

Venous sacrifice in neurosurgery: new insights from venous indocyanine green videoangiography

Clinical article

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Object. The purpose of this paper is to evaluate whether venous indocyanine green (ICG) videoangiography has any potential for predicting the presence of a safe collateral circulation for veins that are at risk for intentional or unintentional damage during surgery.

Methods. The authors performed venous ICG videoangiography during 153 consecutive neurosurgical procedures. On those occasions in which a venous sacrifice occurred during surgery, whether that sacrifice was preplanned (intended) or unintended, venous ICG videoangiography was repeated so as to allow us to study the effect of venous sacrifice. A specific test to predict the presence of venous collateral circulation was also applied in 8 of these cases.

Results. Venous ICG videoangiography allowed for an intraoperative real-time flow assessment of the exposed veins with excellent image quality and resolution in all cases. The veins observed in this study were found to be extremely different with respect to flow dynamics and could be divided in 3 groups: 1) arterialized veins; 2) fast-draining veins with uniform filling and clear flow direction; and 3) slow-draining veins with nonuniform filling. Temporary clipping was found to be a simple and reversible way to test for the presence of potential anastomotic circulation.

Conclusions. Venous ICG videoangiography is able to reveal substantial variability in the venous flow dynamics. “Slow veins,” when they are tributaries of bridging veins, might hide a potential for anastomotic circulation that deserve further investigation. (DOI: 10.3171/2011.3.JNS10620)

KEY WORDS • cerebral veins • cerebrovascular neurosurgery •
indocyanine green angiography • surgical technique

VENOUS sacrifice in neurosurgery can lead to devastating consequences.¹⁹ The attention that the neurosurgical community has paid to this issue has been minimal, and nothing new has been added to the literature that might allow the surgeon to predict the consequences of venous sacrifice for a specific patient. The general trend in recent years has been for neurosurgeons to avoid the question of “sacrifice” whenever and wherever possible. Interestingly enough, venous sacrifice may actually prove to be desirable under certain circumstances: 1) as a way of increasing the exposure of a targeted pathological site; or 2) as a means of allowing for a more radical tumor resection. Nevertheless, the results of intended or unintended venous sacrifice are unpredictable, particularly because we lack an intraoperative method that would provide reliable data to determine the presence of venous collateral circulation.^{2,30} Recently, microscope-integrated near-infrared ICG videoangiography has been employed during vascular neurosurgery as

a means of visualizing the arterial flow during aneurysm clipping, bypasses, and treatment of vascular malformations.^{3,4,8,9,13,16,21,22} There is, however, a paucity of data that have shed any light on the dynamics of venous ICG videoangiography.^{6,7,10,14} The purpose of this paper is to evaluate whether venous ICG videoangiography has any potential to be able to predict the presence of a safe collateral circulation for veins that are at risk for intended or unintended damage.

Methods

In a 3-year period (between December 2006 and December 2009), 221 patients underwent ICG videoangiography during standard craniotomies for treatment of tumors and/or vascular malformations at our institution. All of these procedures followed the standard protocol that has been described elsewhere.^{20–22} Written informed consent was obtained from all patients. In all cases, ICG was administered intravenously by an anesthesiologist (25 mg in 5 ml of saline). After a few seconds, vessel fluorescence appeared under the microscope (Pentero, Carl Zeiss Co.) and was cleared within 10–15 minutes, which

Abbreviations used in this paper: ICG = indocyanine green; ROI = region of interest.

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allowed for additional injections, when required. The resulting video was shown on the microscope screen in the operative room during surgery and recorded for further visualizations; it allowed us to visualize arterial, capillary, and venous phases. We performed ICG videoangiography in 153 of these 221 patients (63 with high-grade gliomas, 18 with low-grade gliomas, 16 with metastatic lesions, 29 with meningiomas, 7 with arteriovenous dural fistulas, 5 with arteriovenous malformations, 8 with cavernous angiomas and associated development venous anomalies, 3 with hemangioblastomas, 1 with a central neurocytoma, and 3 undergoing microvascular decompression for trigeminal neuralgia) with the specific aim of evaluating the venous phase, which was always recorded for at least 2 minutes. On those occasions in which a venous sacrifice was performed during surgery, whether that sacrifice was preplanned (intended) or unintended, venous ICG videoangiography was repeated so as to allow us to study the effects of venous sacrifice. For an intended sacrifice of bridging veins (either to enlarge the surgical corridor or to obtain a more radical tumor resection) we designed a specific test that would provide us with information on venous circulation. This test was conducted in 8 cases (7 for venous tributaries of the superior sagittal sinus, 1 for a petrosal vein draining into the superior petrosal sinus). The test was performed as follows: after a baseline ICG videoangiogram was obtained, a temporary clip (or more simply the closed tips of bipolar forceps) was placed on the vein to be tested and flow direction and dynamic were again analyzed by ICG videoangiography (ICG temporary clipping test). Flow stagnation was considered to be a sign of lack of collateral circulation whereas flow reversal was interpreted as a sign of the presence of collateral circulation.

In the last 6 of these patients we used the Flow 800 software (Carl Zeiss) to conduct both our data analysis and postprocessing. Flow 800 is a software upgrade that can be implemented on the same microscope (Pentero, Carl Zeiss) used for the classic ICG videoangiography, providing a semiquantitative analysis of vascular blood flow dynamics. This method allowed us to visualize temporal fluorescence projection of vessel dynamics on a map in which red color represents the initial blood flow followed by a graded color scale for subsequent blood flow sequences. A pinpoint analysis that freely positions up to 8 ROIs can then be performed. This allows us to visualize the change of blood flow, over time, in a particular ROI (Fig. 1A–D, F, and G).

Results

Venous ICG videoangiography allowed for intraoperative real-time flow assessment of the exposed veins with excellent image quality and resolution in all cases. We found the veins we observed to be extremely different insofar as their flow dynamics were concerned. In the last 6 of the 8 cases we studied during the clipping test, postprocessing with Flow 800 allowed us to make a semiquantitative comparison of different flow patterns in the veins we observed. With this method we were able to observe these patterns at different moments in time (Fig. 1).

Arterialized Veins

These veins are easily recognizable, even without ICG videoangiography, because of their red color (Fig. 2A). We found these arterialized veins in vascular malformations but also in glioblastomas, hemangioblastomas, metastases, and more rarely in meningiomas. The use of ICG enabled us to show flow direction in all of these cases. In the early phases of filling, different streams (Fig. 2B–D and Video 1) that were directly related to the position of arterial inflow could be seen.

VIDEO 1. ICG videoangiography in a case of glioblastoma (also described in Fig. 2) detecting different filling times in a vein, related to multiple direct arteriovenous fistulas from the tumor. [Click here to view with Windows Media Player.](#) [Click here to view with Quicktime.](#)

After surgical exclusion of the arterial inflow the vein flow dynamics changed dramatically. We were also able to demonstrate venous thromboses when they occurred.

Fast-Draining Veins With Uniform Filling and Clear Flow Direction

These veins began filling within 5–7 seconds from the beginning of the arterial phase, and we were able to observe this filling pattern even in small veins under physiological conditions (Video 2).

VIDEO 2. ICG videoangiography of a parasagittal multiple bridging vein complex (also described in Fig. 1). Fluorescence in the vessel clearly depicts a different filling time, differentiating fast from slow veins, the latter possibly demonstrating collateral circulation in cases in which venous sacrifice is considered (see text). [Click here to view with Windows Media Player.](#) [Click here to view with Quicktime.](#)

We also observed this pattern of circulation in developmental venous anomalies.¹⁰

Slow-Draining Veins With Nonuniform Filling

These veins started to fill later than 5–7 seconds from the beginning of the arterial phase. Multiple streams could be readily observed during the early filling phase. This kind of flow dynamic was found to exist in these veins under physiological as well as pathological conditions, such as in the case of tumor-induced congestion. The flow in large bridging veins was observed to come from many tributary veins that had different draining patterns (Video 2).

Venous ICG Videoangiography Temporary Occlusion Test

In 3 cases we applied the venous ICG videoangiography temporary occlusion test to bridging veins with a fast pattern of circulation (fast-draining veins with uniform filling and clear flow direction). Flow stagnation was observed, but when we observed the flow to resume it did so in an antegrade direction immediately after clip removal. None of these veins were sacrificed.

In 5 cases we applied the venous ICG videoangiography temporary occlusion test to bridging veins, with at least one of these slow veins being an afferent vessel (slow-draining vein with nonuniform filling): in every one of these 5 cases these slow veins revealed a potential for flow reversal and functioned as alternative anastomotic pathways (Fig. 1). These 5 bridging veins were then

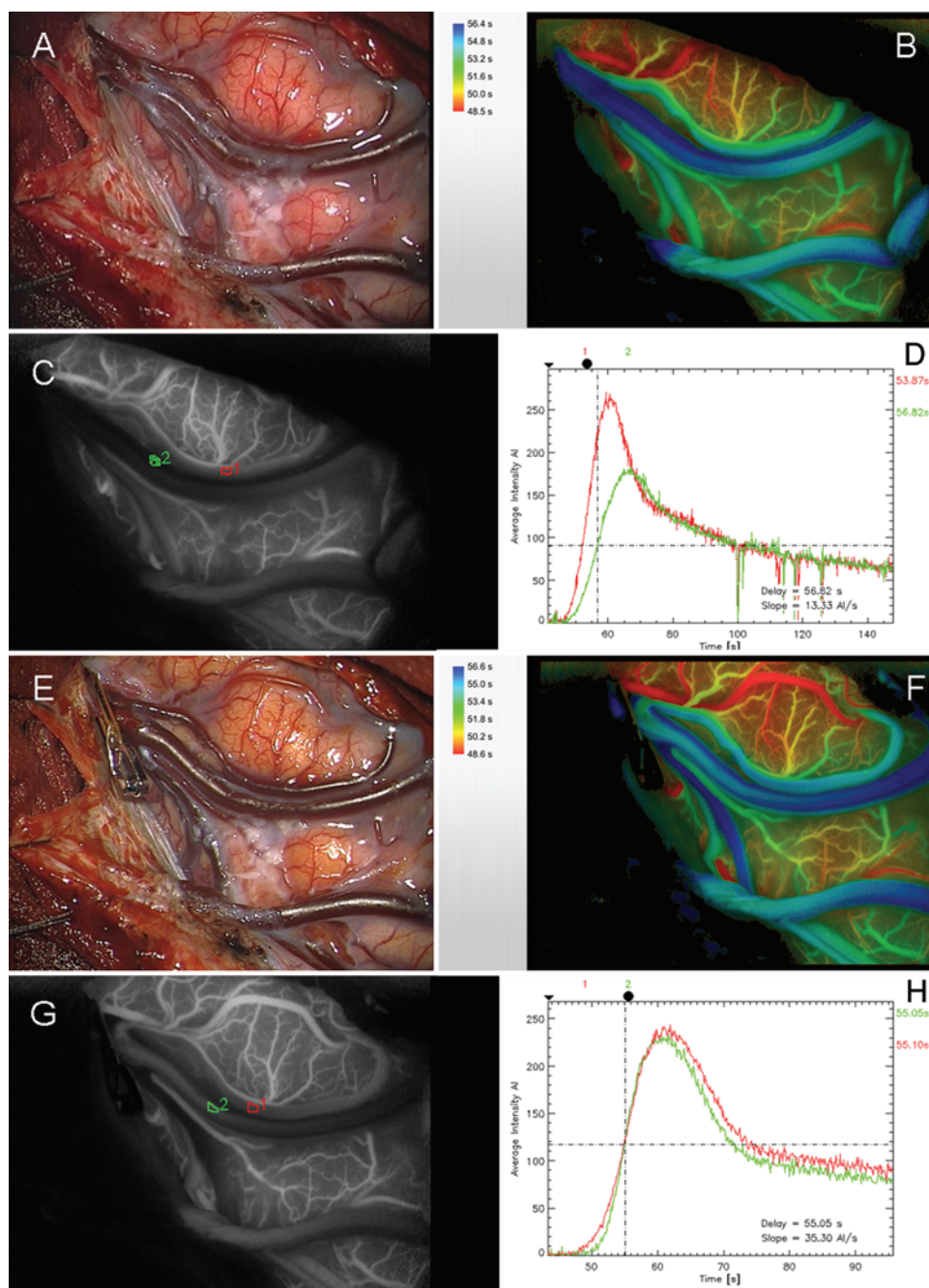


FIG. 1. Right transcallosal approach for removal of an intraventricular lesion. Under microscopic view, 2 main bridging vein complexes draining into the superior sagittal sinus are clearly identified (**A**). After intravenous administration of ICG, the Flow 800 software view shows the temporal fluorescence projection in the exposed vessels under physiological conditions (**B**). Regions of interest are identified on a classic ICG videoangiographic map: the *red* ROI is positioned on the fast vein, while the *green* ROI is on the slow vein (**C**). The graph clearly confirms the difference in flow speed between a fast vein (*red* line) and a slow vein (*green* line) (**D**). The clipping test (see text) is shown in a microscopic view (**E**). The Flow 800 software identifies the changes in temporal fluorescence projection in the exposed vessels during the clipping test, demonstrating that the fast vein is now draining through a common chamber into the slow one (**F**). The same ROIs are positioned as in C, during the clipping test (**G**). The graph shows that the flow speed in the 2 veins is now almost the same (**H**). Abbreviation: s = second.

sacrificed very close to the superior sagittal sinus which allowed for a free and open chamber of communication between fast- and slow-draining veins. We were able to rule out any signs of venous congestion by means of early postoperative T2-weighted MR imaging (Fig. 3).

Discussion

In 1996, Auque and Civit¹ published a paper suggesting that the likelihood of having negative effects after the sacrifice of a specific single vein could be generally

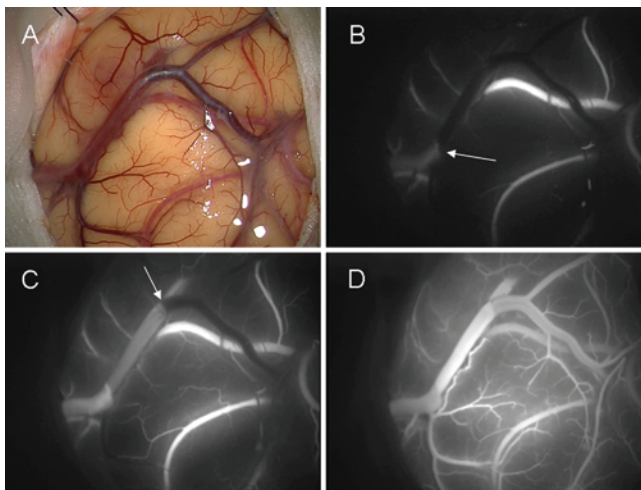


FIG. 2. **A:** Microscopic view during glioblastoma removal: the color of the vein in the middle of the surgical field is clearly red, suggesting arterialization and the existence of a direct arteriovenous fistula. **B–D:** ICG videoangiography was able to detect different times of filling in the same vein: a part of the vein can be seen to receive faster flow from a early arteriovenous fistula (white arrow, **B**). The same vein was found to have another fistula site with slower flow (white arrow, **C**). In the final view, the more proximal part of the vein can be seen receiving blood from normal peritumoral parenchyma (**D**).

predicted. Studies have been carried out to test the collateral potential of major dural venous sinuses.²³ Nonetheless, until now there has been no way to test, with any precision, for the existence of any collateral circulation in a given vein during surgery in an individual patient. To our knowledge, nothing new has been added to the neurosurgical literature in this specific area of interest in the past decade. Venous sacrifice continues to be thought of as something that must be avoided whenever possible, in part because of our inability to predict its safety. Venous sacrifice certainly has the potential, under certain circumstances, to enhance the exposure obtained by particular approaches (supracerebellar infratentorial, interhemispheric, subtemporal, and so forth) as well as to contribute to a more complete tumor removal. However, devastating complications and consequences have been observed in connection with venous congestion.¹⁹ ICG videoangiography offers the possibility of a relatively new technique for intraoperative investigation that has only recently been applied and used in the field of vascular neurosurgery.^{3,4,8,9,11–14,16,18,21,22,27–29} Our previous report on the use of ICG videoangiography in a case of developmental venous anomaly represents, to our knowledge, the only application of this method to an intraoperative investigation to the study of flow dynamics in veins.¹⁰ As far as venous circulation is concerned, however, decades of angiographic cerebral studies have consistently shown a tremendous interindividual variability when conventional angiography was the main radiological means of studying the cerebral circulation and tumors. Today, conventional angiography is only rarely used when dealing with cerebral tumors, for example, since less invasive techniques are available. Despite advances in neuroimaging, neurosurgeons still lack an intraoperative method that can yield

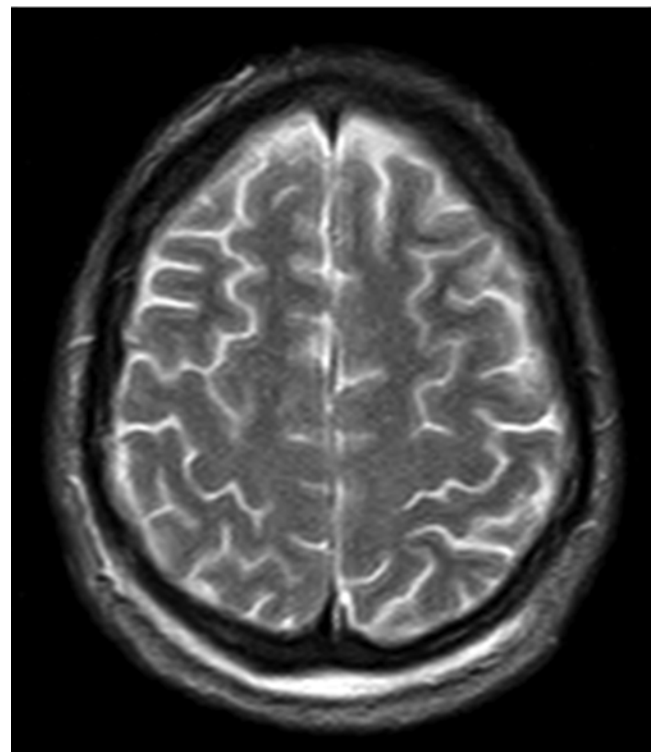
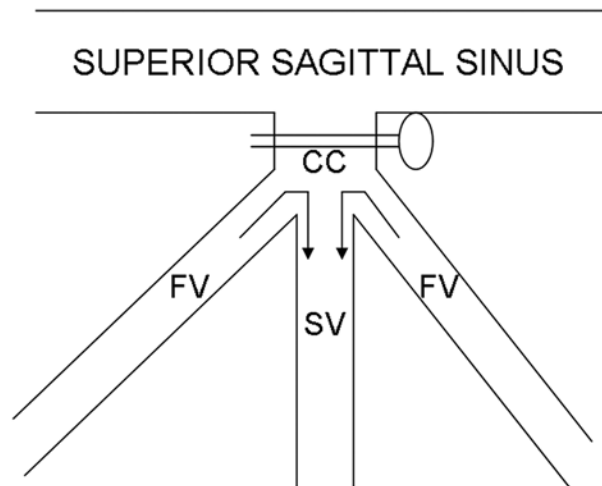


FIG. 3. **Upper:** Schematic diagram showing the clipping test applied to a multiple bridging vein complex. After the clip was positioned on the distal part of the common tract, the blood coming from the fast veins (FV) could be directly drained through the common chamber (CC) into the slow vein (SV) ensuring collateral circulation. The vein could be coagulated distal to the clip site to allow persistence of the CC. **Lower:** Postoperative T2-weighted axial MR image obtained in the patient whose case is described in Fig. 1 showing no regions of ischemia or edema in the territory drained by the clipped vein complex.

significant data that will enable them to predict the effects of the sacrifice of that single vein that has been exposed in that specific patient. In our hands, ICG videoangiography was found to provide potentially useful insights into the dynamics of venous circulation. The temporary clipping test that we describe represents a simple and reversible way to test for the presence of any potential anastomotic circle. The information that can be provided

by ICG videoangiography performed during the venous phase was found to be particularly interesting inasmuch as flow dynamics seems to provide us with a means of detecting the presence of alternative drainage pathways. Slow-draining veins with nonuniform filling, the tributaries of big bridging veins, might suggest the presence of an anastomotic circulation. A prompt flow reversal under the artificial and reversible conditions induced by the venous ICG videoangiography clipping test has the possibility of confirming the presence of anastomoses, suggesting that the bridging vein might be safely sacrificed, if needed. In all the 5 cases we observed in which the bridging veins were sacrificed after testing, the flow from the fast veins could be observed to fill the slow vein that demonstrated a reversal in flow direction. We observed no clinical consequences after this procedure nor did we observe any signs of venous congestion on early postoperative MR images. It should be noted that the possibility of postoperative complications in the case of venous sacrifice during neurosurgical procedures has always been a subject of considerable debate.^{5,12,15,17,24–26} However, until now there has been no effective way of helping the neurosurgeon predict the rate of postoperative complications related to the sacrifice of single veins in various sorts of patients. The risk of venous sacrifice can obviously be traced to the variability that preoperative angiographic studies have shown to exist in individual patterns of venous drainage. But it is not possible to use these preoperative tests to investigate the real potential of compensatory anastomoses because any kind of preoperative occlusive test on a single vein is technically impractical. Our data using ICG videoangiography, however, though preliminary and non-quantitative, do offer an interesting possibility that may prove valuable to neurosurgeons. Certainly much more data will be necessary, and this paradigm will have to be validated in a much larger series of patients. However, the nature of the information and the favorable outcomes we have obtained in these 8 cases is definitely encouraging. ICG videoangiography seems to be able to offer some useful and much-needed information regarding individual venous variability of a very practical nature.

Conclusions

Venous ICG videoangiography is able to reveal a large variability in the venous dynamic of flow. “Slow veins,” when tributaries of bridging veins, might hide a potential for anastomotic circulation that deserves further investigation.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Ferroli, Acerbi. Acquisition of data: Acerbi, Albanese, M Broggi. Analysis and interpretation of data: Ferroli, Acerbi. Drafting the article: Albanese, M Broggi. Critically revising the article: Ferroli, Acerbi, Tringali, Franzini, G Broggi. Reviewed final version of the manuscript and approved it for submission: all authors. Study supervision: G Broggi.

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Supplemental online information:

Video 1: <http://mfile.akamai.com/21488/mov/digitalwbc.download.akamai.com/21492/qt.digitalsource-global/JNS10-620video1.mov> (Quicktime)

<http://mfile.akamai.com/21490/wmv/digitalwbc.download.akamai.com/21492/wm.digitalsource-na-regional/JNS10-620video1.aspx> (Windows Media)

Video 2: <http://mfile.akamai.com/21488/mov/digitalwbc.download.akamai.com/21492/qt.digitalsource-global/JNS10-620video2.mov> (Quicktime)

<http://mfile.akamai.com/21490/wmv/digitalwbc.download.akamai.com/21492/wm.digitalsource-na-regional/JNS10-620video2.aspx> (Windows Media)

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