Indocyanine green video-angiography in Neurosurgery: a glance beyond vascular applications.

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Disclosure statement: the authors declare no interest to disclose, they have any personal or institutional financial interest in drugs, materials, or devices described in this submission and that they did not receive any specific funding. The paper and any of its contents have been presented previously

ABSTRACT

Objective:

Indocyanine green video angiography (ICG-VA) is a non invasive, easy to use and a very useful tool for various neurosurgical procedures. Initially introduced in vascular neurosurgery since 2003, it's applications have broadened over time, both in vascular applications and in other neurosurgical fields. The objective of our study is to review all published literature about ICG –VA, cataloguing its different applications.

Methods:

A systematic review of all pertinent literature articles published from January 2003 to May 2014 using Pubmed access was performed using pertinent keywords; cross check of references of selected articles was performed in order to complete bibliographical research. Results of research were grouped by pathology.

Results and Conclusions

The paper systematically analyses ICG-VA different applications in neurosurgery, from vascular neurosurgery to tumour resection and endoscopic applications, focusing on reported advantages and disadvantages, and discussing future perspectives.

Keywords: Indyocianine Green; Video angiography; ICG; ICG-VA

INTRODUCTION

Indocyanine green (ICG) was approved by FDA in 1956 for cardiocirculatory and liver function diagnostic uses and in 1975 for ophthalmic angiography. Raabe et al. in 2003 described for the first time the use of ICG Video Angiography (ICG-VA) in aneurysms surgery; thereafter ICG-VA became very popular in vascular neurosurgery and has also been used in other kind of procedures such as brain tumor surgery[1].

ICG is a near infrared diagnostic dye with an absorption and emission peaks of 805 and 835 nm, respectively. It is given by intravenous route with a recommended dose of 0.2-0.5 mg/kg with a maximum daily dose of 5 mg/kg[2-3]. When administeredit bounds to proteins, mainly globulins, remaining intravascular. The liver deals with its metabolism and excretion. Its half-life is about 3-4 minutes. A NIR (near infrared) sensitive digital camera integrated in themicroscope, allows to see the ICG diffusion in the cerebral vessels. The procedure can be easily repeated after 5 to 10 minutes. Adverse reactions are comparable to those of other types of contrast media, with frequencies of 0.05% (hypotension, arrhythmia, or, more rarely, anaphylactic shock) to 0.2% (nausea, pruritus, syncope, or skin eruptions)[4].

Recently ICG-VA has been also introduced in neurosurgery with an increasing number of potential applications; applications in vascular neurosurgery have significantly broadened over time including complex aneurysms, bypass, atero-venous malformations (AVM) atero-venous fistuals (AVF), evaluation of cortical perfusion. Even if vascular neurosurgery remains the most significant field of application, recent experiences worldwide have shown ICG-VA potential use in a large variety of neurosurgical branches, including oncological surgery, endocscopy, pituitary, cerebral hemodynamic studies.

The aim of our study is to review its uses in neurosurgery as an intraoperative vascular imaging technique and the actual state of the art, in order to give a better and complete comprehension of its resources and to be a cue for future developments.

METHODS

We reviewed articles published from January 2003 to May 2014 usingpubmed access. Articles written in English were included.

Search terms included: Infracyanine green, ICG, Indocyanine green, Intraoperative angiography, bypass patency, extracranial–intracranial bypass surgery, intracranial aneurysm, Videoangiography, brain perfusion, cerebral blood flow. Cross check of references of the selected articles was performed in order to complete bibliographical research.

Results were grouped on the basis of pathology. For each group advantages and disadvantages of the ICG-VA were reported and discussed.

RESULTS

A total of 71 articles from Pubmed access were collected and analyzed. 4 of these were review articles focusing only on vascular applications. The other 67 articles were grouped in 3 main categories: Vascular (45 articles, divided into 4 subgroups: 19 Aneurysms, 7 AVMs, 8 Bypasses, 8 Arterovenous Fistulas (AVFs) and 3 Cavernomas), Tumors (16 articles) and Other applications (6 articles). Results are reported in **Table 1**.

VASCULAR – Aneurysms

We reviewed 19 articles published between 2003 and May 2014 [1, 5-22].

The first systematic report on ICG-VA application in cerebral aneurysm surgery study was published in 2003 by Raabeet al.[1]. Following this preliminary experience, several consistent patient series were published on ICG-VA use in aneurysm surgery by Roessler in 2014[21], Dashti-Hernesniemi in 2009[13], Raabe- Spetzler in 2005[15], Ozgiray[16] and Washington [5] in 2013 and include respectively 232, 190, 114, 109 and 155 patients. ICG is often compared to micro-doppler and digital subtraction angiography (DSA) to evaluate vascular anatomy, before and after clipping, and to assess correct position of the clip, presence of aneurysm residuals, patency of normal vessels. Few studies focused specifically on paraclinoid aneurysms[10, 19] and on quantitative blood flow study[7, 12, 18](which allows an objective evaluation of the results rather than the subjective assessment of fluorescence using ICG–VA). One interesting paper reports about a patient suffering from a giant aneurysm of the right MCA; indocyanine green was injected inside the aneurysm in order to identify a target middle cerebral artery branch (MCA) for bypass and allowing confident preservation of blood supply to distal areas to the sacrificed vessel [11]. The study published by Roessler[21] including 295 cases is nowadays the largest published series on this topic. They reported a repositioning of aneurysm clips in 9% of the procedures because of parent vessel or adjacent perforating arteries occlusion not detected by micro-Doppler ultrasonography. Moreover in 4.5% of the procedures residual perfusion was detected and one or more clips were applied. Nevertheless postoperative angiography in 9.1 % of successful ICG - VA guided clip applications demonstrated unexpected residual aneurysms. A very interesting study was published by Hardesty et al. [22] where a comparison between 2 "eras", the intraoperative DSA one and the ICG-VA. They retrospectively evaluated whether the rates of perioperative stroke, unexpected ostoperative aneurysm residual, or parent vessel stenos is differed in 100 patients from each era.

The issue of per-patient cost of intraoperative imaging was also estimated ina study published by Nishyama et al. (patients undergoing ICG - VA and endoscopy in order to facilitate intraoperative real-time assessment of the patency of perforating arteries behind parent arteries or aneurysms) [9]. In a more recent paper by Bruneau, endoscopic ICG-VA was used in anterior communicating artery aneurysm clipping providing information regarding aneurysm occlusion and patency of parent and branching vessels and small perforating arteries [6].

VASCULAR – AVMs

AVMs surgery is complex and contemplate few steps, starting from the localization of the malformation to the identification of arterial feeders and draining veins. 7 articles have been published about ICG and AVMs[23-29], the first one was by Takagi et al.[28] in 2007 where ICG-VA was used to evaluate the complete exclusion of an AVM in a child. Zaidi and Spetzler in 2014 published a retrospective chart review done for all patients undergoing resection of an AVM between 2007 and 2013. A total of 130 cases (56 ICG, 74 non-ICG) were identified [29]. Other important series have also been published by Takagi-Myamoto in 2011 on 11 patients[25], and by Ng et al. in 2013 on 24 patients [23]where ICG – VA was compared to pre and post feeding arteries clipping and post dissection DSAs.

VASCULAR - Bypasses

The flow evaluation in bypass surgery is of primary importance. We reviewed 8 articles[30-37]: the most important studies were published by Woitzik[33]and Schuette[31] respectively on 40 and 47 patients. Different kind of bypass were included STA-MCA OA – PICA, radial artery, saphenous vein, IC – IC, STA – PCA.

Some studies focused on possible ICG-VA application after bypass surgery to evaluate flow. Awano et al [35] recently analyzed the ICG perfusion area at the pointat which fluorescence intensity reached the maximum level and measuring cortical oxygen saturation before anastomosis by means of visual light spectroscopy.

An interesting study was made by Januszewski et al[36]on 39 patients, where 3 different pattern on ICG-VA angiography are established and correlated to bypass patency in the next 24-48 hours. Type I,(86%) robust anterograde flow; Type II (11%), delayed flow compared with that in other vascular structures but patent and anterograde; or Type III (3%), anterograde flow but delayed with no continuity to the bypass site or no convincing flow.

Prinz et al published on the potential application of ICG-VA in the assessment of hemodynamic changes within the macrocirculation and microcirculation after bypass surgery on 30 cases, by the use of a microscope-integrated software tool for instant color-coded visualization and analysis of the temporal distribution dynamics of the fluorescent ICG (FLOW 800)[37].

VASCULAR- AVFs

The treatment of cranial and spinal AVFs currently consists of an occlusion of the fistulous site. 8 studies have been published about the use of ICG – VA in the AVFs treatment[2, 31, 38-43]: the first and one of the most important series have been published by Schuette – Barrow in 2010 on 25 patients (13 cerebral and 12 spinal)[8]. Other studies included a lower number of patients[2, 38, 40-42].

Fontes et al. recently published ICG-VA application as a tool in a minimally invasive approach for ligation of dural AVFs[39].

VASCULAR- Cavernomas

Overall 3 studies were published about cavernomas[44-46]. The largest spinal series is by Endo et al who published a retrospective review of 8 cases who had undergone surgery for intramedullary cavernomas, concluding that ICG provided useful information about lesion margins and associated venous anomalies [45]. Murakami [34] reported his experience on cerebral and orbital cavernous malformation in 9 patients, while Murai [33] reported a pioneer case of ICG-VA application in the resection of optic-cavernous angioma.

TUMORS

One of the first experiences about ICG – VA use during tumor resection has been published since 2010 by Bruneau[47]et al. about the use of ICG-VA for vertebral artery evaluation during tumor resection. The largest series has been published by Ferroli [48]and Broggi[49] respectively including 153 and 100 patients.

We reviewed an overall of 16 studies on this topic, in which ICG-VA was used in the identification of tumor related vessels, normal brain parenchima vessels, bridging veins, tumor margin infiltration[8, 47-62]. A study by Litvack et al. reports an experience in endoscopic surgery with the use of ICG-VA for visual differentiation of pituitary tumor from surrounding structures in 16 patients [57]. One other study by Tamura et al. reports on its use for the identification of feeding vessel in hemangioblastoma resection[58]. Specifically concerning haemangioblastoma Benedetto et al., Hao et al. and Hojo et al published respectively a single spinal cases, seven spinal casesand twelve brain/spinal cases in which they used ICG to detect minimal changes in the vascular supply during the dissection, improving the capability to detect changes in vascular patterns [55-56, 59]. Della Puppa et al. reviewed 43 patients who underwent intraoperative ICG –VA for parasagittal meningioma surgery at different surgical stages (before dural opening, after dural opening, during resection, after resection) [62]. The authors conclude that ICG - VA is useful also in parasagittal meningiomas when venous preservation is strictly connected to both extent of resection and clinical outcome [62].

OTHER APPLICATIONS

Others potential uses of ICG – VA have been experimented and reported. We reviewed 5 articles[63-67]: Faber et al. [24] was the first to attempt a quantitative flow evaluation in 2 patients suffering from AVMs, while Kamp et al.[66] realized such assessment on 30 patients, suffering from different kind of pathologies (intracranial tumors with involvement of cerebral vessels, aneurysms, intracerebral hemorrhage and arteriovenous malformation, sDAVF, extra- /intracranial bypass procedures).

Czbanka[63] analyzed cortical microvascularization using ICG – VA in patients suffering from Moya-Moya disease. A further experience on evaluation of microvascularisation was published by Woitzik in 2006 [67].

ICG-VA was also applied in 6 patients undergoing decompressive craniectomy and allowed to evaluate the superficial vascular anatomy: authors concluded that appears to be a valuable tool to precisely detect relative cortical tissue perfusion, providing useful research data on the pathophysiology of human stroke, helping surgeons to maintain adequate brain perfusion intraoperatively, and simplify adequate placement of tissue probes to monitor critically hypoperfused brain tissue.

One other singular application was published by Wacther at al in 2013 who introduced endoscopic ICG angiography in endoscopic third-ventriculostomy (ETV) for intraoperative visualization of the basilar artery and its perforators to reduce the risk of vascular injury[64].

DISCUSSION

ICG – VA use has been recently spreading in neurosurgery. The first application was in neurovascular surgery, because it was born as an intravascular tracer for vessels visualization[12]; this has been really useful in aneurysms, AVMs and dural fistulas surgery where identification, obliteration or patency of vessels is essential.

Thanks to its quickness and noninvasiveness and providing real-time information it has become an invaluable tool to intraoperative surgical decision-making and it has been widely proved that its accuracy can be totally compared to intraoperative DSA or microdoppler[25, 28]. Potential applications in vascular neurosurgery have significantly broadened over time; in addition, recent experiences have shown ICG-VA potential use in a very different set neurosurgical branches, including oncological surgery, endocscopy, pituitary, cerebral hemodynamic studies.

Aneurysms

During aneurysms surgery its use is already consolidated, it’s easy, rapid to perform and non invasive[12]; it has a good spatial resolution[13-14] and allows a good evaluation of the complete aneurysm exclusion, neck remnant, blood flow in the parent arteries and perforating arteries [12, 14]. On the other hand it has a limited view to the operating field [12, 19]and in presence of blood clots, intramural thrombi, or calcifications [25], it can give a limited ability to visualize the part of the base behind the aneurysm dome in deeply located aneurysms[13, 30].A percentage of unexpected neck residuals and close vessels occlusion has been reported (6% in the theDashti-Hernesniemi study)[13]. Similarly the recent large aneurysm series by Ozgiray[16] et al and Washingtonet al [5]display a persistent residual flow in the aneurysm respectively in 5% and 4%. Roessler presented the largest series on aneurysm surgery[21]. Despite confirming the several advantages of the technique, in particular for intraoperative clip modification (15%),clearly highlights its limits. In particular he reported ICG -VA missed small, < 2-mm-wide neckremnants and a 6-mm residual aneurysm in up to 10% of patients. His conclusion is that in complex aneurysm, when hidden parts of the parent, branching, and perforator vessels as well as undissected parts of the aneurysm dome are more difficult to visualize by ICG -VA, DSA is still mandatory[21].

Conversely, the study by Hardesty et al. comparing 100 patients respectively from intraoperative DSA and ICG-VA eras, didn't report any difference about unexpected aneurysm filling (4% vs 2%), parent vessel compromise (2% vs 2%), and perioperative strokes(4% vs 3%)[22]. Intraoperative ICG-VA is considered a valuable but primarly cost-effective replacement to routine intraoperative diagnostic angiography. Nevertheless postoperative DSA still cannot be avoided because of a remaining little percentage of inaccuracy of both intraoperative techniques[22]. Thus, care should be taken when considering ICG- VA as the sole means for intraoperative evaluation of aneurysm clip application.

However, some of these obstacles have been attempted to overcome by recent endoscopic applications in aneurysm surgery. The paper published by Bruneau et al [6]demonstrate how some limitations of microscopic ICG-VA (such deeper areas, including the aneurysm sac/neck posterior side, or areas hidden by the aneurysm, clips, or surrounding structures) can be overcame by endoscope ICG-VA that allows a wider area of visualization, thus providing relevant information regarding aneurysm occlusion and patency of parent and branching vessels and small perforating arteries, improving the ability to view less accessible regions, especially posterior to the aneurysm clip.

Bypass

In bypass surgery ICG – VA has always had a leading role: it has been used in all kind of bypasses[30-31, 33] because of its high definition and online information on graft patency[31]and the rapid identification of the parent and recipient arteries[30-31]. The main disadvantage is the limited visualization restricted to the operating field. The next step is the availability of quantitative and qualitative evaluation of blood flow. Recent pioneer experiences have been reported on bypass-surgery with regards to semi-quantitative analysis for cortical perfusion assessment: Awano et al. measured ICG perfusion area in order to monitor hemodynamic changes caused by bypass surgery in MoyaMoya disease and non-moyamoya ischemic stroke for improving postoperative management [35].

Also the study by Januszewski et al. [36]attempted to establish classification not only evaluating EC- IC and IC-IC graft patency , but also establishing the type of flow through the bypass graft, that authors divided into three main categories. Type I flow (robust anterograde flow) strongly correlates with early postoperative graft patency. Type II (anterograde flow but delayed compared to other adjacent vascular structures) and Type III (anterograde flow but delayed with no continuity to the bypass site) are both predicative of early graft failure and need to be intraoperative revised in order to avoid postoperative complications.

Recently Prinz et al [37] published the potential application of ICG-VA in the assessment of hemodynamic changes within the macrocirculation and microcirculationafter bypass surgery, by the use of a microscope-integrated software tool for instant color-coded visualization and analysis of the temporal distribution dynamics of the fluorescent ICG (namely FLOW 800, Carl Zeiss, Oberkochen, Germany)[37]; currently, thereis no routine method offering intraoperative visualization and quantitative measurement of cortical microcirculatory perfusion in high-temporospatial resolution. Instant color-coded-mapping of hemodynamic parameters permits high-resolution visualization of the vasculature within the imaging field and allows immediate interpretation, which could be very helpful for the selection of a suitable recipient vessel particularly during bypass surgery [37]. However, it should be underlined that Flow 800 is not capable of continuous real-time assessment of flow, and thus it appears useful mainly for comparison before and after a treatment and for regional comparison within the same patient, but not for quantitative flow assessment [37]. Very interesting is the application of the FLOW 800 tool in the assessment or quantification of acute hypoperfusion after SAH, in order to predict outcome and adjust intraoperative therapies, recently proposed by Shubert et al[68].

AVM/AVF

In AVMs surgery ICG – VA is considered to give a moderate contribution. As reported in the paper by Zaidi and Spetzler [29] it can be useful for the intraoperative mapping of the angio-architecture of superficial AVMs; it gives the possibility to visualize flow variations directly on surgical field and to confirm the occlusion of nidus feeding arteries. Unfortunately is considered uselessness in the residual detection [28], and the difficult visualization in deep located AVMs [25]could limit its application. Indeed in the most important series (56 patients) published by Zaidi and Spetzler, do not report any difference between patients undergoing or not ICG-VA in terms of residual disease or clinical outcomes. Similarly they also consider ICG-VA quite unuseful for deep seated lesions[29].

In dAVFs surgery, one of the most important step is the correct identification of fistulous site.main reported advantages are: the 100% correspondence to postoperative controls[38], the identification of the fistulous site and confirmation of its obliteration during surgery [38, 40]and the possibility to identify both the early-filling fistula and the presence of abnormal retrograde drainage thanks to the visualization of the timing and direction of blood flow[40].

Main reported disadvantages are: the increase of operating time[38]and the limited visualization to the operating field with a need to fully expose the fistula[2, 38].

Tumors

A recent application of ICG - VA has been in tumors resection. The 2 most important studies have collected an impressive number of patients (153 and 100)[48-49]and show several advantages that can surely improve surgical outcome:the possibility to recognize potential anastomotic circle in order to avoid brain damages and preventing venous infarction in normal brain parenchima during tumor resection. In the peritumoral vessels identification [47, 54] ICG-VA allows to distinguish if it's a tumor- related or a normal passing-by vessel and to check on the patency of blood vessels around a tumor in order to avoid brain infarction. Other authors also suggest a potential application in the evaluation of the patency of perforating arteries, or of the vertebral artery after manipulation during vertebral artery region surgery are reported. ICG –VA also allows the bridging veins evaluation in parasagittal meningiomas resection [54].

Inintramedullary spinal lesions resection it clearly depicts the posterior median sulcus separating the two fasciculi gracili, therefore allowing a safe myelotomy to approach the lesion and the discrimination between feeding and draining vasculature of the tumor[8]. Endo et al. reported their experience on intramedullary cavernomas, where ICG-VA provided useful information for the detection of lesion margins and possible venous anomalies.ICG contributed to reach a safe and complete removal of the cavernoma's by visualizing the venous structure[45].

Finally it also allows to detect the tumor margins[3, 51], a new application that could be really innovative especially for malignant gliomas resection, distinguishing features of normal brain and tumor regions, potentially providing information about the border on the histological magnification[51].

On vascular tumors surgery such as hemangioblastomas ICG-VA has been introduced as a supporting tool during resection. It can provide real-time information about the tumor vasculature during surgery and help in intraoperative decision-making, as interpretation of dynamic images of tumor blood flow can be useful for discrimination of transit feeders and also for estimation of unexposed feeders covered with brain parenchyma[55]. Post-resection ICG-VA could confirm complete tumor resection and normalized blood flow in surrounding vessels[55-56, 59].

ICG-VA found a good application also in parasagittal meningioma surgery, as reported by Della Puppa et al[62]. Using it in a multistep model, can guide the vein management and tumor resection strategies with a favorable final clinical outcome. ICG-VA specifically affected surgical strategy in 20% of cases. However authors in order to maximally improve function preservation still consider of paramount importance a multitask approach (ICGVA, functional monitoring, temporary venous clipping, flow measurements)[62].

Other applications

ICG has been also introduced in endoscopic pituitary surgery: Pituitary adenomas have a different vascular capillarity and ICG fluorescence endoscopy can distinguish the tumor from normal tissues, identifying areas of dural invasion and facilitating a complete resection[57].

Thanks to its non invasiveness, easiness to perform and the very low rate of adverse reactions, ICG – VA is being tested in several application like Moya-Moya disease where it demonstrated a significantly increased microvascular density and microvascular diameter, leading to increased microvascular surface that might represent a disease specific compensation mechanism for impaired cerebral blood flow[63].

For patients undergoing decompressivecraniectomy, ICG – VA allowed to evaluate the superficial vascular anatomy and leptomeningeal anastomosis patency[67]. It appears to be a valuable tool to precisely detect relative cortical tissue perfusion, providing useful research data on the pathophysiology of human stroke, helping surgeons to maintain adequate brain perfusion intraoperatively, and simplify adequate placement of tissue probes to monitor critically hypoperfused brain tissue.

Probably for cavernomas surgery ICG-VA still lack an importance in terms of real benefits. Published studies enrolled a low number of patients, and because cavernomas are often deep seated lesions surrounded by normal brain parenchima, the vision is very limited. So the value of ICG in brain cavernomas is highly debatable.

Future Perspectives

Conventional ICG-VA allows evaluation of vessel patency but, unfortunately, does not allow quantitative, time-dependent and spatially precise analysis of intravascular blood flow. In fact, conventional ICG-VA gives information about vessel patency but not quantitative, time-dependent and spatially precise analysis of intravascular blood flow[14].Faber et al. [24]and Kamp et al.[66] thanks to the FLOW 800 imaging software (Carl Zeiss Surgical, Oberkochen, Germany) managed to create overview maps where ICG fluorescence was translated into colours from red (early appearance) to blue (late appearance). They developed color-coded maps of time to half-maximal peak that appeared to be of value for giving an overview of blood flow perturbations and distribution by extracting data already contained in conventional ICG-VA [25]. These studies could be a good springboard for the ICG – VA use for blood flow quantification and the shown methods be re-proposed for further studies enrolling more patients.

One other interesting potential ICG application has been proposed during craniotomy after acute SAH, to evaluate cerebral hemodynamic alterations. The first minutes and hours after SAH are predictive of overall outcome and important for the prognosis [68-69]. Cerebral blood flow (CBF) changes appear to play a pivotal role in the acute phase, but intraoperative estimation of CBF still poses a significant challenge, whileat the same time, it could potentially influence and improve clinical management [68, 70]. Shubert et al [68] recently published their research on the use of cortical ICG in the setting of acute SAH as it provides evidence of acute vasoconstriction after emorrhage, but more importantly provides a measurement of CBF intraoperatively (by means of measurement of reflected tissue signal analyzed using the Flow 800 software analysis tool)[68]. Monitoring of perfusion changes before and after intraoperative therapeutic interventions may represent an additional prospective application: it would be valuable to detect decreases in CBF and resultant brain ischemia during aneurysm surgery, particularly after specific maneuvers like application of a temporary clip or imperfect application of a permanent clip. Conversely, it would be valuable to quantitatei ncreases in CBF after initiation of flow in a bypass.

Recently, ICG-VA has been also used for endoscopic procedures, like in the study published by Nishyama et al.[9]for endoscopic-assisted aneurysm surgery, where the association of endoscopic view to standard microscopic one allows a better observation of perforating arteries, that often, because their deepness, are not visible to the sole microscopic view. ICG-VA has been also proposed for other endoscopic applications such as ETV for intraoperative visualization of the basilar artery and its perforators to reduce the risk of vascular injury, especially in the presence of aberrant vasculature, a nontranslucent floor of the third ventricle, or in case of re-operations [64].

Conclusions

From our review of the pertinent literature we can conclude that ICG-VA has reached in recent years a wide utilization in various neurosurgical fields, mainly in neurovascular surgery. The technique allows future developments such as quantitative evaluation of cerebral blood flow or the combined use with the endoscope. It should be considered among the most promising easy and low cost tools towards the direction of a minimally invasive and safer neurosurgery.

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Table 1: Details of published literature concerning applications of ICG-VA in Neurosurgery.

Vascular – Aneurysm

Year	Authors	Title	N° pts
2014	Roessler	Essentials in intraoperativeindocyanine green videoangiographyassessment for intracranialaneurysmsurgery: conclusions from 295 consecutivelyclippedaneurysms and review of the literature	232
2014	Hardesty	Safety, efficacy, and cost of intraoperativeindocyanine green angiographycompared to intraoperativecatheterangiography in cerebralaneurysmsurgery	200
2013	Washington	Comparing indocyanine green videoangiography to the gold standard of intraoperative digital subtraction angiography used in aneurysm surgery.	155
2013	Özgiray	How reliable and accurate is indocyanine green video angiography in the evaluation of aneurysm obliteration?	109
2013	Bruneau	Endoscope-integrated ICG technology: first application during intracranial aneurysm surgery.	1
2013	Son	Quantitative analysis of intraoperative indocyanine green video angiography in aneurysm surgery	16
2012	Schubert	Cortical ICG Videography for Quantification of Acute Hypoperfusion After Subarachnoid Hemorrhage – A Feasibility Study.	25
2012	Nishiyama	Endoscopic indocyanine green video angiography in aneurysm surgery: an innovative method for intraoperative assessment of blood flow in vasculature hidden from microscopic view	3
2011	Murai	Intraoperative Matas test using microscope-integrated intraoperative indocyanine green videoangiography with temporary unilateral occlusion of the A1 segment of the anterior cerebral artery.	5
2011	Jumpei Oda	Intraoperative near-infrared indocyanine green–videoangiography (ICG–VA) and graphic analysis of fluorescence intensity in cerebral aneurysm surgery	39
2011	Seifert	Exclusively intradural exposure and clip reconstruction in complex paraclinoid aneurysms	62
2010	Bain	Targeted extracranial-intracranial bypass with intra-aneurysmal administration of indocyanine green: case report.	1
2010	Fischer	Near-infrared indocyanine green videoangiography versus microvascular Doppler sonography in aneurysm surgery	50
2009	Xu	Microsurgical management of large and giant paraclinoid aneurysms	51
2009	Chi-Yuan Ma	Intraoperative indocyanine green angiography in intracranial aneurysm surgery: Microsurgical clipping and revascularization	45
2009	Dashti	Microscope-integrated near-infrared indocyanine green videoangiography during surgery of intracranial aneurysms: the Helsinki experience	190
2007	de Oliveira	Assesment of flow in perforating arteries during intracranial aneurysm surgery using intraoperative near-infaredindocyanine green videoangiograhy	60
2005	Raabe	Prospective evaluation of surgical microscope–integrated intraoperative near-infrared indocyanine green	114

Table 1: Details of published literature concerning applications of ICG-VA in Neurosurgery.

		videoangiography during aneurysm surgery	
2003	Raabe	Near-infrared indocyanine green videoangiography: a new method for intraoperative 2ssessment of vascular flow	14

Vascular – Bypass

2014	Januszewski	Flow-based evaluation of cerebral revascularization using near-infrared indocyanine green videoangiography	33
2014	Prinz	FLOW 800 Allows Visualization of Hemodynamic Changes After Extracranial-to-Intracranial Bypass Surgery but Not Assessment of Quantitative Perfusion or Flow	30
2013	Uchino	Semiquantitative analysis of indocyanine green videoangiography for cortical perfusion assessment in superficial temporal artery to middle cerebral artery anastomosis.	7
2012	Esposito	Selective-targeted extra-intracranial bypass surgery in complex middle cerebral artery aneurysms: correctly identifying the recipient artery using indocyanine green videoangiography.	7
2011	Schuette	Indocyanine Green Videoangiography for Confirmation of Bypass Graft Patency	47
2011	Rodríguez - Hernandez	Flash Fluorescence with ICG Videoangiography to Identify the Recipient Artery for Bypass with Distal Middle Cerebral Artery Aneurysms:operative technique.	3
2010	Awano	Intraoperative EC-IC bypass blood flow assessment with indocyanine green angiography in moyamoya and non-moyamoya ischemic stroke.	34
2005	Woitzik	Intraoperative control of extracranial–intracranial bypass patency by near-infrared indocyanine green videoangiography	40

Vascular – AVM

2014	Zaidi - Spetzler	Indocyanine green angiography in the surgical management of cerebralarteriovenousmalformations: lessonslearned in 130 consecutive cases.	56
2013	Ng	Uses and limitations of indocyanine green videoangiography for flow analysis in arteriovenous malformation surgery.	24
2012	Takagi	Evaluation of serial intraoperative surgical microscope-integrated intraoperative near-infrared indocyanine green videoangiography in patients with cerebral arteriovenous malformations	11
2011	Faber	Enhanced analysis of intracerebralarterioveneous malformations by the intraoperative use of analytical indocyanine green videoangiography: technical note	2
2010	Hänggi	The impact of microscope-integrated intraoperative near-infrared indocyanine green videoangiography on surgery of arteriovenous malformations and dural arteriovenous fistulae.	17

Table 1: Details of published literature concerning applications of ICG-VA in Neurosurgery.

2010	Ferroli	ArteriovenousMicromalformation of the Trigeminal Root: Intraoperative Diagnosis With Indocyanine Green Videoangiography: Case Report	1
2007	Takagi	Detection of a residual nidus by surgical microscope- integrated intraoperative near-infrared indocyanine green videoangiography in a child with a cerebral arteriovenous malformation	1

Vascular – AVF

2013	Fontes	Minimally invasive treatment of spinal dural arteriovenous fistula with the use of intraoperative indocyanine green angiography	1
2013	Holling	Dynamic ICG Fluorescence Provides Better Intra-operative Understanding of Arterio-venous Fistulas.	5
2013	SimalJulián	Indocyanine green videoangiography "in negative": definition and usefulness in spinal dural arteriovenous fistulae.	4
2012	Yamamoto	Selective intraarterial injection of ICG for fluorescence angiography as a guide to extirpate perimedullaryarteriovenous fistulas.	1
2011	Horie	IntraarterialIndocyanine Green Angiography in the Management of Spinal Arteriovenous Fistulae	2
2011	Oh	Intraoperative Indocyanine Green Video-Angiography: Spinal Dural Arteriovenous Fistula	1
2010	Schuette	Indocyanine Green Videoangiography in the Management of Dural Arteriovenous Fistulae	25
2010	Hanel	Use of Microscope-Integrated Near-Infrared Indocyanine Green Videoangiography in the Surgical Treatment of Spinal Dural Arteriovenous Fistulae	6

Vascular – cavernoma

2013	Endo	Use of microscope-integrated near-infrared indocyanine green videoangiography in the surgical treatment of intramedullary cavernous malformations: report of 8 cases	8
2012	Murakami	An analysis of flow dynamics in cerebral cavernous malformation and orbital cavernous angioma using indocyanine green videoangiography	9
2011	Murai	Indocyanine green videoangiography of optic cavernous angioma - case report	1

Vascular- Review

2011	Balamurugan	Intra operative indocyanine green video-angiography in cerebrovascular surgery: An overview with review	-

Table 1: Details of published literature concerning applications of ICG-VA in Neurosurgery.

		of literature	
2011	Chen	The application of intraoperative near-infrared indocyanine green videoangiography and analysis of fluorescence intensity in cerebrovascular surgery	-
2011	Dashti	Microscope integrated indocyanine green video-angiography in cerebrovascular surgery.	-
2010	Dashti	Application of microscope integrated indocyanine green video-angiography during microneurosurgical treatment of intracranial aneurysms: a review.	-

Tumors

2014	Della Puppa	Application of indocyanine green video angiography in parasagittalmeningiomasurgery	43
2013	Benedetto	Use of near-infrared indocyaninevideoangiography and Flow 800 in the resectioning of a spinal cord haemangioblastoma.	1
2013	Hojo	Usefulness of Tumor Blood Flow Imaging by Intraoperative Indocyanine Green Videoangiography in Hemangioblastoma Surgery	
2013	d'Avella	Indocyanine green videoangiography (ICGV)-guided surgery of parasagittal meningiomas occluding the superior sagittal sinus (SSS).	5
2013	Torres	Indocyanine Green for Vessel Identification and Preservation Prior to Dural Opening for Parasagittal Lesions.	2
2013	Hao	Application of intraoperative indocyanine green videoangiography for resection of spinal cord hemangioblastoma: Advantages and limitations	7
2012	Tamura	The use of intraoperative near-infrared indocyanine green videoangiography in the microscopic resection of hemangioblastomas.	9
2012	Litvack	Indocyanine green fluorescence endoscopy for visual differentiation of pituitary tumor from surrounding structures.	16
2011	Ferroli	Venous sacrifice in neurosurgery: new insights from venous indocyanine green videoangiography	153
2011	Ferroli	Application of intraoperative indocyanine green angiography for CNS tumors: results on the first 100 cases.	100
2011	Eui Hyun Kim	Application of intraoperative indocyanine green videoangiography to brain tumor surgery	23
2011	Ferroli	Indocyanine Green (ICG) Temporary Clipping Test to Assess Collateral Circulation Before Venous Sacrifice	2
2011	Nussbaum	The Use of Indocyanine Green Videoangiography to Optimize the Dural Opening for Intracranial Parasagittal Lesions	3
2011	Martirosya	Use of in vivo near-infrared laser confocal endomicroscopy with indocyanine green to detect the boundary of infiltrative tumor	30

Table 1: Details of published literature concerning applications of ICG-VA in Neurosurgery.

2011	Schubert	ICG Videography Facilitates Interpretation of Vascular Supply and Anatomical Landmarks in Intramedullary Spinal Lesions	2
2010	Bruneau	Preliminary Personal Experiences With the Application of Near-Infrared Indocyanine Green Videoangiography in Extracranial Vertebral Artery Surgery	9

Others

2013	Wacther	Indocyanine Green Angiography in Endoscopic Third Ventriculostomy	11
2012	Schubert	CorticalIndocyanine Green Videography for Quantification of Acute HypoperfusionAfterSubarachnoidHemorrhage: A FeasibilityStudy	25
2012	Kim	Indocyanine-Green Videoangiogram to Assess Collateral Circulation Before Arterial Sacrifice for Management of Complex Vascular and Neoplastic Lesions.	4
2011	Kamp	Microscope integrated quantitative analysis of intra-operative indocyanine green fluorescence angiography for blood flow assessment:First experience in 30 patients	30
2008	Czbanka	Characterization of Cortical Microvascularization in Adult Moyamoya Disease	16
2006	Woitzik	Cortical Perfusion Measurement by Indocyanine-Green Videoangiography in Patients Undergoing Hemicraniectomy for Malignant Stroke	6