Targeting the leukotriene B4 pathway and/or complement C5 via dual-functional recombinant coversin (nomacopan) in Experimental Autoimmune Uveitis (EAU)

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Background

Non-infectious posterior uveitis, a major cause of blindness, has an unclear etiology, and many patients fail to respond to treatment.

Using the Experimental Autoimmune Uveitis (EAU) model of retinal inflammation, we are able to validate the efficacy of anti-inflammatory drugs, study the mechanism of drug action and learn more about ocular inflammatory diseases. As a result, it is a successful preclinical model for translational studies. Uveitis and its mouse model are multifactorial diseases caused by many contributing factors and inflammatory pathways. Simultaneously targeting different pathways involved in disease development therefore has significant therapeutic potential.

Preventing the cleavage of C5 and generation of the major pro-inflammatory factors C5a and C5b-9 has therapeutic potential to protect against tissue damage in organ-specific immune responses including EAU[2]. Whilst, targeting the leukotriene B4 (LTB4) receptor (BLT1) by applying a BLT1 antagonist in mouse uveitis has been shown to significantly downregulate disease[3]. The leukotrienes (LT) are also important multifunctional mediators of inflammation. Coversin (nomacopan) is a bifunctional recombinant protein derived from blood-feeding ticks that specifically prevents complement (C)-mediated C5 activation and also sequesters leukotriene B4 (LTB4) within an internal binding pocket[4] (Figure 1).

In this study we have investigated the therapeutic effect of:

- Nomacopan – inhibits C5 and LTB4
- Variant nomacopan (Leukasin) - inhibits LTB4 only
- PAS-nomacopan - long-acting, inhibits C5 and LTB4
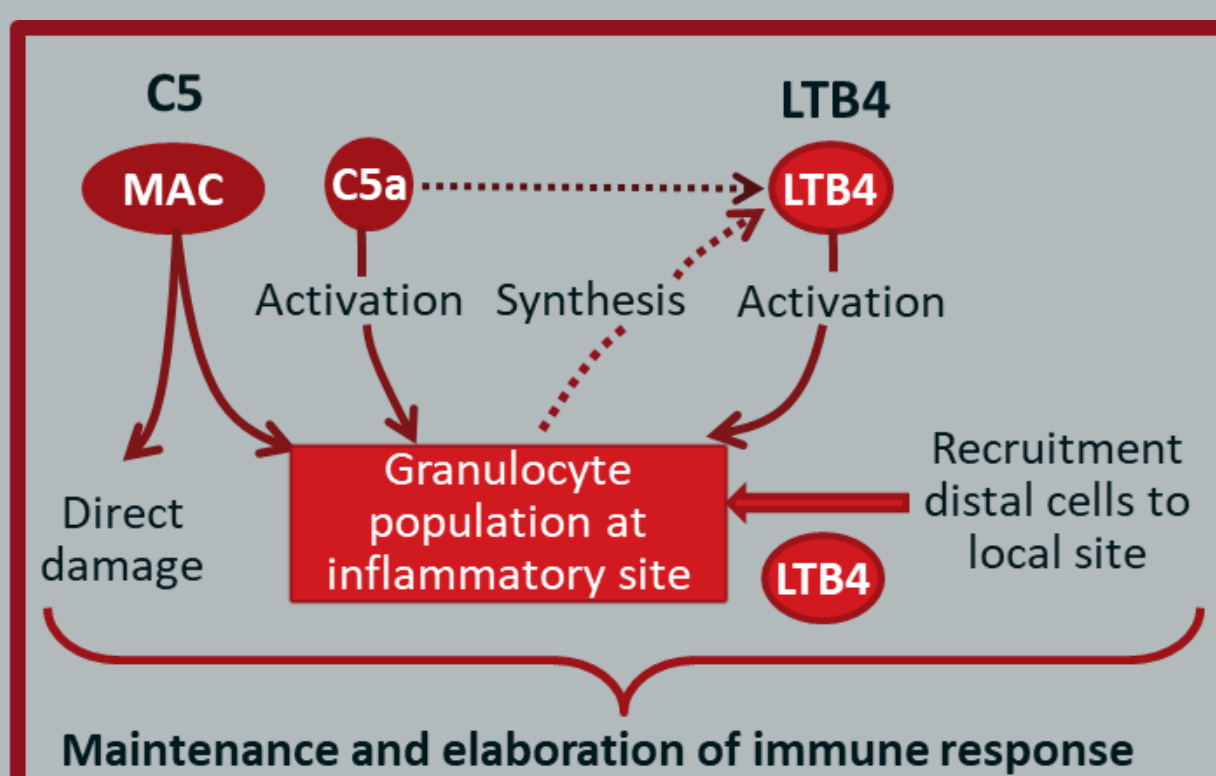- Variant PAS-nomacopan (PAS-Leukasin) - long acting LTB4 only

Purpose
To explore the impact of nomacopan, Leukasin and their long-acting engineered forms, when administered intravitreally or topically during active EAU.

Figure 1

Cartoon structure of Coversin (nomacopan) determined to 1.9 Å by X-ray crystallography
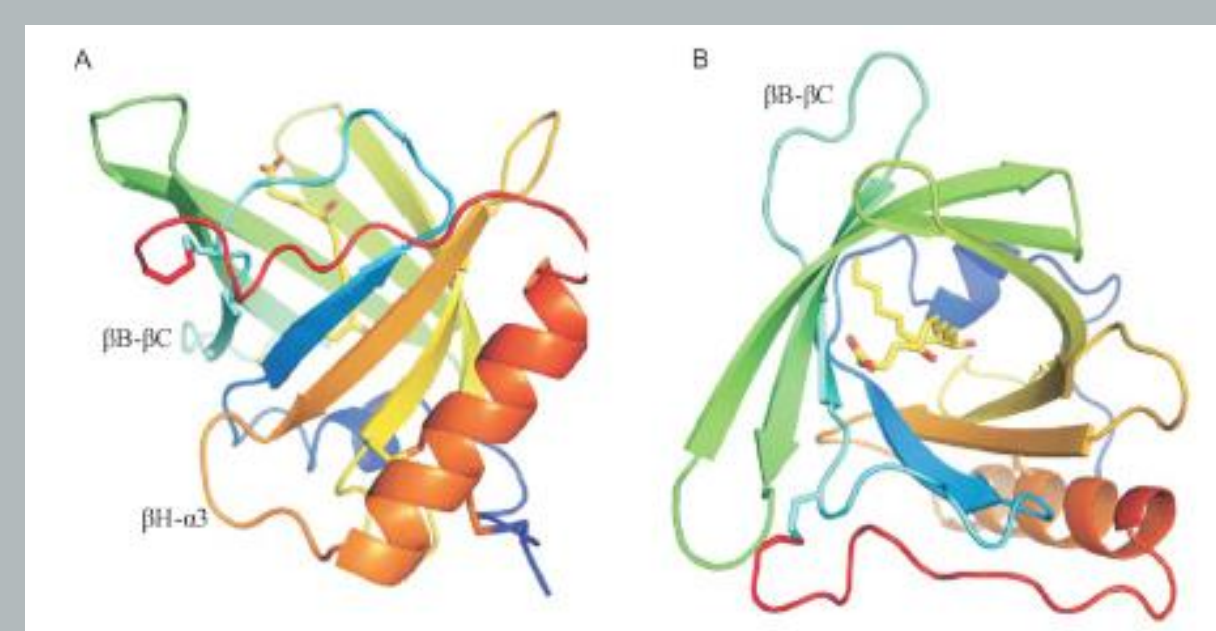
- Bifunctional and equally active on C5 and LTB4 from mice to men
- Compact globular 17kDa protein with 3-disulphide bridges
- Highly soluble and low viscosity (like water at 150mg/mL)
- No post-translational modifications

- Clinical efficacy proven with approved products inhibiting C5 (Soliris®) & LTB4 (Zileuton®)
- Applicable to many orphan inflammatory diseases where steroids (with their known off-target effects) are SOC
- Growing use of combination and bifunctional biotherapeutics in recognition that diseases are multifactorial
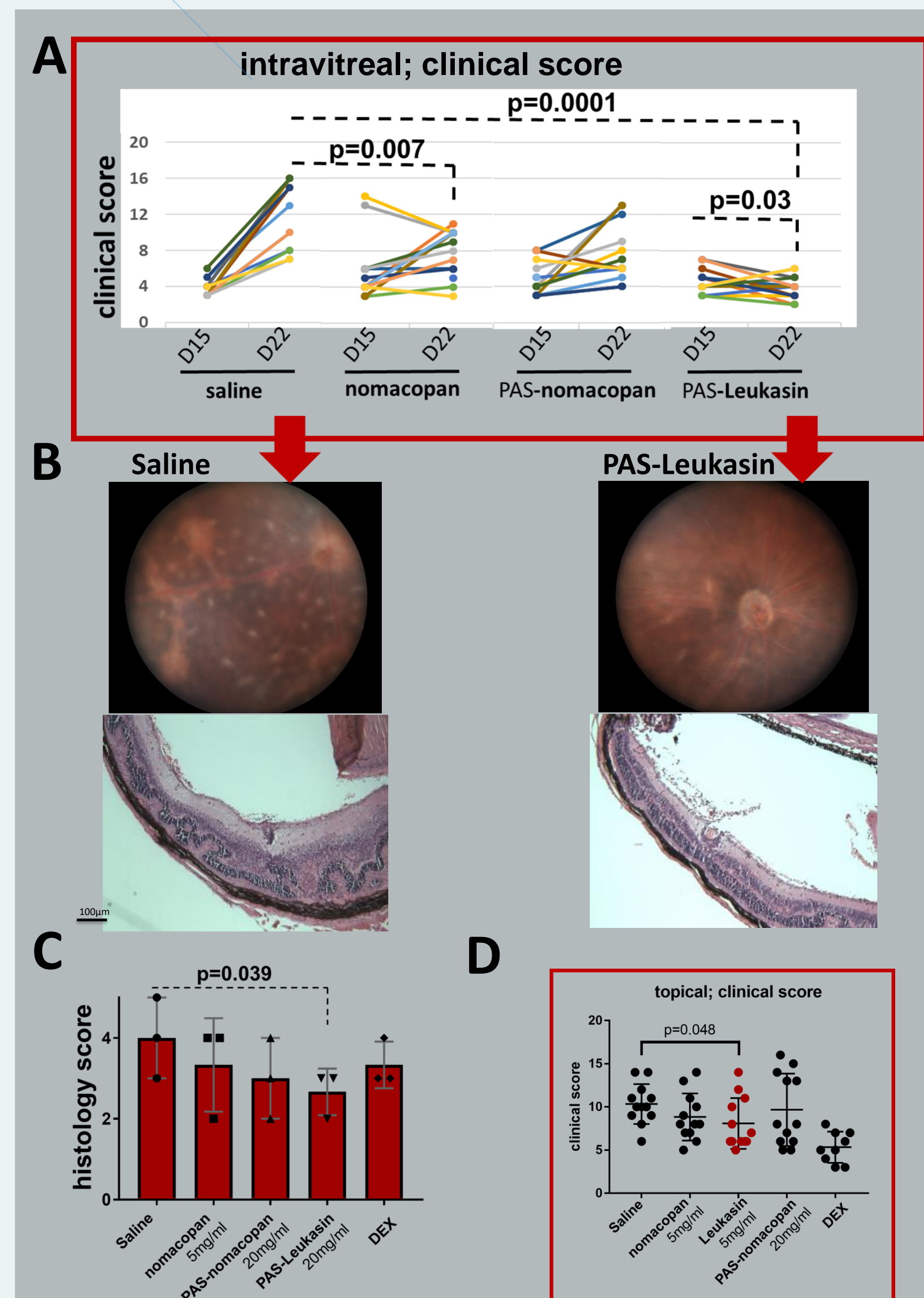
Maintenance and elaboration of immune response

Methods

EAU: As described[1].

Treatments: For intravitreal administration, mice were treated on days 15 and 18 post immunization by nomacopan, long acting nomacopan (PAS-nomacopan), long acting LTB4 binding only nomacopan (PAS-Leukasin), dexamethasone (Maxidex; DEX) or saline. For topical administration the mice were treated twice daily with 2-5 µl of nomacopan, PAS-nomacopan, LTB4 binding only nomacopan (Leukasin), DEX or saline for 7 days. Disease progression was graded clinically by retinal fundoscopy pre- and post- treatment and scored histologically.

Immunofluorescence microscopy: FFPE blocks were prepared and analysed as described before[1].

Tissue dissection: For retinal flow cytometry, retinal layers were collected, minced, filtered and re-suspended in media for *ex vivo* stimulation (PMA & Ionomycine, 4 hours) and stained for cell surface and intracellular markers[1].

Results

Intravitreal (IVT) administration of Nomacopan and long acting versions

We found that PAS-Leukasin mitigated disease progression post IVT administration as determined by clinical scoring (Figure 2A-C; mean score ±SEM; 3.81±1.01; n=16) relative to saline controls (12.36±1.01; n=16; P= 0.0001).
Decreases in Th17 (IL-17A⁺CD4⁺) cells in the nomacopan and PAS-nomacopan treated groups (mean % ±SEM; 14.67±3.53 and 7.02±3.01 respectively, n=8) were detected relative to saline controls (27.47±3.46; n=8; P=0.02 and 0.0007).
A significant decrease in retinal double-positive Th1/Th17 (RORγt⁺T-bet⁺) cells (4.717±2.627; n=8) was also observed in PAS-nomacopan treated EAU mice as compared to saline controls (21.28±3.54; n=8; P=0.003). after two IVT treatments (day 15 and 18) (Figures 3, 4) while there was no significant difference in the expression levels of other T cell subsets (data not shown).

Topical administration of nomacopan and long-acting variants

We found that PAS-Leukasin mitigated disease progression post topical administration as determined by clinical scoring (Figure 2D; mean score±SEM; 8.08±0.85; n=12) relative to saline controls (10.33±0.67; n=12; P=0.048). However, we did not observe any significant changes in CD4⁺T cell numbers or subtypes in treated mice.

Presence of LTB4 receptor (BLT1) and C5a receptor (C5aR) in infiltrating immune cells

Immunofluorescence staining of retinal tissue sections using MAbs recognising LTB4 receptors (BLT1; green) and C5a receptors (red) counterstained with DAPI (blue to indicate nuclei), showed that both receptors expressed in inflammatory cells. Some individual cells co-expressed both receptors, whilst many single receptor-expressing cells were also observed (Figure 5).
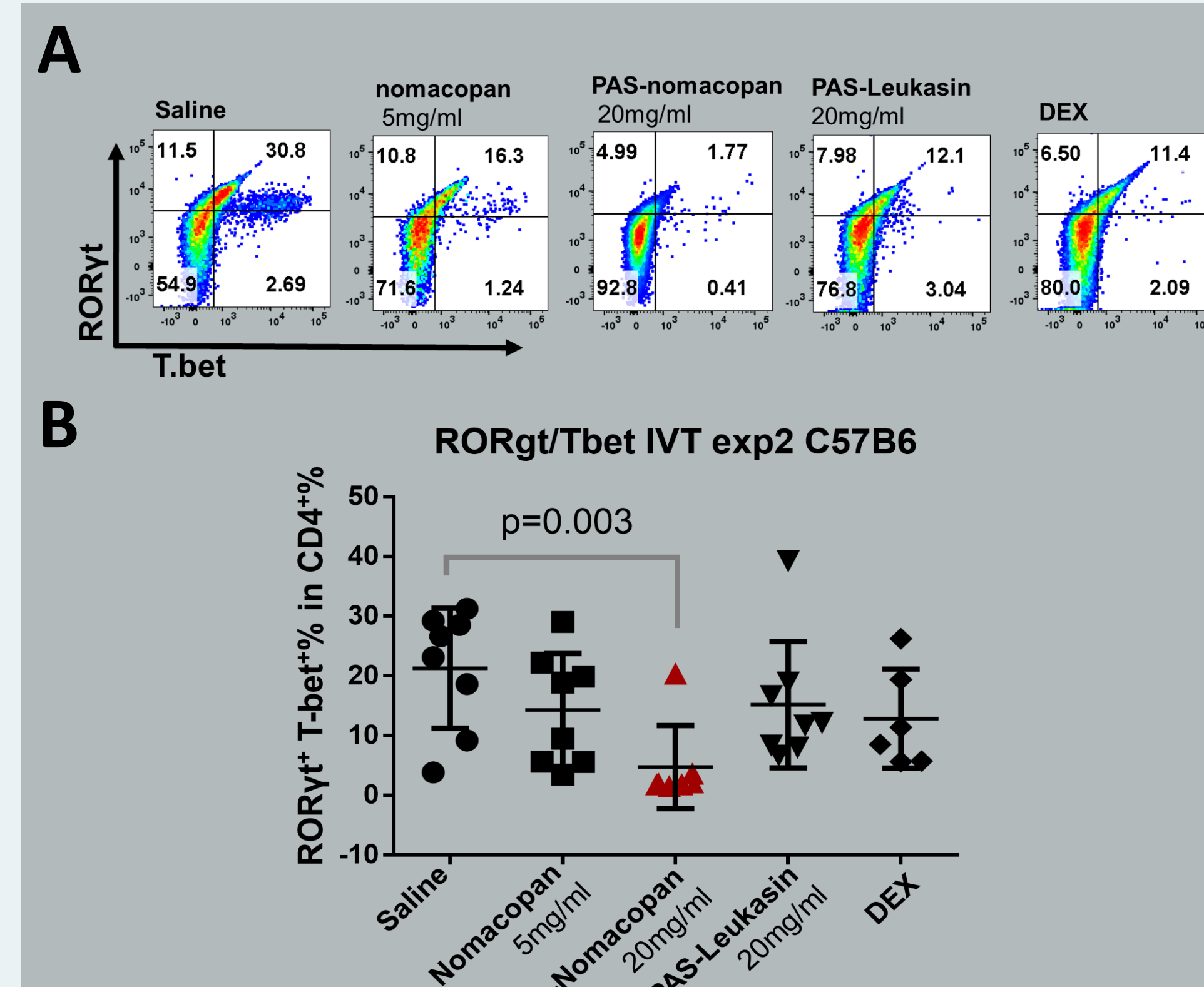

Figure 2. *Disease suppression;* **A.** Fundoscopic evaluation of disease was performed on day 15 (pre-treatment) and 22 (post treatment) for individual eyes (n=16). On day 15 and 18 EAU mice were treated intravitreally with 1-2 ul of indicated concentration of compounds. **B.** Representative fundus and corresponding histopathology images. **C.** Graphical summary showing histology score from IVT treated mice (n=3 in each group). **D.** Fundus examination for individual eyes (n=12) after 7 days of topical treatment on day 21 post immunization. Bars indicate SD or SEM (histology and fundus scores, respectively) and two tailed nonparametric t test has been applied.

Figure 3. *Suppression of double-positive RORγt⁺T-bet⁺ CD4⁺ T cells.* **A.** Representative retina flow plots on infiltrating cells derived from EAU mice treated intravitreally with saline control and compared with indicated treatments. **B.** Graphical summary showing the expression levels RORγt and T-bet in CD4⁺T cells. Bars indicate SEM. p=0.003 by two tailed nonparametric t test. The graph shows means of 8 mice in each group (DEX n=6).
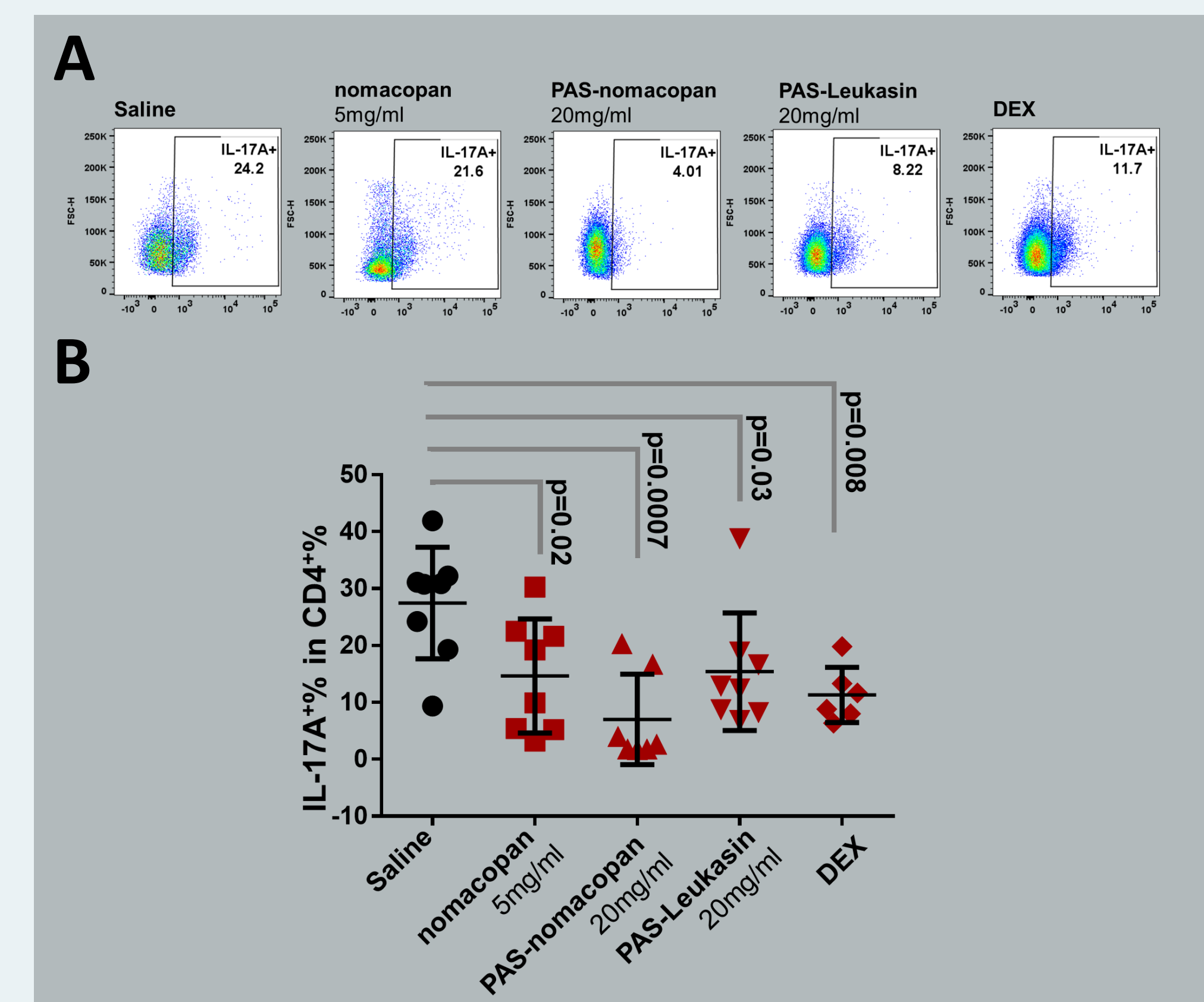

Figure 4. *Suppression of IL-17⁺ CD4⁺ T cells.* **A.** Representative retina flow plots on infiltrating cells derived from EAU mice treated intravitreally with saline control and compared with indicated treatments. **B.** Graphical summary showing the expression levels IL-17A in CD4⁺T cells. Bars indicate SEM. P=0.007 and P=0.02 by two tailed nonparametric t test. The graph shows means of 8 mice in each group (DEX n=6).
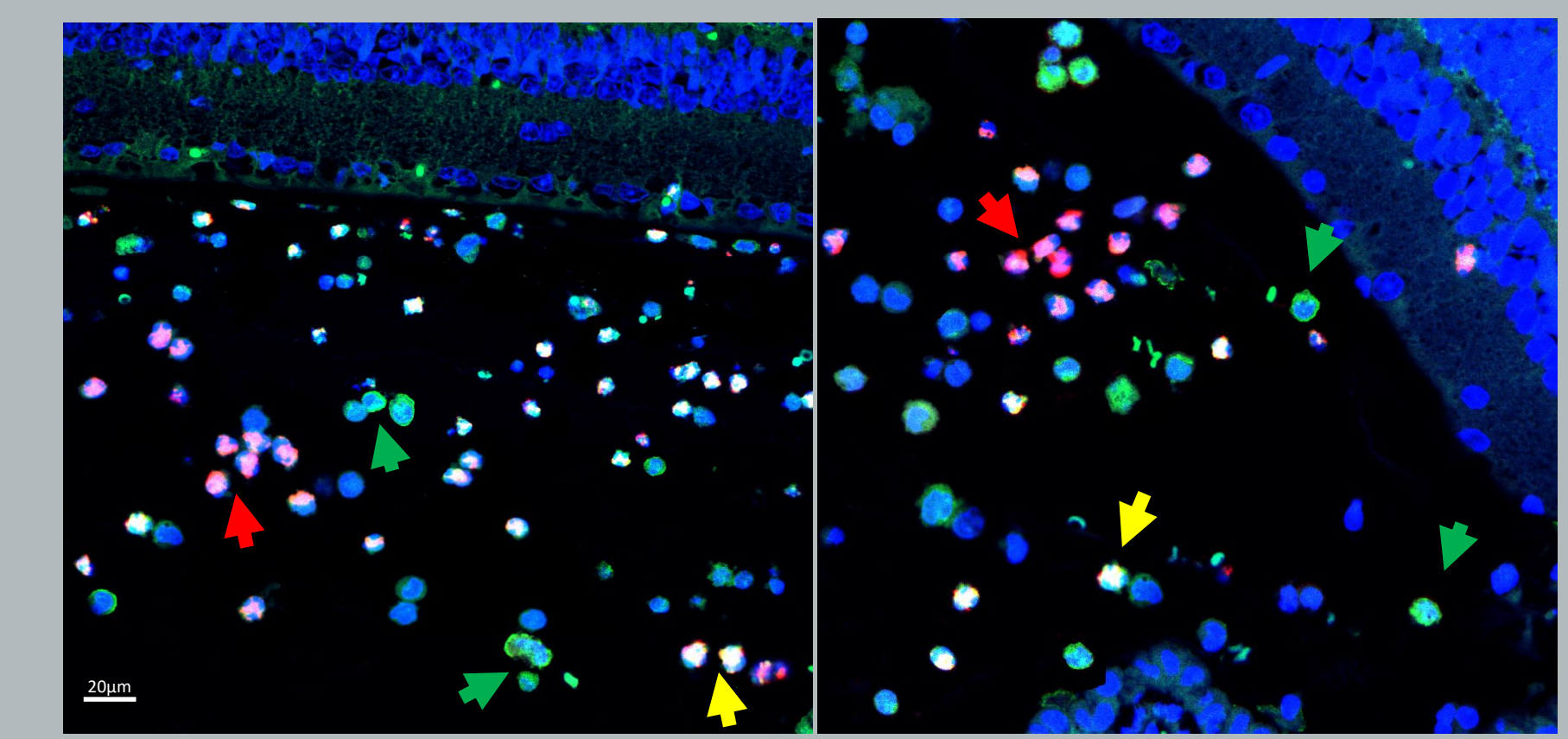

LTB4 receptor
C5a receptor

Figure 5. *Immunofluorescent staining for LTB4 receptor (BLT1, Green), C5aR (Red) on EAU sections.* Infiltrating cells captured in vitreous show cells expressing only BLT1 (Green) or C5aR (Red) while there are cells expressing both receptors (yellow). Cells indicated by arrows.

Conclusion

These data suggest that both LTB4 and the terminal complement pathways may be important in the aetiology of EAU, and raise the possibility of clinical intervention with a dual functional molecule. Administered IVT both of the long-acting versions (PAS-nomacopan and PAS-Leukasin) appeared to more effectively decrease T effector cells than unmodified nomacopan. The suggestion that Leukasin showed activity after topical administration raises the possibility that combination therapy by intravitreal injection and topical drops may be a therapeutic option.

Reference

1. M Eskandarpour et al. (2017) Pharmacological Inhibition of Bromodomain Proteins Suppresses Retinal Inflammatory Disease and Downregulates Retinal Th17 Cells. *J Immunol.* 198(3):1093-1103. 2. D A Copland, et al. (2009) Systemic and local anti-C5 therapy reduces the disease severity in experimental autoimmune uveoretinitis. *Clin Exp Immunol* 159: 303–314. 3. L Zhang, et al. (2016) Complement anaphylatoxin receptors C3aR and C5aR are required in the pathogenesis of experimental autoimmune uveitis. *J. Leukoc. Biol.* 99: 447–454. 4. T Liao, et al. (2006) Blockade of the Interaction of Leukotriene B4 with Its Receptor Prevents Development of Autoimmune Uveitis. *Invest Ophthalmol Vis Sci.* 47:1543–1549. 5. P Roversi, et al. (2013) Bifunctional Lipocalin Ameliorates Murine Immune Complex-induced Acute Lung Injury. *J Biol Chem* 26, 288, 18789–18802.