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THE BASICS OF INDOCYANINE GREEN ANGIOGRAPHY

By

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INTRODUCTION

Indocyanine green angiography is a photographic technique, which uses a green dye (indocyanine green) to visualize the choroid. Since certain pathologies, like systemic lupus erythematosus and age-related macular degeneration, have shown to benefit from a procedure of this sort, it is imperative that ophthalmic personnel have a basis of understanding for the usefulness of this technology. This article explores the benefit of doing such a procedure by describing certain characteristic fluorescence patterns in particular diseases with the hopes of diagnosing, treating, and managing a patient appropriately.

LEARNING OBJECTIVES

After reading this article, the student should be able to:

- 1) Describe the properties of the indocyanine green molecule.
- 2) Discuss the indications, contraindications, and side effects associated with indocyanine green angiography.
- 3) Identify the indocyanine green angiographic patterns seen with various pathologies.
- 4) Understand the different phases of indocyanine green angiography.

History

Indocyanine green angiography (ICGA) is an innovative photographic technique that is useful for studying choroidal circulation. Although it is most useful for imaging subcategories of choroidal neovascularization, it is also a valuable tool for investigating other abnormalities that can manifest themselves in the choroid.ⁱ Used as an adjunct to fluorescein angiography (FA), the ICG dye, which is larger than sodium fluorescein, binds more tightly to serum albumin (98%). Its high affinity for protein binding inhibits it from easily traveling through the well-fenestrated walls of the choriocapillaris. Because only 80% of sodium fluorescein binds to plasma proteins, the resultant fluorescence from unbound dye under the retinal pigment epithelium prevents sharp delineation of the choroidal vasculature. The Mie scatter property of the infrared spectrum permits ICG absorption and emission at 805 nm and 835 nm, respectively, for transmission through serosanguineous fluid, blood, infiltrates, lipid exudates, melanin, and xanthophylls despite emitting only 4% of the fluorescence of sodium fluorescein.

In the mid-1950s, an official from the Eastman Kodak Company, who was also a patient of Dr. Irwin Fox at the Mayo Clinic, was invited to aid in the development of novel dyes for medical use. He collected an assortment of tricarbocyanine dyes, which were previously used as a cyan-forming layer in color film and in the manufacture of Wratten filters.ⁱⁱ One of these dyes was ICG. A pharmaceutical firm managed by Dunning, Hynson, and Westcott further developed the dye and received Food and Drug Administration approval in 1956 for use in angiographic studies in cardiology and hepatology. Investigations involving work on monkeys and cats performed by Flower and Hochheimer, respectively, led to the first use of ICGA in humans in the early 1970s.ⁱⁱⁱ Building upon previous work by Hayashi and colleagues, Yannuzzi and associates coupled the fundus camera, Topcon TRC-IA retinal camera, with the ICG IMAGEnet ICG digital imaging system.^{iv} Today ICGA is performed principally using an electronic digital imaging system in lieu of a scanning laser ophthalmoscope. The novel digital systems include a fundus camera networked to a source of infrared radiation, a monitor, a computer with imaging software, and barrier and excitatory filters with infrared coatings.^v

Properties of ICG

ICG is a sterile, water-soluble anhydro-3,3,3',3'-tetramethyl-1-1'-di-(4-sulfobutyl)-4,5,4',5'-dibenzoindotricarbocyanine hydroxide sodium salt of the polymethine group of biological stains.⁵ With an empirical formula of $C_{43}H_{47}N_2NaO_6S_2$ and molecular weight of 774.6 daltons, it is the product of the

synthesis of a derivative of glutaconic aldehyde with an indolium hydroxide compound (Figure 1). Despite the commonly held view that sodium iodide is a major component of the dye, it is in fact only 5% of the compound. The lyophilized form of ICG achieves solubility and safety for human use due to this dipolar ion and the supplied aqueous solvent. This reconstituted state of usable ICG is stable for 10 hours. Generally, 40 mg in 2 mL of aqueous solvent is used for injection, though it is important to note that dosage in humans should not exceed 5 mg/kg due to toxicities.^{vi} Some practitioners use a 5 mL saline flush in an attempt to propel the dye. After the injection of ICG, the parenchymal cells of the liver absorb the dye and subsequently excrete it into the bile. Conversely, the kidneys excrete sodium fluorescein.

Contraindications and Side Effects

The main side effect of ICG is the discoloration of stools for several days.⁵ The dye is contraindicated in patients with iodine and shellfish allergies. Furthermore, patients with a history of liver disease and those undergoing hemodialysis for chronic renal failure may be at an increased risk of experiencing adverse side effects. Like sodium fluorescein, ICG has not been proven to be teratogenic, though many ophthalmologists elect not to perform the study on pregnant females.

Potential adverse reactions range from nausea to circulatory shock. Mild reactions include nausea, vomiting, and extravasation of dye. If extravasation does occur, localized pain may ensue. Despite the fact that ICG has a lower pH than sodium fluorescein, tissue necrosis as a result of extravasation has only been reported with the use of fluorescein sodium. More severe potential reactions include urticaria, syncope, laryngospasm, anaphylaxis, circulatory shock and myocardial infarctions. Only three deaths have ever been reported due to ICG adverse reactions.

Normal Phases of ICG Angiography

Prior to administration of ICG dye, images under the red-free filter (560 nm) are taken. The dye is delivered through the antecubital vein to initiate the study. In 1973, Flower and Hochheimer described the normal phases of the study.^{vii} During arterial filling of the choroidal transit phase, the first appearance of the dye (at 8 to 10 seconds) is seen in the medium-sized choroidal arteries. The large choroidal veins remain dark. This phase typically lasts for less than 2 seconds. In the early venous phase, the dye fills the choroidal veins and though the filling of the choriocapillaris is complete, it is weak and difficult to appreciate. The ensuing late venous phase gives a more uniform appearance to the dye in the choroidal vessels. The retinal arteries also fill during this early phase.

It is during the initial minute of the ICG angiogram when the phenomenon of “blooming” may occur. During image exposure, each pixel of the fundus camera absorbs a fixed quantity of light.^{viii} However, if the imaging light exceeds the pixel’s capacity, it becomes inundated with excessive light leading to an overabundance of light of the surrounding pixels. This digital photographic artifact can be visualized in patients with choroidal tumors, disciform scars, and large hemorrhages. To minimize this effect, the gain control is turned down sequentially to compensate for the increased fluorescence. During the middle phase, which takes place at approximately ten minutes, ICG is equally distributed throughout the choroidal vasculature and the surrounding interstitial space. In the inversion (late) phase, occurring between 15 to 40 minutes, the optic nerve head and large choroidal vessels appear dark as compared to the seemingly hyperfluorescent extrachoroidal background.

Anterior Segment ICG Angiography

Though anterior segment ICGA is not commonly used, it can prove to be beneficial in differentiating a variety of disorders, such as rubeosis iridis, episcleritis, scleritis, and metastatic iris tumors. ICG plays a key contributory role in the diagnosis and treatment of these conditions. Furthermore, due to its protracted time in the anterior segment circulation, its ability to detect weakened vessels is greater than FA. The standard dose of ICG is used though in patients with dark irides, 50 mg of ICG dye with 3 mL of saline solution is indicated in order to visualize the iridic vasculature. ICG angiography of the healthy anterior segment shows no leakage at all in any phase.^{ix} Given these results, it is reasonable to conclude that all leakage seen via this photographic technique may be regarded as pathologic and a sign of inflammatory or vascular activity. Nieuwenhuizen and colleagues were able to delineate the subtle differences existing in the subtypes of episcleritis (simple and nodular) and scleritis (diffuse, nodular, and necrotizing) via anterior segment ICGA.^x In their findings, both forms of anterior segment inflammation, with the exception of necrotizing scleritis, exhibited a short transit time with rapid filling. In necrotizing scleritis accompanied by active inflammation, there was late leakage from new or damaged vessels. Late leakage of ICG is also a common finding seen in rubeosis iridis. When compared to iris FA, ICG allows for a better recognition of iris hypoperfusion and anastomotic vessels in addition to the ability to reveal iris pigment epithelium defects.^{xi}

Combination of FA and ICG Angiography

When simultaneous angiographic testing is performed, the dosage of 50 mg of ICG in 3 mL of aqueous solvent in a mixture of 25% fluorescein sodium in 2 mL of aqueous solvent are placed in the same syringe.^{xii} It is also important not to use heparin during this procedure because the sodium bisulfite in the anticoagulant affects the absorption peak of ICG and diminishes the image quality. Initially, the early phase of the FA is recorded. Subsequently, the infrared filters are put in place and, through the adjustment of appropriate filters, alternate FA and ICG images are captured.

Retinal Diseases

It can be convincingly shown that the most important use of ICG is in identifying subfoveal choroidal neovascularization (CNV) in patients with the exudative form of age-related macular degeneration (AMD). In particular, areas of occult CNV lesions in AMD that may not be visible by FA nor slit-lamp examination can be detected using ICGA. As it travels through the choroidal circulation tightly adhering to serum proteins, the ICG molecule barely leaks from the fenestrations of the choriocapillaris. Consequently, areas of CNV under pigment epithelial detachments (PED), exudates, and hemorrhages are imaged more efficiently via the ICG angiographic method.⁴ However, ICG is also advantageous in studies of fibrovascular, serous and non-serous PEDs; classic CNV; neurosensory detachment (NSD); idiopathic polypoidal choroidal vasculopathy (IPCV); central serous retinopathy (CSR); angioid streaks; and pathologic myopia (PM).

In cases of classic CNV, FA findings are akin to those of ICGA and, therefore, ICG may not be indicated. In the early phase of the study, vascular hyperfluorescence predominates with progressive leakage occurring during the late stage. However, in occult lesions of AMD, which represent 85% of newly diagnosed patients with this retinal disease, ICGA is a major asset. In a serous PED, the study enables the discovery of an angiogenic process. CNV hyperfluorescence may appear early and late. In the absence of a serous PED, early vascular hyperfluorescence occurs with late staining of abnormal vessels and the CNV is easier to delineate.

During the study, identification of CNV may be classified into three categories: hot spot, plaque, and a combination of both. A hot spot (focal CNV) is described as a well-defined hyperfluorescent area that is less than 1 disc diameter (DD) in size, which usually fluoresces early. Any area of an occult lesion more than 1 DD is termed a plaque. Unlike hot spots, plaques usually do not fluoresce early and their intensity diminishes late in the study. Nonetheless, a combination of a hot spot and plaque may appear. In these eyes, the hot spots may be located at the edge of the plaque, overlie the plaque, or be adjacent to the plaque.^{xiii}

Differentiation of fibrovascular PEDs, which are more common than serous PEDs, occurs with ICGA more readily than FA and, thus, spares ophthalmologists from performing unnecessary laser treatment. It is important to consider that some areas that do not stain may not be devoid of abnormal vessels. This has particular significance for a fibrovascular PED, where the occult CNV may be shielded by subretinal fluid.^{xiv} In recurrent CNV, infrared laser-guided treatment of feeder vessels may obliterate the neovascular process, which is enhanced by the photochemical reaction using ICG.

Initially described by Stern and colleagues in 1985,^{xv} IPCV is now recognized as an entity that can most easily be detected with ICG angiography. Characterized by a polyp-like “clustered grape appearance,” these enlarged choroidal structures may leak slowly, appearing hyperfluorescent early and becoming progressively more hyperfluorescent if they are active (Figures 2 and 3). In successful post-operative laser treatment of this vascular complex, hypofluorescence is noted.

Because choroidal hyperpermeability reveals hyperfluorescence on ICGA, better delineation of the distinctive focal leak of the RPE in CSR is appreciated. In cases where there are associated PEDs and NSDs, the deeper penetration allows for an easier understanding of the source of leakage. In a study of thirty eyes with CSR, Hayashi and associates found focal areas of choroidal ischemia in addition to areas of ICG dye leakage from the choriocapillaris.^{xvi}

Systemic Diseases

Although FA is typically performed to rule out any vasculitic changes with sufficient accuracy, performing an ICG on patients with systemic disease may shed light on the state of the choroid. The precise site(s) of localized inflammation or ischemia within the choroid may be detected in patients with Adamantiades-Behçet’s Disease (ABD), systemic lupus erythematosus (SLE), and sarcoidosis. Matsuo and colleagues reported that in patients with ABD-

associated retinal vasculitis, ICG revealed choroidal abnormalities not present on fundoscopic examination nor slit-lamp examination.¹⁷ This is also the case in SLE patients. During the early phase, ICG findings may include focal areas of hypofluorescence, which may appear as hyperfluorescent pinpoint dots in the late stage of the study.¹⁸ In a study done by Wolfensberger and co-workers¹⁹ on patients with ocular sarcoidosis four disparate patterns on ICGA were noted. In the first pattern, patients exhibited hypofluorescent choroidal lesions in the early and intermediate phases, which were irregularly dispersed and localized in the midperiphery in 63% of patients. All of the patients displaying this pattern had lesions that became isofluorescent (co-existent hypofluorescence and hyperfluorescence of a particular area) in the late phase of the angiogram. In the second pattern, eighty-nine percent of patients had focal hyperfluorescent pinpoints visible in the intermediate and late phases, while in the third pattern fuzzy choroidal vessels with leakage in the intermediate phase of the angiogram predominated. Lastly, in the fourth pattern, diffuse late zonal choroidal hyperfluorescence with staining in the late phase of the angiogram was present in all patients within this subgroup. These characteristic ICGA findings may hold additional information for diagnosing and monitoring these diseases.

Infectious Diseases

ICG has also been shown to be beneficial in detecting additional choroidal lesions caused by infectious diseases, such as tuberculosis, toxoplasmosis, and syphilis. Areas of hypofluorescence have been shown to correlate with recognizable areas of active choroidal inflammation. This finding is typically seen in choroidal tuberculomas. Tayanc and associates²⁰ detected an additional active lesion on ICGA, which like the first lesion remained hypofluorescent throughout the course of the study. After treatment, though these lesions persisted, they assumed a less hypofluorescent state. Unlike ocular tuberculosis, active lesions of toxoplasmosis retinochoroiditis may reveal areas of hypofluorescence or hyperfluorescence in the early phases while exhibiting hyperfluorescence in the late phases.²¹ This finding is helpful for identifying a recurrence of ocular toxoplasmosis because it can identify area(s) of reactivation undetectable by FA or clinical examination. Additionally, ICG can help distinguish areas of choroidal neovascularization, which may be a complication of this disease process. In their studies done on patients with ocular syphilis, Mora et al²² identified ICGA anomalies in 75% of eyes where 91.6% of this group showed speckled hyperfluorescent spots in the late phase. These irregularities disappeared with a repeat ICG performed 5 +/- 1 weeks after treatment with anti-treponemal therapy.

Ocular Tumors

The fact that ICG diffuses much more gradually out of small, fenestrated choroidal vessels than sodium fluorescein makes it very attractive as a means to image choroidal tumor vasculature. Obtaining ICG images of this type of large choroidal pathology requires strict adherence to pigmentation, thickness, and inherent vascularity of the lesion being investigated.²³ In pigmented choroidal nevi and congenital hypertrophy of the retinal pigment epithelium (CHRPE), hypofluorescence predominates. In CHRPE, subtle geographic hypofluorescence may be apparent. However, in amelanotic nevi, the early and middle stages of the study reveal hyperfluorescence or isofluorescence. In the late frames, a subtle, scattered fluorescence of the nevus is observed. Diffuse hypofluorescence and inability to visualize the underlying choroidal vasculature is characteristic of choroidal osteomas in the early frames. Diffuse leakage into the tumor occurs in the middle phase while retaining its hypofluorescent status in the late phase.

The vessels of choroidal hemangiomas appearing on ICGA present much differently than seen in patients with choroidal melanomas and choroidal metastases. These web-like configured vessels display hyperfluorescence early in the study. Choroidal hemangiomas demonstrate a swift, intense hyperfluorescence unlike any other tumor during the initial minute of the study. During the middle frames, the degree of fluorescence subsides followed by the almost always present “washout” hypofluorescent appearance of the tumor in the late phase. In choroidal melanomas, the greater the vascularity and thickness, the greater the fluorescence is appreciated on ICGA. Decreased pigmentation of the tumor is also valuable in determining the extent of leakage present on the study. These three findings are especially notable in a mushroom-shaped melanoma. During the study, the tumor vasculature of choroidal melanomas, with its characteristic dilated, corkscrew-shaped vessels, is generally identifiable in the early phase where the filling pattern shows a variety of irregular vessels within the first few minutes of the study. Hyperfluorescence of the tumor eventually follows occurring between 20 to 30 minutes. ICG dye leakage may occur inside the tumor beneath a retinal detachment. Conversely, the tumor may assume a hypofluorescent state if there is significant pigmentation, lack of evident tumor vascularity, or compression from tightly packed tumor cells. In choroidal metastasis due to a multitude of carcinomas, such as breast, lung or liver, a diffuse homogeneous hypofluorescence is noted early in the study compared to the surrounding normal choroid. Faint staining occurs in later frames. Leakage may also appear if an associated NSD is present.

Inflammatory Diseases

ICGA has vast potential for recognizing underlying choroidal pathology in ocular inflammatory disease. Determination of the intrinsic cause of inflammation or ischemia of the choroid is further facilitated by ICGA due to novel capabilities of imaging the small, medium, and large choroidal veins in addition to the choroidal stroma. In the realm of ocular inflammatory disease, perhaps ICHG has the greatest benefit in identifying the depigmented lesions of birdshot retinochoroidopathy (BSRC). These well-demarcated, circular lesions, initially described by Ryan and Maumenee,²⁴ certainly appear more numerous on ICGA than on clinical examination and FA, which emphasizes the diffuse nature of this disease (Figure 4).²⁴ *Hypofluorescence occurs throughout the entire study (Figure 5). These BSRC lesions are more numerous than multiple evanescent white dot syndrome (MEWDS) and multifocal choroiditis and panuveitis (MCP) on ICGA. One hypothesis as to why these lesions are so abundant may be that perhaps these choroidal infiltrates undergo a fibrotic process wherein choroidal atrophy results. However, theories as to the true underlying cause remain open to conjecture.*

Like BSRC, acute and healed posterior multifocal placoid pigment epitheliopathy (APMPPE) lesions show marked hypofluorescence. The acute lesions are especially notable for their distinct hypofluorescence in the late phase.^{25, 26} On the other hand, healed APMPEE lesions are less in quantity^{27, 28} and display a better-delineated area of hypofluorescence. Large choroidal vessels can be seen in the early phase, suggesting that the disease emanates from the choriocapillaris. The hypofluorescent lesions become sharper, but irregularly shaped towards the end of the ICGA. Persistent ICG hypofluorescence is observed months and years after the active APMPEE lesions have resolved. Theories as to why there is choroidal hypoperfusion in APMPPE are still in flux. Park and colleagues²⁹ have suggested that this phenomenon occurs due to partial choroidal occlusive vasculitis secondary to a delayed-type hypersensitivity reaction; this is based on ICG angiographic findings of choroidal hypoperfusion and the previously documented reports in the literature of systemic vasculitis associated with the ocular findings in APMPPE. Additional histopathologic studies will be needed in order to explain why choriocapillaris infarcts are noted in both acute and healed APMPPE.

The active serpentine-spreading grayish-yellow cream-colored lesions³⁰ of serpiginous choroidopathy display marked, persistent, and homogeneous hypofluorescence throughout the course of the ICGA. Choroidal vessels are also obscured during the active stage of the disease. This could potentially be caused by a combination of choroidal nonperfusion and blockage by inflammatory exudates. In the late phase of the angiogram, the active lesions

take on a sharper appearance as compared to the indistinct borders in the early phase. However, active inflammation may manifest itself as a rim of hyperfluorescence on the edges of these hypofluorescent lesions.³¹ The mid- and large choroidal vessels within the lesion are more clearly defined during the subacute stage. Delay in perfusion of the choriocapillaris and small vessels is evident, which gives the lesion a more heterogeneous form. This appearance is more classically seen after resolution of the acute inflammatory changes associated with RPE edema. In the healed state, deep choroidal vessels are better visualized due to atrophied regions of RPE and choriocapillaris. The chorioretinal scar hypofluoresces early and stains late in the ICGA. ICG findings support the notion that a better distinction between active lesions, which may represent a more threatening yet conceivably more treatable form of serpiginous choroiditis, and subacute lesions, which are already undergoing resolution, can be made to avoid unnecessary treatment.³²

The multiple, round lesions typically seen in MEWDS are instantly recognizable on ICGA unlike the subtlety of presentation on FA and clinical examination. They present as a clearly visible pattern of hypofluorescent spots diffusely spread all throughout the posterior pole and peripheral retina.³³ Like BSRC, the lesions are more numerous on ICGA. Several patients have a blind-spot enlargement consistent with a circumferential loop of hypofluorescence around the optic nerve.³⁴ During the active stage of MEWDS, the first lesions appear during the middle phase extending into the late phase.³⁵ The lesions are indicative of RPE and involvement in conjunction with possible choriocapillaris injury (Figure 6). When MEWDS resolves, the hypofluorescent spots regress and ultimately vanish. This occurs concomitantly with restoration of vision. Evidence as to why this transpires awaits further investigation.

Conclusion

Though ICGA is still not as frequently used in practice, it has certainly proven to enhance our understanding of the natural course of ocular diseases. ICGA has frequently revealed abnormalities which neither clinical examination nor FA has provided. This has helped many patients avoid needless laser treatment and, as a result, has expedited the healing process. More research on ICGA is needed in order to address fundamental questions as to why these pathogenetic processes occur within the choroid.

THE BASICS OF INDOCYANINE GREEN ANGIOGRAPHY

CE on the Internet Quiz

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- 1) ICG is absorbed at _____ nm and emitted at _____ nm.
 - A. 800, 830
 - B. 810, 845
 - C. 805, 835
 - D. 800, 835
 - E. 815, 840

- 2) ICG is _____ than sodium fluorescein and binds _____ to plasma proteins.
 - A. smaller, 90%
 - B. larger, 80%
 - C. larger, 98%
 - D. smaller, 80%
 - E. smaller, 75%

- 3) Side effects associated with ICG include all, except:
 - A. nausea
 - B. circulatory shock
 - C. urine discoloration
 - D. extravasation
 - E. sclerotic vessels

- 4) Anterior segment ICGA is useful in the following conditions, except:
 - A. episcleritis
 - B. rubeosis iridis
 - C. scleritis
 - D. keratoconus
 - E. retinal detachment

- 5) Occult lesions of AMD account for what percentage of newly-diagnosed cases?
 - A. 50%
 - B. 65%
 - C. 75%
 - D. 85%
 - E. 90%

- 6) A _____ is defined as a well-delineated hyperfluorescent area less than 1 disc diameter.
- A. plaque
 - B. mixed lesion
 - C. lacquer crack
 - D. hot spot
 - E. occult choroidal neovascular membrane
- 7) BSRC is characterized by _____ in the early phase and _____ in the late phase of ICGA.
- A. hypofluorescence, hyperfluorescence
 - B. hypofluorescence, hypofluorescence
 - C. hyperfluorescence, hypofluorescence
 - D. hyperfluorescence, hyperfluorescence
 - E. isofluorescence, hypofluorescence
- 8) ICG dye underwent FDA approval in the year _____.
- A. 1950
 - B. 1956
 - C. 1960
 - D. 1966
 - E. 1970
- 9) Generally, 40 mg in _____ mL of aqueous solvent is used for injection.
- A. 2
 - B. 3
 - C. 4
 - D. 5
 - E. 1
- 10) The late (inversion) phase may last anywhere from _____ to _____ minutes.
- A. 5, 10
 - B. 10, 15
 - C. 40, 60
 - D. 15, 40
 - E. 20, 25

THE BASICS OF INDOCYANINE GREEN ANGIOGRAPHY

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- 1. How long have you been employed in the field of ophthalmology? _____ years
2. This written article was designed at a level right for me. (circle one) YES NO
3. Please read the following statements. Then, circle the number corresponding to the degree to which you agree with each statement.

Table with 6 columns: Statement, Strongly Agree, Agree, Disagree, Strongly Disagree, Not Applicable. Rows include statements about material organization, usefulness, and satisfaction.

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Two horizontal lines for writing the answer to question 4.

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