrane, and the blots were blocked in 3% skim-milk for 1 h at room temperature, followed by incubation overnight at 4 °C with a primary goat polyclonal antibody directed to ICAM-1 (1:200 dilution; sc-1511; Santa Cruz Biotechnology, Santa Cruz, CA, USA), or with primary rabbit polyclonal antibody directed to GFAP (1:200 dilution; sc-9065; Santa Cruz Biotechnology) or iNOS (1:200 dilution; sc-8310; Santa Cruz Biotechnology). Finally, blots were incubated for one hour at room temperature with HRP-conjugated secondary antibodies (1:5000; Santa Cruz Biotechnology) and developed with Clarity Western enhanced chemiluminescence substrate (Bio-Rad Laboratories, Inc., Hercules, CA, USA). Images were acquired

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(ChemiDoc XRS+; Bio-Rad Laboratories, Inc., Hercules, CA, USA), and the optical density (OD) of the bands was evaluated (Image Lab 3.0 software; Bio-Rad Laboratories, Inc., Hercules, CA, USA). The data were normalized to the corresponding OD of β-actin. All experiments were performed in duplicate.

2.8. RGC Immunohistochemistry and Quantification

Mice were anesthetized and euthanized (n = 4 for each experimental group), eyeballs were enucleated (after a small incision was made in the dorsal margin of the ora serrata for orientation) and explanted retinas were immersion-fixed for 90 min in 4% paraformaldehyde in 0.1 M phosphate buffer (PB) at 4 °C. Retinas were then transferred to 25% sucrose in 0.1 M PB and stored at 4 °C. They were incubated overnight at 4 °C with primary antibody against Brn3a (1:100 dilution; sc-6026; Santa Cruz Biotechnology, Santa Cruz, CA, USA) in PB containing 5% BSA and 2% TritonX-100. Retinas were washed three times with PB and incubated for 2 h at room temperature with secondary antibodies conjugated to AlexaFluor 546 (1:100 dilution; Molecular Probes, Eugene, OR, USA). Finally, the retinas were washed three times with PB and mounted on gelatin-coated glass slides and cover-slipped with a 0.1 M PB-glycerin mixture (the vitreous side facing up). Brn3a-positive RGCs were viewed with a fluorescence microscope (Ni-E; Nikon-Europe, Amsterdam, The Netherlands) and images were acquired with DS-Fi1c camera (Nikon-Europe). The number of Brn3a-positive cells was quantified using NIS-Elements software (Nikon-Europe).

2.9. Statistical Analysis

All data were analyzed by the Shapiro-Wilk test to certify normal distribution. Statistical significance was evaluated with Prism 5.03 (GraphPad Software, Inc., San Diego, CA, USA) using One-way analysis of variance (ANOVA) followed by Newman–Keuls' multiple comparison post-test or two-way ANOVA followed by Bonferroni's multiple comparison post-test as appropriate. After statistical analysis, the data from different experiments were plotted and averaged in the same graph. Results were expressed as the mean ± S.E.M. of the indicated n values. Differences with $p < 0.05$ were considered significant.

3. Results

3.1. nFAG Delays the Onset of EAE

The effects of daily gavage with 10 mg nFAG were investigated in MOG-treated mice. As shown in Figure 1, MOG-treated mice developed a typical course of chronic EAE, marked by ascending paralysis beginning approximately 10 days after immunization, peaking several days later (Figure 1). Treatment with nFAG significantly delayed the onset of EAE although 16 days post immunization EAE severity reached levels equivalent to those observed in mice that did not received nFAG.

3.2. nFAG Supplementation Reduces Inflammatory Processes

Figure 2 shows the increased expression of inflammatory cytokines and the effects of nFAG supplementation on their upregulated expression as evaluated at the transcript and the protein level. At the transcript level, after MOG, TNF-α (Figure 2A), IL-1β (Figure 2C), IL-6 (Figure 2E), and IL-8 (Figure 2G) increased to approximately 3.0-, 2.9-, 3.3- and 2.4-fold ($p < 0.001$), whereas at the protein level, inflammatory cytokines (Figure 2B,D,F,H) increased to approximately 7.1-, 4.7-, 15.3- and 14.5-fold ($p < 0.001$). nFAG supplementation did not affect the levels of inflammatory cytokines in controls, whereas significantly decreased their upregulated levels in MOG-treated mice. At the transcript level, TNF-α, IL-1β, IL-6, and IL-8 were reduced by nearly 1.2-, 1.5-, 1.3- and 1.4-fold ($p < 0.001$), whereas their protein level were reduced by about 1.5-, 1.6-, 1.5- and 2.1-fold ($p < 0.001$).

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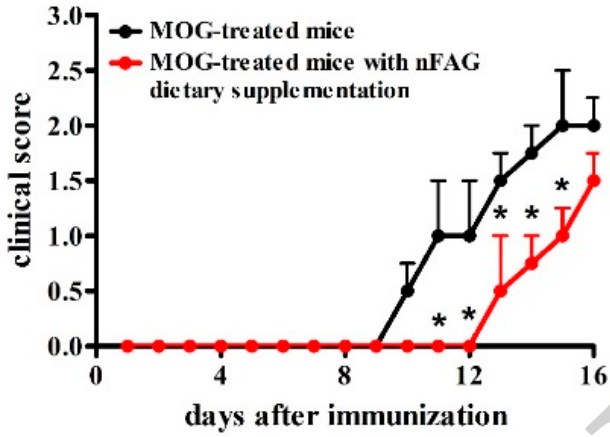
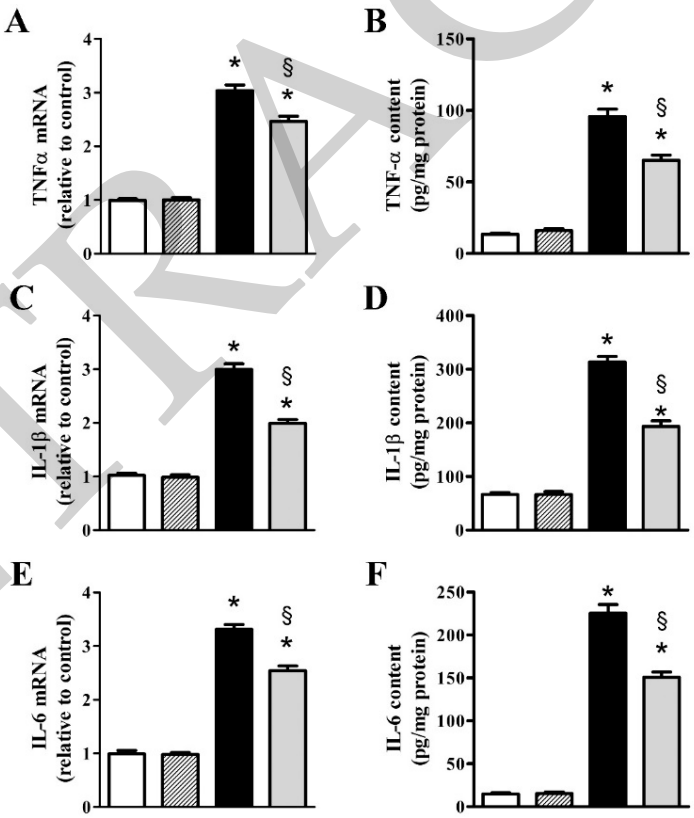


Figure 1. Neuro-FAG (nFAG) dietary supplementation delays the onset of experimental autoimmune encephalomyelitis (EAE). Myelin oligodendrocyte glycoprotein (MOG)-treated mice, without or with nFAG dietary supplementation (n = 13 for each experimental group), were examined daily until their sacrifice, 16 days after MOG administration, using a clinical EAE scoring system ranging from 0 (no signs) to 5 (complete paralysis or death). * $p < 0.05$ versus MOG-treated mice (two-way ANOVA followed by Bonferroni's multiple comparison post-test). Black circles and black line, MOG-treated mice; red circles and red line, MOG-treated mice with nFAG dietary supplementation.



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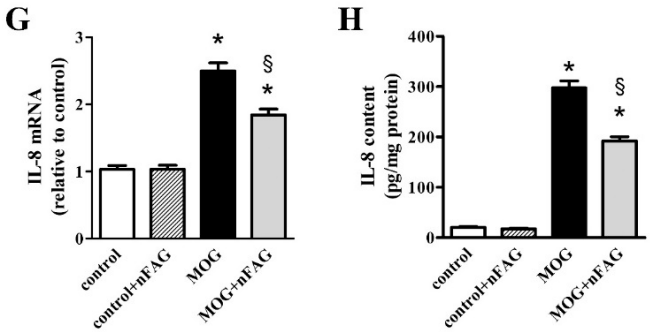
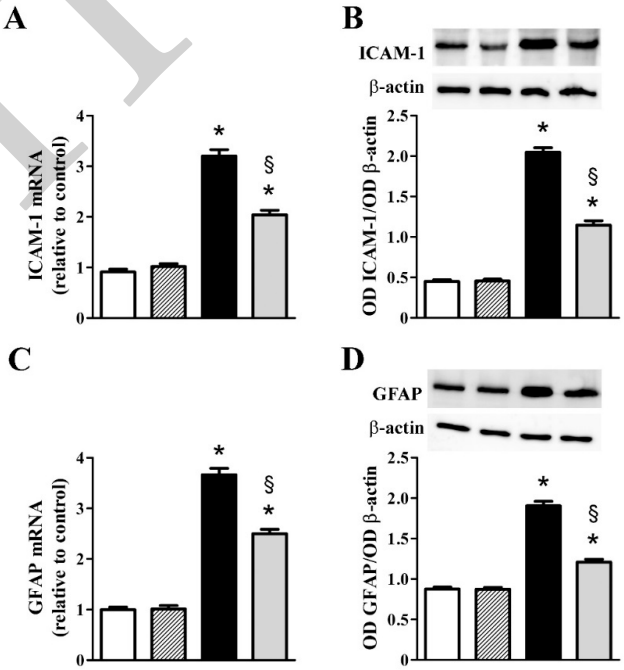


Figure 2. nFAG dietary supplementation reduces MOG-induced upregulation of markers of inflammation including tumor necrosis factor-α (TNF-α; **A**,**B**); interleukin (IL)-1β (**C**,**D**); IL-6 (**E**,**F**) and IL-8 (**G**,**H**). Levels were evaluated in control and MOG-treated mice, without or with nFAG dietary supplementation. Transcripts (**A**,**C**,**E**,**G**) were evaluated by relative quantification with quantitative real-time PCR (qPCR). Data were analyzed by the formula $2^{-\Delta\Delta CT}$ using Rpl13a as the internal standard. Proteins (**B**,**D**,**F**,**H**) were evaluated by ELISA (R&D Systems, Minneapolis, MN, USA for TNF-α, IL-1β, and IL-6; MyBioSource, San Diego, CA, USA for IL-8). Data are shown as the mean ± S.E.M. ($n = 9$ for each experimental group). * $p < 0.001$ versus control. § $p < 0.001$ versus MOG (one-way ANOVA followed by the Newman-Keuls multiple comparison post-hoc test). White bars, control mice; dashed bars, control mice with nFAG dietary supplementation; black bars, MOG-treated mice; grey bars, MOG-treated mice with nFAG dietary supplementation.

Additional inflammatory markers including ICAM-1, GFAP, and iNOS were also evaluated at the transcript and the protein level. As shown in Figure 3, we found that ICAM-1 (Figure 3A), GFAP (Figure 3C), and iNOS (Figure 3E) transcripts increased to approximately 3.5-, 3.7- and 3.4-fold ($p < 0.001$), whereas their protein levels (Figure 3B,D,F) increased to approximately 4.6-, 2.2- and 3.1-fold ($p < 0.001$). nFAG supplementation did not affect the levels of inflammatory markers in controls, whereas significantly decreased their upregulated levels in MOG-treated mice with ICAM-1, GFAP, and iNOS transcripts reduced by nearly 1.6-, 1.5- and 1.6-fold ($p < 0.001$). At the protein level, nFAG reduced ICAM-1, GFAP, and iNOS by about 1.8-, 1.6- and 1.6-fold ($p < 0.001$).



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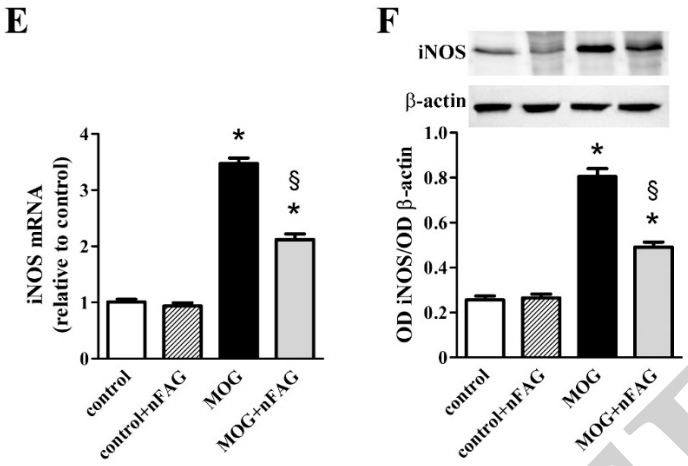
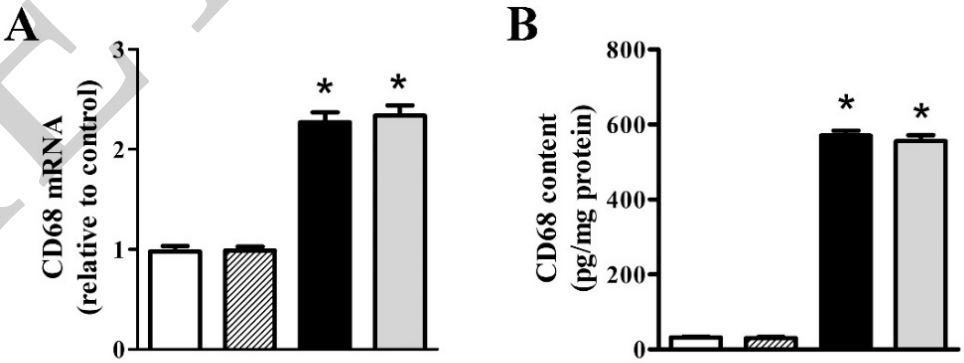


Figure 3. nFAG dietary supplementation reduces MOG-induced upregulation of markers of inflammation including intercellular adhesion molecule-1 (ICAM-1; **A**,**B**); glial fibrillary acidic protein (GFAP; **C**,**D**) and the inducible form of nitric oxide synthase (iNOS; **E**,**F**). Levels were evaluated in control and MOG-treated mice, supplemented or not with nFAG. Transcripts (**A**,**C**,**E**) were evaluated by relative quantification with qPCR. Data were analyzed by the formula $2^{-\Delta\Delta CT}$ using Rpl13a as the internal standard. Proteins (**B**,**D**,**F**) were evaluated by western blot using β-actin as loading control. Data are shown as the mean ± S.E.M. ($n = 9$ for each experimental group). * $p < 0.001$ versus control. § $p < 0.001$ versus MOG (one-way ANOVA followed by the Newman-Keuls multiple comparison post-hoc test). White bars, control mice; dashed bars, control mice with nFAG dietary supplementation; black bars, MOG-treated mice; grey bars, MOG-treated mice with nFAG dietary supplementation.

As shown in Figure 4, we investigated the effects of nFAG dietary supplementation on levels of markers of macrophage infiltration including CD68, a transmembrane protein possibly involved in peptide transport and antigen processing [27], and F4/80, a marker of mouse macrophages that plays a role in the induction of immunological tolerance [28]. After MOG, retinal levels of CD68 and F4/80 transcripts (Figure 4A,C) and proteins (Figure 4B,D) increased to nearly 2.3- and 1.9-fold ($p < 0.001$), and 17.6- and 5.8-fold ($p < 0.001$), respectively. No effects were found after nFAG supplementation, neither in controls nor in MOG-treated mice, indicating that MOG-induced macrophage activation was unaffected by the diet supplement. In concomitance with macrophage activation, OCM transcripts (Figure 4E) and proteins (Figure 4F) increased to nearly 2.1-fold ($p < 0.001$) and 5.5-fold ($p < 0.001$), respectively. No effects on OCM levels were found after nFAG supplementation.



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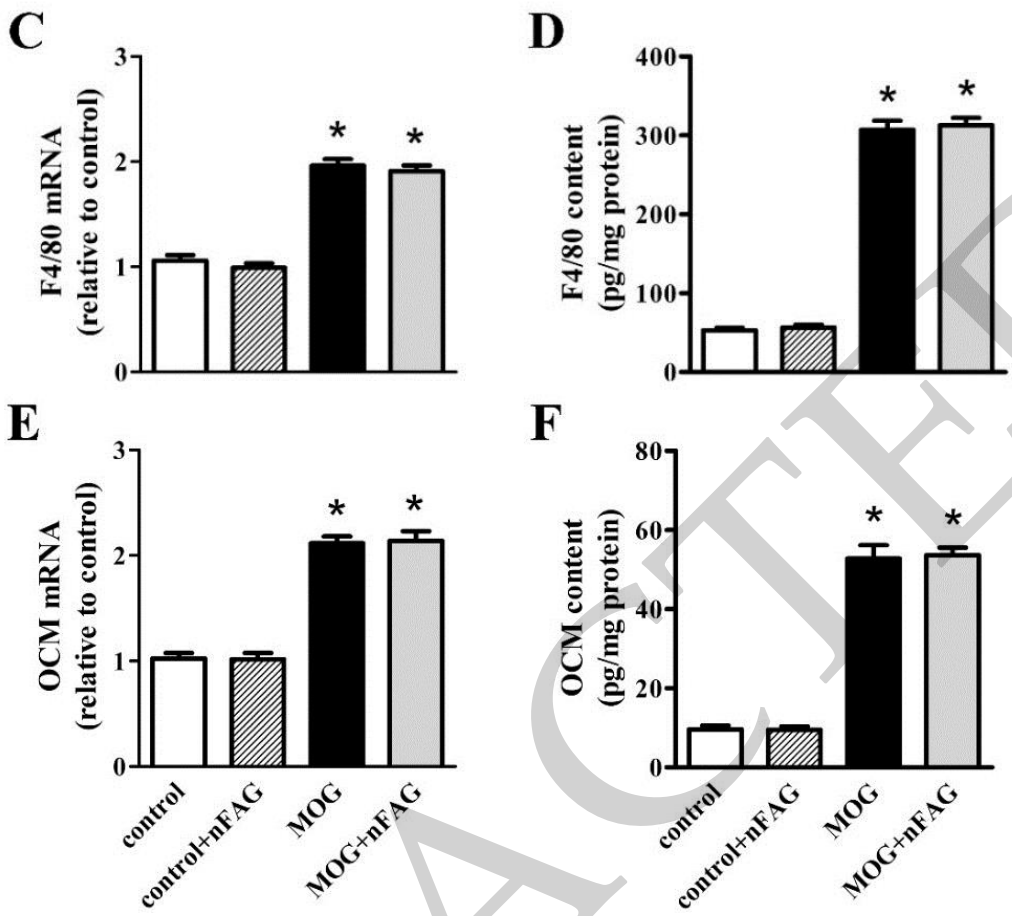

Figure 4. nFAG dietary supplementation does not affect MOG-induced upregulation of markers of macrophage infiltration including cluster of differentiation 68 (CD68; **A**,**B**) and endothelial growth factor-like module-containing mucin-like hormone receptor-like 1 (F4/80; **C**,**D**), as well as the expression and the content of oncomodulin (OCM; **E**,**F**). Levels were evaluated in control and MOG-treated mice, without or with nFAG dietary supplementation. Transcripts (**A**,**C**,**E**) were evaluated by relative quantification with qPCR. Data were analyzed by the formula $2^{-\Delta\Delta CT}$ using Rpl13a as the internal standard. Proteins (**B**,**D**,**F**) were evaluated by ELISA (LifeSpan Biosciences, Inc., Seattle, WA, USA). Data are shown as the mean ± S.E.M. (n = 9 for each experimental group). * $p < 0.001$ versus control (one-way ANOVA followed by the Newman-Keuls multiple comparison post-hoc test). White bars, control mice; dashed bars, control mice with nFAG dietary supplementation; black bars, MOG-treated mice; grey bars, MOG-treated mice with nFAG dietary supplementation.

3.3. nFAG Supplementation Reduces RGC Loss

MOG-induced retinal damage, as a hallmark of optic neuritis-like mouse model, has been previously characterized by a drastic loss of RGCs [24]. Here, RGCs of animals immunized with MOG, supplemented or not with nFAG, were stained with Brn-3a, a marker of RGCs. nFAG supplementation in control mice did not affect RGC number (not shown). As shown in Figure 5, as compared to control mice (Figure 5A), a significant RGC loss was observed in retinal whole-mounts of MOG-treated mice (Figure 5B). RGC degeneration was reduced in MOG-treated mice with nFAG dietary supplementation (Figure 5C). The high magnification images (Figure 5D–F) of the boxed areas shown in Figure 5A–C further confirm the effectiveness of nFAG in reducing RGC loss.

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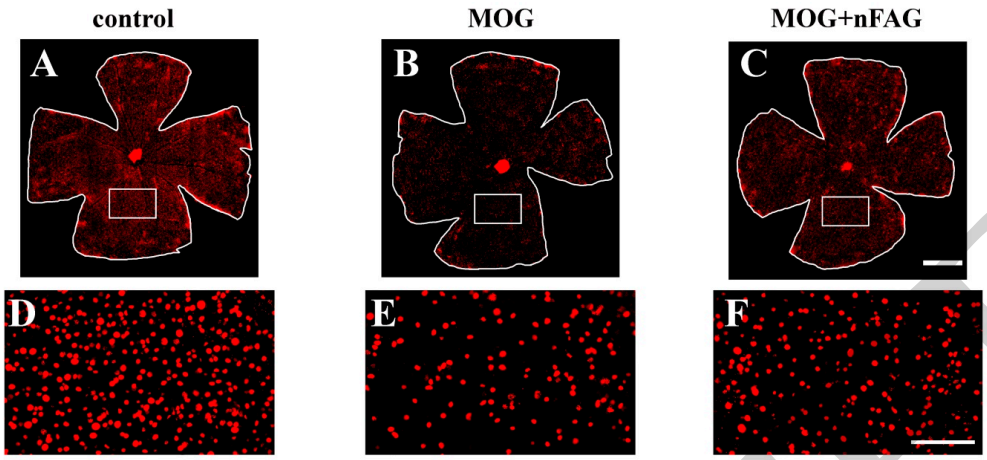

Figure 5. nFAG dietary supplementation reduces retinal ganglion cell (RGC) loss. Representative images of Brn3a-labeled RGCs in retinal whole mounts from control mice (**A**); MOG-treated mice without nFAG dietary supplementation (**B**) or MOG-treated mice with nFAG dietary supplementation (**C**) (n = 4 for each experimental condition); (**D**–**F**) High magnifications views of the boxed areas in panels **A**–**C**. Scale bars: 1 mm (**A**–**C**) or 250 μm (**D**–**F**).

As shown in Figure 6, RGC quantification demonstrated that in MOG-treated mice the RGC number decreased by about 32% compared to that measured in control mice ($p < 0.01$). nFAG supplementation significantly prevented the RGC loss ($p < 0.05$ versus MOG-treated mice). RGC sparing involved the entire retina demonstrating that the effectiveness of dietary supplementation was not limited to specific retinal quadrants (not shown).

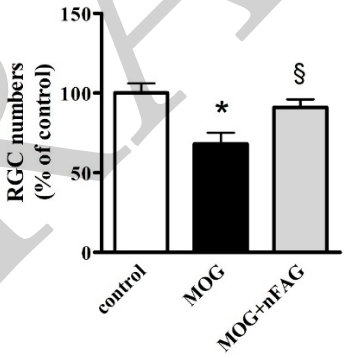

Figure 6. nFAG dietary supplementation prevents RGC loss. Counting of RGCs immunolabeled with Brn3a antibody refers to the whole mounts shown in Figure 5. * $p < 0.01$ versus control. § $p < 0.05$ versus MOG (one-way ANOVA followed by the Newman-Keuls multiple comparison post-hoc test). White bars, control mice; black bars, MOG-treated mice; grey bars, MOG-treated mice with nFAG dietary supplementation.

4. Discussion

Food supplements or dietary interventions including essential FAs are used frequently in patients with MS (64.7% of cases) and there is indication that diet and dietary supplements with long-chain omega-3 FAs may modulate MS-associated inflammatory processes (see [29]). However, MS therapy cannot be firmly associated with a particular diet due to the paucity of information on the effects of nutrition on this disease. In addition, there is little information on the role of dietary supplementation on optic neuritis [30] and no data are available about possible beneficial effects of omega-3 FAs. However, there is evidence from EAE animal models that systemically administered short chain FAs such as valproic or lipoic acids reduces ON inflammation [15,31]. In addition, beneficial effects of

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omega-3 FAs have been demonstrated in animal models of RGC degeneration. For instance, in a transgenic mouse overexpressing omega-3 FAs, RGC survival is enhanced in response to ON crush [32]. As to the limited capability in synthesizing long chain polyunsaturated FAs, diet supplements enriched in omega-3 FAs are today available on the market and are used to improve physical and mental well-being as well as general health [33].

As shown by the present results, the MS-associated mouse model of optic neuritis is characterized by increased levels of molecules involved in inflammation, gliosis and macrophage infiltration suggesting that the altered regulation of interlinked pathways plays a central role in the pathogenesis of optic neuritis. Upregulation of inflammatory markers found here is in line with previous results [24]. Accumulation of inflammatory factors leads to macrophage infiltration that further activates inflammatory processes by producing a plethora of potentially dangerous cytokines [34]. Among them, TNF-α, which plays a major role in inflammatory responses, is secreted by several cells in the retina including macrophages, microglia and Müller cells [35,36]. The basal release of TNF-α is necessary for normal physiological functions, for instance to stimulate the release of neuroprotective molecules [37]. However, chronic inflammatory reactions have opposite functions, mediating the onset and the progression of neurodegenerative processes through the production of several proinflammatory molecules, including ILs [38]. Among the ILs, IL-1β stimulates the production of IL-6, and acts upstream of iNOS which, in turn, induces ICAM-1 upregulation [39,40]. iNOS is also a marker of microglia activation [41] and excessive microglia activation might prompt the release of cytotoxic factors causing retinal cell death (see [42]). ICAM-1 overexpression reverberates on inflammation leading to the activation of leukocytes and the release of inflammatory cytokines, most of which are produced by gliotic Müller cells [43]. As also shown here, MOG-induced MS is associated with Müller cell gliosis, as demonstrated by the marked increase in retinal GFAP expression. Overall, marked inflammation and gliosis participate in macrophage infiltration, a major event contributing to ON demyelination with the consequent RGC degeneration [44]. In this respect, macrophage infiltration of the ON plays a key role also in neuromyelitis optica, a disease different from MS-associated optic neuritis [45], but, similarly to optic neuritis, equally characterized by ON fiber loss and RGC degeneration [46]. On the other hand, retinal samples investigated here may not fully represent the inflammation in eyes as in acute intraocular inflammation infiltrated macrophages mostly stay into the vitreous. For instance, in a chronic infantile intraocular inflammation, the cytological examination of a vitrectomy specimen shows abundant cellularity confirmed by immunohistochemistry as macrophages [47]. In this respect, we cannot exclude that in the EAE model the majority of infiltrating macrophages mostly stay into the vitreous and further work will be required to clarify this possibility.

As also shown here, retinal levels of OCM are upregulated in response to MOG indicating that infiltrating macrophages may be responsible for OCM production, as OCM is a chemical signal produced by macrophages and neutrophils in response to lens injury, ON crush and/or to inflammatory conditions of the retina (see [48]). In this respect, OCM would act to protect the neuroretina from degenerative events suggesting that macrophages may play a dual role in MS pathogenesis (likely depending on their phenotypic stage M1 or M2) either contributing to axonal damage and lesion formation or supporting survival and repair processes [49].

At the structural level, MOG-induced retinal damage is in agreement with previous data [7,24,50,51]. In the mouse model of EAE, inflammatory cell infiltration appears to mediate ON fiber demyelination thus leading to RGC death [52]. For instance, inflammation seems to precede RGC loss in transgenic mice that spontaneously develop optic neuritis indicating that MOG-immunization leads to inflammatory processes causing demyelinating lesions of the ON [53]. On the other hand, RGC degeneration has been considered as an early event that may precede ON inflammation and demyelination thus suggesting that both inflammation-dependent and -independent mechanisms may be involved in RGC death during the course of MS [54,55].

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To evaluate whether diet supplements containing omega-3 FAs may counteract neuroinflammation thus reducing RGC degeneration we have administered nFAG to MOG-treated mice. The food supplement nFAG has been present in the Italian market for about one year, with a main recommendation for the treatment of the inflammatory states of the ON. No clinical data are available so far, however anecdotic observations on patients affected by autoimmune diseases that interrupted their therapeutic chloroquine treatment because of retinal toxicity suggest some rescue of the visual function after three months of nFAG treatment (Caterina Gagliano, personal communication).

The additional finding of a delayed onset of EAE paralysis after nFAG supplementation suggests a preventive effect of nFAG administration on the conversion of optic neuritis to MS. Optic neuritis is indeed one of the most common initial clinical signs of MS preceding its onset and occurring during the course of the disease in 50% or more of MS patients [56]. Therefore, management strategies including acute and long-term therapies aimed at counteracting the development of optic neuritis may be useful in delaying MS onset [5]. For instance, in MOG-immunized EAE mice, HE3286, a synthetic derivative of an adrenal steroid, suppresses inflammation and reduces demyelination and axonal loss promoting RGC survival resulting in a significative delay in the appearance of MS clinical signs [50].

As shown by the present results, nFAG exerts a multitarget role by hampering major retinal events activated by MOG as demonstrated by the general reduction of pro-inflammatory markers associated with optic neuritis indicating that a balanced mixture of omega-3 and omega-6 FAs may be useful to control inflammatory processes. It is known that both omega-3 and omega-6 FAs may be converted by several cell populations in bioactive lipids, which mediate the end of an inflammatory response thus preventing the occurrence of a pathological chronic inflammation (see [57]). In this respect, we have previously demonstrated in a mouse model of dry age-related macular degeneration, characterized by a strong inflammatory component leading to retinal thinning, that a patented diet supplement composed by omega-3 and omega-6 FAs, lycopene and spirulina reduces inflammation and prevents retinal degeneration [21]. In addition, the finding that nFAG reduces inflammation and gliosis without interfering with macrophage infiltration and the related OCM production may be beneficial since infiltrating macrophages are a known source of trophic and growth factors [58]. In this respect, the compound would act by modulating the phenotype of macrophages, decreasing their pro-inflammatory activity and proportionally increasing their tissue restoring capabilities with a positive effect on neuroprotection and neuronal rescue. In this line, omega-3 FAs have been shown to reduce retinal inflammation and RGC death in a rat model of ischemic neuropathy by regulating macrophage phenotype [59]. An additional possibility is that the diet supplement acts on gliotic Müller cells as suggested by the finding that nFAG reduces the expression of GFAP, a protein which is indeed prominently expressed by Müller cells during retinal injuries [60]. In this respect, treatment of human Müller cells with a mixture of omega-3 FAs has been demonstrated to reduce the toxic effect of the β amyloid peptide suggesting that diet supplements rich in polyunsaturated FAs may be useful in the treatment of degenerative pathologies [61].

Our result that nFAG prevents RGC degeneration demonstrates for the first time that dietary supplementation with FAs may result in neuroprotective effects in the MOG-induced EAE model. In this respect, there is evidence that in the EAE model, oral administration of several drugs with anti-oxidant or anti-inflammatory activity promotes RGC survival with restoration of visual function [7,51]. In this line, nFAG neuroprotective role may contribute to mechanisms of increased visual function although this possibility has not been investigated in the present study and additional research will be required. The additional finding that RGCs are spared by nFAG without any difference among the retinal quadrants is in agreement with previous results [7,24,52,62]. In contrast, in the EAE model, a synthetic derivative of a natural steroid has been shown to significantly reduce RGC loss in the temporal quadrant of the retina, but with a trend toward increased survival in the other retinal quadrants [50]. In this respect, different drugs may exert more or less limited neuroprotective

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properties possibly depending on their mechanism of action that may be indirect, secondary to the reduced inflammation, direct on RGCs, or a combination of both.

5. Conclusions

In conclusion, immunization with MOG induces a neuroinflammatory state that, in turn, triggers optic neuritis that is characterized by gliosis, production of inflammatory cytokines and macrophage infiltration in line with previous works. Here, we show that MOG also induces the production of OCM that would act to protect the ON from degenerative events. As also shown by the present findings, nFAG exerts a predominant anti-inflammatory action without influencing macrophage infiltration, which safely maintains unaltered OCM production thus preserving its trophic role. As shown in the schematic representation of Figure 7, our hypothesis is that the combined effects of nFAG and OCM may counteract the development of optic neuritis by protecting RGCs from death. Overall, the present data demonstrate an ability of nFAG to preserve significantly RGCs from death in experimental optic neuritis with suppression of inflammation. These neuroprotective effects may be independent of and/or secondary to anti-inflammatory effects indicating nFAG as a possible adjuvant in therapies against inflammatory diseases of the eye.

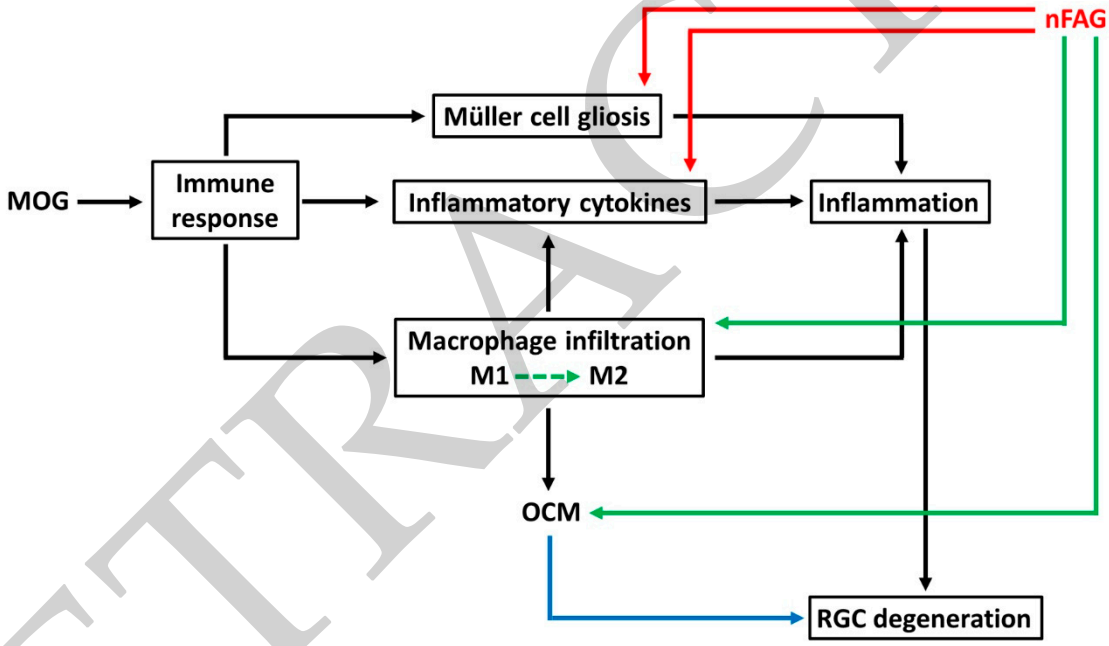

Figure 7. Schematic diagram depicting a possible mechanism of action of nFAG. MOG induces an immune response resulting in Müller cell gliosis, overproduction of inflammatory cytokines and macrophage infiltration. Infiltrating macrophages further activates inflammatory processes by producing potentially dangerous cytokines. The production of a pro-inflammatory niche likely induces RGC degeneration. Macrophages are also responsible for the production of oncomodulin (OCM), which would exert a trophic role on degenerating RGCs (blue arrow). nFAG reduces Müller cell gliosis and the overproduction of inflammatory cytokines (red arrows) thus substantially attenuating inflammatory processes. Having no effects on macrophage infiltration and OCM production (green arrows), the positive effect of OCM on neuroprotection and neuronal rescue would be preserved. We suggest the possibility that nFAG modulates the polarization of macrophages shifting them from a phenotype involved in inflammatory processes (M1) to a phenotype involved in neural repair (M2) therefore decreasing their pro-inflammatory activity, but proportionally increasing their tissue restoring capabilities (dotted green arrow).

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Supplementary Materials: The following is available online at www.mdpi.com/2072-6643/10/3/325/s1, Table S1: Sequences of primer sets used for qPCR experiments.

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Author Contributions: D.R. and P.B. conceived and designed the experiments; M.C., F.L., R.A. and S.M. managed the model; M.D.M. and M.C. performed the experiments and analyzed the data; P.B., M.D.M. and D.R. wrote the paper.

Conflicts of Interest: M.C. received a study grant from Sooft Italia SpA. D.R. is an employee of Sooft Italia SpA, which however had no direct role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

References

1. Kipp, M.; Nyamoya, S.; Hochstrasser, T.; Amor, S. Multiple sclerosis animal models: A clinical and histopathological perspective. *Brain Pathol.* **2017**, *27*, 123–137. [CrossRef] [PubMed]
2. Levin, M.; Bennett, J.L.; Verkman, A.S. Optic neuritis in neuromyelitis optica. *Prog. Retin. Eye Res.* **2013**, *36*, 159–171. [CrossRef] [PubMed]
3. Graham, S.L.; Klistorner, A. Afferent visual pathways in multiple sclerosis: A review. *Clin. Exp. Ophthalmol.* **2017**, *45*, 62–72. [CrossRef] [PubMed]
4. Yin, Y.; Cui, Q.; Gilbert, H.Y.; Yang, Y.; Yang, Z.; Berlinicke, C.; Li, Z.; Zaverucha-do-Valle, C.; He, H.; Petkova, V.; et al. Oncomodulin links inflammation to optic nerve regeneration. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 19587–19592. [CrossRef] [PubMed]
5. Kale, N. Optic neuritis as an early sign of multiple sclerosis. *Eye Brain* **2016**, *8*, 195–202. [CrossRef] [PubMed]
6. Beck, R.W.; Gal, R.L. Treatment of acute optic neuritis: A summary of findings from the optic neuritis treatment trial. *Arch. Ophthalmol.* **2008**, *126*, 995. [CrossRef] [PubMed]
7. Khan, R.S.; Dine, K.; Geisler, J.G.; Shindler, K.S. Mitochondrial Uncoupler Prodrug of 2,4-Dinitrophenol, MP201, Prevents Neuronal Damage and Preserves Vision in Experimental Optic Neuritis. *Oxid. Med. Cell. Longev.* **2017**, *2017*, 7180632. [CrossRef] [PubMed]
8. Moss, H.E. Visual consequences of medications for multiple sclerosis: The good, the bad, the ugly, and the unknown. *Eye Brain* **2017**, *9*, 13–21. [CrossRef] [PubMed]
9. Abu-Amero, K.K.; Kondkar, A.A.; Chalam, K.V. Resveratrol and Ophthalmic Diseases. *Nutrients* **2016**, *8*, 200. [CrossRef] [PubMed]
10. Zhang, B.; Rusciano, D.; Osborne, N.N. Orally administered epigallocatechin gallate attenuates retinal neuronal death in vivo and light-induced apoptosis in vitro. *Brain Res.* **2008**, *1198*, 141–152. [CrossRef] [PubMed]
11. Kumar, P.R.; Essa, M.M.; Al-Adawi, S.; Dradekh, G.; Memon, M.A.; Akbar, M.; Manivasagam, T. Omega-3 Fatty acids could alleviate the risks of traumatic brain injury—A mini review. *J. Tradit. Complement. Med.* **2014**, *4*, 89–92. [CrossRef] [PubMed]
12. Michael-Titus, A.T.; Priestley, J.V. Omega-3 fatty acids and traumatic neurological injury: From neuroprotection to neuroplasticity? *Trends Neurosci.* **2014**, *37*, 30–38. [CrossRef] [PubMed]
13. Lim, S.N.; Huang, W.; Hall, J.C.; Michael-Titus, A.T.; Priestley, J.V. Improved outcome after spinal cord compression injury in mice treated with docosahexaenoic acid. *Exp. Neurol.* **2013**, *239*, 13–27. [CrossRef] [PubMed]
14. Haghikia, A.; Jörg, S.; Duscha, A.; Berg, J.; Manzel, A.; Waschbisch, A.; Hammer, A.; Lee, D.H.; May, C.; Wilck, N.; et al. Dietary Fatty Acids Directly Impact Central Nervous System Autoimmunity via the Small Intestine. *Immunity* **2015**, *43*, 817–829. [CrossRef] [PubMed]
15. Chaudhary, P.; Marracci, G.; Yu, X.; Galipeau, D.; Morris, B.; Bourdette, D. Lipoic acid decreases inflammation and confers neuroprotection in experimental autoimmune optic neuritis. *J. Neuroimmunol.* **2011**, *233*, 90–96. [CrossRef] [PubMed]
16. Gong, Y.; Fu, Z.; Liegl, R.; Chen, J.; Hellström, A.; Smith, L.E. ω-3 and ω-6 long-chain PUFAs and their enzymatic metabolites in neovascular eye diseases. *Am. J. Clin. Nutr.* **2017**, *106*, 16–26. [CrossRef] [PubMed]
17. Souied, E.H.; Aslam, T.; Garcia-Layana, A.; Holz, F.G.; Leys, A.; Silva, R.; Delcourt, C. Omega-3 Fatty Acids and Age-Related Macular Degeneration. *Ophthalmic Res.* **2015**, *55*, 62–89. [CrossRef] [PubMed]

RETRACTED

18. Pinazo-Durán, M.D.; Gómez-Ulla, F.; Arias, L.; Araiz, J.; Casaroli-Marano, R.; Gallego-Pinazo, R.; García-Medina, J.J.; López-Gálvez, M.I.; Manzanas, L.; Salas, A.; et al. Do nutritional supplements have a role in age macular degeneration prevention? *J. Ophthalmol.* **2014**, *2014*, 901686. [CrossRef] [PubMed]
19. Age-Related Eye Disease Study 2 Research Group. Lutein + zeaxanthin and omega-3 fatty acids for age-related macular degeneration: The Age-Related Eye Disease Study 2 (AREDS2) randomized clinical trial. *JAMA* **2013**, *309*, 2005–2015. [CrossRef]
20. D'Abrosca, F.; Facchini, D. Effectiveness test: Anti-inflammatory action of the F.A.G. (Fatty Acid Groups). *J. Res. Ther.* **2016**, *1*, 3–8.
21. Cammalleri, M.; Dal Monte, M.; Locri, F.; Lardner, E.; Kvanta, A.; Rusciano, D.; André, H.; Bagnoli, P. Efficacy of a Fatty Acids Dietary Supplement in a Polyethylene Glycol-Induced Mouse Model of Retinal Degeneration. *Nutrients* **2017**, *9*, 1079. [CrossRef] [PubMed]
22. Horstmann, L.; Kuehn, S.; Pedreiturria, X.; Haak, K.; Pfarrer, C.; Dick, H.B.; Kleiter, I.; Joachim, S.C. Microglia response in retina and optic nerve in chronic experimental autoimmune encephalomyelitis. *J. Neuroimmunol.* **2016**, *298*, 32–41. [CrossRef] [PubMed]
23. Voskuhl, R.R.; Palaszynski, K. Sex hormones in experimental autoimmune encephalomyelitis: Implications for multiple sclerosis. *Neuroscientist* **2001**, *7*, 258–270. [CrossRef] [PubMed]
24. Horstmann, L.; Schmid, H.; Heinen, A.P.; Kurschus, F.C.; Dick, H.B.; Joachim, S.C. Inflammatory demyelination induces glia alterations and ganglion cell loss in the retina of an experimental autoimmune encephalomyelitis model. *J. Neuroinflamm.* **2013**, *10*, 120. [CrossRef] [PubMed]
25. Google Patents. Available online: https://encrypted.google.com/patents/WO2014135529A1?cl=ar (accessed on 5 February 2018).
26. Reagan-Shaw, S.; Nihal, M.; Ahmad, N. Dose translation from animal to human studies revisited. *FASEB J.* **2008**, *22*, 659–661. [CrossRef] [PubMed]
27. Chistiakov, D.A.; Killingsworth, M.C.; Myasoedova, V.A.; Orekhov, A.N.; Bobryshev, Y.V. CD68/macrosialin: Not just a histochemical marker. *Lab. Investig.* **2017**, *97*, 4–13. [CrossRef] [PubMed]
28. Van den Berg, T.K.; Kraal, G. A function for the macrophage F4/80 molecule in tolerance induction. *Trends Immunol.* **2005**, *26*, 506–509. [CrossRef] [PubMed]
29. Bagur, M.J.; Murcia, M.A.; Jiménez-Monreal, A.M.; Tur, J.A.; Bibiloni, M.M.; Alonso, G.L.; Martínez-Tomé, M. Influence of Diet in Multiple Sclerosis: A Systematic Review. *Adv. Nutr.* **2017**, *8*, 463–472. [CrossRef] [PubMed]
30. Derakhshandi, H.; Etemadifar, M.; Feizi, A.; Abtahi, S.H.; Minagar, A.; Abtahi, M.A.; Abtahi, Z.A.; Dehghani, A.; Sajjadi, S.; Tabrizi, N. Preventive effect of vitamin D3 supplementation on conversion of optic neuritis to clinically definite multiple sclerosis: A double blind, randomized, placebo-controlled pilot clinical trial. *Acta Neurol. Belg.* **2013**, *113*, 257–263. [CrossRef] [PubMed]
31. Azuchi, Y.; Kimura, A.; Guo, X.; Akiyama, G.; Noro, T.; Harada, C.; Nishigaki, A.; Namekata, K.; Harada, T. Valproic acid and ASK1 deficiency ameliorate optic neuritis and neurodegeneration in an animal model of multiple sclerosis. *Neurosci. Lett.* **2017**, *639*, 82–87. [CrossRef] [PubMed]
32. Peng, S.; Shi, Z.; Su, H.; So, K.F.; Cui, Q. Increased production of omega-3 fatty acids protects retinal ganglion cells after optic nerve injury in mice. *Exp. Eye Res.* **2016**, *148*, 90–96. [CrossRef] [PubMed]
33. Parry, D.A.; Oeppen, R.S.; Amin, M.; Brennan, P.A. Can dietary supplements improve a clinician's well-being and health? *Br. J. Oral Maxillofac. Surg.* **2017**. [CrossRef] [PubMed]
34. Cui, Q.; Yin, Y.; Benowitz, L.I. The role of macrophages in optic nerve regeneration. *Neuroscience* **2009**, *158*, 1039–1048. [CrossRef] [PubMed]
35. Al-Gayyar, M.M.; Elsherbiny, N.M. Contribution of TNF-α to the development of retinal neurodegenerative disorders. *Eur. Cytokine Netw.* **2013**, *24*, 27–36. [CrossRef] [PubMed]
36. Nelson, C.M.; Ackerman, K.M.; O'Hayer, P.; Bailey, T.J.; Gorsuch, R.A.; Hyde, D.R. Tumor necrosis factor-alpha is produced by dying retinal neurons and is required for Muller glia proliferation during zebrafish retinal regeneration. *J. Neurosci.* **2013**, *33*, 6524–6539. [CrossRef] [PubMed]
37. Saha, R.N.; Liu, X.; Pahan, K. Up-regulation of BDNF in astrocytes by TNF-alpha: A case for the neuroprotective role of cytokine. *J. Neuroimmune Pharmacol.* **2006**, *1*, 212–222. [CrossRef] [PubMed]
38. Li, Z.; Zheng, Z.; Ruan, J.; Li, Z.; Tzeng, C.M. Chronic Inflammation Links Cancer and Parkinson's Disease. *Front. Aging Neurosci.* **2016**, *8*, 126. [CrossRef] [PubMed]

RETRACTED

39. Liu, X.; Ye, F.; Xiong, H.; Hu, D.N.; Limb, G.A.; Xie, T.; Peng, L.; Zhang, P.; Wei, Y.; Zhang, W.; et al. IL-1β induces IL-6 production in retinal Müller cells predominantly through the activation of p38 MAPK/NF-κB signaling pathway. *Exp. Cell Res.* **2015**, *331*, 223–231. [CrossRef] [PubMed]
40. Tang, J.; Kern, T.S. Inflammation in diabetic retinopathy. *Prog. Retin. Eye Res.* **2011**, *30*, 343–358. [CrossRef] [PubMed]
41. Couturier, A.; Bousquet, E.; Zhao, M.; Naud, M.C.; Klein, C.; Jonet, L.; Tadayoni, R.; de Kozak, Y.; Behar-Cohen, F. Anti-vascular endothelial growth factor acts on retinal microglia/macrophage activation in a rat model of ocular inflammation. *Mol. Vis.* **2014**, *20*, 908–920. [PubMed]
42. Ramirez, A.I.; de Hoz, R.; Salobrar-Garcia, E.; Salazar, J.J.; Rojas, B.; Ajoy, D.; López-Cuenca, I.; Rojas, P.; Triviño, A.; Ramírez, J.M. The Role of Microglia in Retinal Neurodegeneration: Alzheimer's Disease, Parkinson, and Glaucoma. *Front. Aging Neurosci.* **2017**, *9*, 214. [CrossRef] [PubMed]
43. Sorrentino, F.S.; Allkabes, M.; Salsini, G.; Bonifazzi, C.; Perri, P. The importance of glial cells in the homeostasis of the retinal microenvironment and their pivotal role in the course of diabetic retinopathy. *Life Sci.* **2016**, *162*, 54–59. [CrossRef] [PubMed]
44. Zindler, E.; Zipp, F. Neuronal injury in chronic CNS inflammation. *Best Pract. Res. Clin. Anaesthesiol.* **2010**, *24*, 551–562. [CrossRef] [PubMed]
45. Kawachi, I.; Lassmann, H. Neurodegeneration in multiple sclerosis and neuromyelitis optica. *J. Neurol. Neurosurg. Psychiatry* **2017**, *88*, 137–145. [CrossRef] [PubMed]
46. Papadopoulos, M.C.; Bennett, J.L.; Verkman, A.S. Treatment of neuromyelitis optica: State-of-the-art and emerging therapies. *Nat. Rev. Neurol.* **2014**, *10*, 493–506. [CrossRef] [PubMed]
47. Adán, A.; Solé, M.; Corcostegui, B.; Navarro, R.; Burés, A. Cytological vitreous findings in a patient with infantile neurological cutaneous and articular (CINCA) syndrome. *BMJ Case Rep.* **2009**. [CrossRef] [PubMed]
48. Benowitz, L.I.; He, Z.; Goldberg, J.L. Reaching the brain: Advances in optic nerve regeneration. *Exp. Neurol.* **2017**, *287*, 365–373. [CrossRef] [PubMed]
49. Vogel, D.Y.; Vereyken, E.J.; Glim, J.E.; Heijnen, P.D.; Moeton, M.; van der Valk, P.; Amor, S.; Teunissen, C.E.; van Horssen, J.; Dijkstra, C.D. Macrophages in inflammatory multiple sclerosis lesions have an intermediate activation status. *J. Neuroinflamm.* **2013**, *10*, 35. [CrossRef] [PubMed]
50. Khan, R.S.; Dine, K.; Luna, E.; Ahlem, C.; Shindler, K.S. HE3286 reduces axonal loss and preserves retinal ganglion cell function in experimental opticneuritis. *Investig. Ophthalmol. Vis. Sci.* **2014**, *55*, 5744–5751. [CrossRef] [PubMed]
51. Guo, X.; Harada, C.; Namekata, K.; Kikushima, K.; Mitamura, Y.; Yoshida, H.; Matsumoto, Y.; Harada, T. Effect of geranylgeranylacetone on optic neuritis in experimental autoimmune encephalomyelitis. *Neurosci. Lett.* **2009**, *462*, 281–285. [CrossRef] [PubMed]
52. Shindler, K.S.; Ventura, E.; Dutt, M.; Rostami, A. Inflammatory demyelination induces axonal injury and retinal ganglion cell apoptosis in experimental optic neuritis. *Exp. Eye Res.* **2008**, *87*, 208–213. [CrossRef] [PubMed]
53. Guan, Y.; Shindler, K.S.; Tabuena, P.; Rostami, A.M. Retinal ganglion cell damage induced by spontaneous autoimmune optic neuritis in MOG-specific TCR transgenic mice. *J. Neuroimmunol.* **2006**, *178*, 40–48. [CrossRef] [PubMed]
54. Fairless, R.; Williams, S.K.; Hoffmann, D.B.; Stojic, A.; Hochmeister, S.; Schmitz, F.; Storch, M.K.; Diem, R. Preclinical retinal neurodegeneration in a model of multiple sclerosis. *J. Neurosci.* **2012**, *32*, 5585–5597. [CrossRef] [PubMed]
55. Hobom, M.; Storch, M.K.; Weissert, R.; Maier, K.; Radhakrishnan, A.; Kramer, B.; Bähr, M.; Diem, R. Mechanisms and time course of neuronal degeneration in experimental autoimmune encephalomyelitis. *Brain Pathol.* **2004**, *14*, 148–157. [CrossRef] [PubMed]
56. Balcer, L.J. Clinical practice. Optic neuritis. *N. Engl. J. Med.* **2006**, *354*, 1273–1280. [CrossRef] [PubMed]
57. Fraga, V.G.; Carvalho, M.D.G.; Caramelli, P.; de Sousa, L.P.; Gomes, K.B. Resolution of inflammation, *n*-3 fatty acid supplementation and Alzheimer disease: A narrative review. *J. Neuroimmunol.* **2017**, *310*, 111–119. [CrossRef] [PubMed]
58. Hu, X.; Leak, R.K.; Shi, Y.; Suenaga, J.; Gao, Y.; Zheng, P.; Chen, J. Microglial and macrophage polarization—New prospects for brain repair. *Nat. Rev. Neurol.* **2015**, *11*, 56–64. [CrossRef] [PubMed]

RETRACTED

59. Georgiou, T.; Wen, Y.T.; Chang, C.H.; Kolovos, P.; Kalogerou, M.; Prokopiou, E.; Neokleous, A.; Huang, C.T.; Tsai, R.K. Neuroprotective Effects of Omega-3 Polyunsaturated Fatty Acids in a Rat Model of Anterior Ischemic Optic Neuropathy. *Investig. Ophthalmol. Vis. Sci.* **2017**, *58*, 1603–1611. [CrossRef] [PubMed]
60. Lewis, G.P.; Fisher, S.K. Up-regulation of glial fibrillary acidic protein in response to retinal injury: Its potential role in glial remodeling and a comparison to vimentin expression. *Int. Rev. Cytol.* **2003**, *230*, 263–290. [CrossRef] [PubMed]
61. Wakx, A.; Dutot, M.; Massicot, F.; Mascarelli, F.; Limb, G.A.; Rat, P. Amyloid β Peptide Induces Apoptosis Through P2X7 Cell Death Receptor in Retinal Cells: Modulation by Marine Omega-3 Fatty Acid DHA and EPA. *Appl. Biochem. Biotechnol.* **2016**, *178*, 368–381. [CrossRef] [PubMed]
62. Lidster, K.; Jackson, S.J.; Ahmed, Z.; Munro, P.; Coffey, P.; Giovannoni, G.; Baker, M.D.; Baker, D. Neuroprotection in a novel mouse model of multiple sclerosis. *PLoS ONE* **2013**, *8*, e79188. [CrossRef] [PubMed]

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