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H K F Yip, T Y Y Lai, K-F So and A K H Kwok

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Retinal ganglion cells toxicity caused by photosensitising effects of intravitreal indocyanine green with illumination in rat eyes

H K F Yip, T Y Y Lai, K-F So, A K H Kwok

Aim: To investigate the effects of indocyanine green (ICG) with or without illumination on rat retinal ganglion cells (RGC) and retinal morphology.

Methods: Intravitreal injections of 1.0 mg/ml ICG solution were performed in rat eyes with or without subsequent illumination for 5 minutes. Eyes in the control group had intravitreal injections of balanced salt solution with illumination. Retrograde labelling of RGC with 6% Fluoro-Gold was performed 1 month later and RGC densities were compared between the three groups. Light microscopy with measurements of outer nuclear layer (ONL) and inner nuclear layer (INL) thicknesses were also performed and compared.

Results: Eyes with ICG without illumination showed insignificant reduction in RGC density compared with the control group (p = 0.28), whereas a significant decrease in RGC density was found in eyes that had ICG injection with illumination (p = 0.036). A significant increase in ONL thickness was also observed in the ICG with illumination treated eyes compared with the ICG without illumination and the control groups (p = 0.001). No significant difference in INL thickness was observed between the three groups.

Conclusions: Intravitreal injection of 0.1 mg/ml ICG in rat eyes followed by illumination resulted in photosensitising toxicity to RGC. Lower ICG concentration or illumination level should be considered when performing ICG assisted macular surgery.

Materials and Methods

Animals
Adult Sprague-Dawley rats (female, 200 g, 8 weeks old; Charles River Laboratories Inc, Wilmington, MA, USA) were obtained from the laboratory animal unit of the University of Hong Kong and used in this study. All experiments were conducted in accordance to the ARVO statements for the use of animals in ophthalmic and vision research. The research protocol of this study was approved by the committee on the use of live animals in teaching and research, the University of Hong Kong.

Preparation of ICG solution
An amount of 25 mg of commercially available ICG (Diagnogreen, Daiichi Pharmaceutical, Tokyo, Japan) was reconstituted with 5 ml of a balanced salt solution (BSS) provided (BSS Plus, Alcon, Fort Worth, TX) to produce a 0.5% (5 mg/ml) solution. The mixture was well shaken for 3 minutes before further dilution with BSS to produce solutions with a final concentration of 1.0 mg/ml. The osmolarities of the diluted ICG solution and BSS solution were 300 mOsmM and 302 mOsmM respectively.

Intravitreal injection and illumination
All animals were anaesthetised with an intraperitoneal injection of a xylazine/ketamine mixture (xylazine 8 mg/kg and ketamine 80 mg/kg). Intravitreal injections were performed in rat eyes using methods as previously described.

Abbreviations: BSS, balanced salt solution; ICG, indocyanine green; ILM, internal limiting membrane; INL, inner nuclear layer; ONL, outer nuclear layer; PBS, phosphate buffered saline; RGC, retinal ganglion cells

EXTENDED REPORT
Briefly, pupils were dilated with 0.5% tropicamide and intravitreal injections were performed by insertion of a 33 gauge needle guided by a stereoscopic microscope. Care was taken to avoid damage to the lens or retina. In order to study the potential toxicity caused by photosensitising effects of ICG, the eyes were divided into three groups: (1) intravitreal BSS injection with illumination (control group); (2) intravitreal ICG injection alone (ICG group); and (3) intravitreal ICG injection with illumination (ICG + light group). A single injection of 8 μl of ICG or BSS solution was delivered into the mid-vitreous over 1 minute. After intravitreal injection of the ICG or BSS solutions, all eyes were exposed to light from a standard endoillumination light pipe (Millennium, Bausch & Lomb, Rochester, NY, USA) with an emission spectrum from 420–800 nm and a luminance of 61.8 cd/mm². The light source was provided by a standard vitrectomy machine positioned 5 mm away from the cornea for 5 minutes. Four radial cuts were made in the peripheral retina and the retina was separated and divided into four quadrants. The retinas were flat mounted with the vitreous side facing up on gelatin coated slides in 30% glycerin. The slides were then examined under ultraviolet illumination on a Zeiss axiophot fluorescent microscope. Labelled RGC were counted along the median line of the four quadrants starting from the optic disc to the peripheral border of the retina at 50 μm intervals, under an eyepiece grid of 200×200 μm. The mean density of labelled RGC of each retina was calculated by the number of labelled RGC in the retina divided by the area of the retina. All measurements were performed by an observer masked to the experimental group.

**Light microscopy and ONL and INL thickness measurement**

Sagittal sections were also performed for retinal morphological analysis and measurements of the outer nuclear layer (ONL) and inner nuclear layer (INL) thicknesses. Retinas were cryoprotected in 30% sucrose and sectioned at 10 μm thickness. Sections were stained with haematoxylin and eosin and examined under light microscopy. The thicknesses of the ONL and INL were measured with an image analysis system (Neurolucida, MicroBrightField, Colchester, VT, USA).

**Statistical analysis**

Statistical analysis was carried out using a SPSS v11.5 (SPSS Inc, Chicago, IL, USA). One way ANOVA with post hoc LSD tests were used to compare the RGC density, and the ONL and INL thickness in the three groups. A p value <0.05 was considered statistically significant.

**RESULTS**

**Retinal ganglion cell density**

Whole mount retina RGC density measurements were performed in retinal specimens from the control, ICG, and the ICG + light groups 1 month and 2 days after intravitreal injections. Fluoro-Gold labelled RGCs were detected in all 21 eyes examined. RGC densities for the control, ICG, and ICG + light groups were 2461 (176) cells/mm² (mean (SEM)), 2213 (134) cells/mm², and 1979 (166) cells/mm², respectively (fig 1). There was a significant reduction in RGC density in the ICG + light group compared with the control group (one way ANOVA post hoc LSD, p = 0.036). No significant difference was found between the three groups.
difference in RGC density was found between the control group and the ICG alone group (one way ANOVA post hoc LSD, p = 0.28).

**Retinal morphology and INL and ONL thickness on light microscopy**

One month after intravitreal injections, all the retinal layers appeared normal morphologically in all three treated groups (fig 2). There was no localised destruction in the retinal architecture observed in any of the specimens under light microscopy. Measurements of INL and ONL thickness were performed on the retinal sections in the three groups. The thickness of the INL for the control, ICG and ICG + light groups were 40.2 (2.3) µm (mean (SEM)), 41.0 (1.0) µm, and 40.8 (1.9) µm, respectively (fig 3). There was no significant difference in the mean INL thickness between the three groups (one way ANOVA, p = 0.95). The thickness of the ONL for the control, ICG and ICG + light groups were 60.5 (0.9) µm (mean (SEM)), 59.5 (1.1) µm, and 68.9 (1.9) µm, respectively. There was a significant increase in the ONL thickness for the ICG with endoillumination group compared with both the ICG alone and the control BSS with endoillumination groups (one way ANOVA, p <0.001) (fig 4).

**DISCUSSION**

In this study, we demonstrated that there was a significant reduction in RGC density in rat eyes following intravitreal injection of 8 µl of 1.0 mg/ml ICG solution with illumination compared with the control group of BSS injection with illumination. Although a small reduction in RGC density was also observed in eyes after 1.0 mg/ml ICG injection alone, the difference was not significant when compared with the control group. We also observed that there was a significant increase in the ONL thickness in eyes treated with ICG and light compared with the control and the ICG only groups. Our results confirmed the hypothesis suggested in previous in vitro experiments that application of ICG under illumination may result in retinal toxicity as a result of the photosensitising effects of ICG. Previous animal studies have shown that ICG may cause retinal morphological damage resulting in the loss of photoreceptors outer segments. Experiments in rabbit eyes have also demonstrated an increase in apoptosis of photoreceptors and RPE cells 1 day after intravitreal injection of higher concentration of ICG solution without illumination. Further studies to investigate the potential ICG related photosensitising toxicity to the photoreceptors are warranted.

In conclusion, our study showed that intravitreal injection of 1.0 mg/ml ICG may result in photosensitising toxicity to RGC in rats with the presence of illumination. Our results should be interpreted with caution since the vitreous volume around 50–60 µl in rat eyes is much smaller than that of human eyes and higher concentration of ICG will therefore accumulate in rat eyes. Moreover, the dye was injected into the vitreous cavity and was not removed but left for 1 month. This would have resulted in prolonged contact with the retina and increased the potential for toxicity. Another shortcoming of this study was the illumination used was transcorneal rather than within the eye and therefore the standard vitrectomy surgery condition could not be fully simulated. This study also only investigated one concentration of ICG and we were unable to demonstrate the concentration dependent toxicity caused by ICG. None the less, previous studies have already demonstrated that such concentration dependent toxicity occur following intravitreal ICG injection in rat eyes. However, in view of the potential retinal toxicity, clinicians should consider using the minimal concentration of ICG if it is required during surgery. Preparing the ICG solution with sodium free BSS or with dextrose may also help to reduce the retinal toxicity. Moreover, surgeons may also consider using lower light levels, shorter light exposure, as well as using different wavelengths of light in order to avoid potential phototoxicity caused by ICG.

**Figure 4** The effects of ICG with endoillumination on the outer nuclear layer (ONL) thickness. A significant increase in the mean ONL thickness was found compared with the control and ICG without illumination groups.
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