Indocyanine green videoangiography “in negative”: definition and usefulness in spinal dural arteriovenous fistulae

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Received: 13 March 2012 / Accepted: 22 December 2012 / Published online: 12 January 2013
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Abstract

Purpose Indocyanine green videoangiography (IGV) has proven its effectiveness in the field of exovascular neurosurgery, both in the intracranial and spinal compartment, but is necessary to define a systematic process for the performance of the IGV to facilitate its interpretation during the procedure. We have defined and applied the concept of videoangiography “in negative” (INIGV) to spinal dural arteriovenous fistulae (dAVF) for the detection and treatment of arteriovenous shunts, so called because the first phase is performed with the vessel suggestive of being pathological occluded.

Methods A Pentero-operating microscope with near-infrared IGV-integrated system (Carl Zeiss Co., Germany) was used. At our institution, 24 patients were treated for a spinal dAVF between 1995 and 2011, only in the last 4 cases, INIGV was performed.

Results We describe the IGV in negative procedure and show the most illustrative cases. In all cases, the fistula occlusion was confirmed by postoperative selective digital subtraction angiography (DSA). INIGV demonstrate its capacity in detecting vessels not actually arterialized that should be respected and avoid some of the main limitations of the conventional IGV. This is a technical description about an Indocyanine green (ICG) videoangiographic procedure modification that is superior to merely performing ICG before and after clipping of a dAVF.

Conclusion The INIGV results are rapid and easy to interpret procedure and provide great advantages to the dAVF treatment. Nevertheless, further studies are needed with a larger sample size to determine if INIGV may reduce the need to perform immediate postoperative DSA.

Keywords Indocyanine green · Videoangiography · Dural arteriovenous fistula

Background

Indocyanine green videoangiography (IGV) has proven its effectiveness in the field of exovascular neurosurgery, both in the intracranial and spinal compartment. Given the nature of the procedure, IGV has certain drawbacks when being used. One of the most reported and described limitations in the literature is the fact of requiring the exposure of the vascular network for its visualization. On the other hand, the ability to distinguish between the arterial and venous phase is complex, since after drug administration and after a few minutes, a progressive filling of the venous and arterial compartment is observed that superimposes the second to the first and not as in conventional arteriography where the venous phase replaces the arterial. This difficulty increases when arterialization of the nervous system is assessed, such as in the cases of AVM or AVF. Therefore, it is necessary to define a systematic process for the performance of the IGV to facilitate its interpretation during the procedure. We have defined and applied the concept of videoangiography “in negative” to spinal dural arteriovenous fistulae (dAVFs) for the detection and treatment of arteriovenous shunts.

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Materials and methods

Intraoperative microscope-integrated near-infrared IGV

A Pentero-operating microscope with near-infrared IGV integrated system (Carl Zeiss Co., Germany) was used. Indocyanine green (ICG) was injected intravenously through a peripheral venous line as a 25 mg bolus dissolved in 5 mL of water. The surgical field was illuminated with a wavelength of 800 nm.

Patients

At our institution, 24 patients were treated for a spinal dAVF between 1995 and 2011. In all of the cases, the spinal dAVF was diagnosed preoperatively by selective digital subtraction angiography (sDSA). In only four cases, IGV was used. Written informed consent was obtained from all the cases to use ICG during their surgical treatment.

Definition of the procedure

We have organized the procedure in several phases for its systematic application.

Phase 0 Exposure of the affected site and dural opening. Identification of the vessel related to the dura mater, suggestive of being pathological, that is, arterialized medullary vein (AMV) ending in the serpiginous venous network (SVN).

Phase 1 Temporary clip placement at the level of the AMV. ICG administration. Wait until beginning and stabilization of vascular filling (1 min).

Phase 2 Removal of temporary clip. Observation of any change in vascular filling respect to phase 1.

Finding consistent with dAVF In phase 1, filling of medullary venous and arterial vessels is observed, whereas no filling was observed in the SVN. In phase 2, a rapid filling of the SVN typical of this pathology was observed.

Finding not consistent with dAVF In phase 1, typical SVN is filled. In phase 2, no significant changes are observed with respect to phase 1.

Results

Illustrative cases examples

Case 1

A 45-year-old man presented with 4 years history of progressive paraparesis. On examining, the patient revealed 4/5 strength in both lower extremities, with spastic

paraparesis. T2-weighted MRI showed signal changes with serpiginous flow voids in the spinal canal suggestive of spinal dAVF. Selective spinal DSA confirmed the diagnosis and showed the fistula being fed by the right T6 artery (Fig. 1). Adamkiewicz artery was located at the left T10 level.

The surgical treatment was performed in prone position under general anesthesia, with motor evoked potentials monitoring. After patient consent, T5T6 right laminectomy and midline durotomy were performed. The right T6 nerve root and arterial periradicular network were identified extradurally. Intradurally, a vein that hung from the dura mater, which continued with a serpiginous and dilated venous network, was observed. This venous vessel with suspected arterialization (AMV) was temporarily clipped and an INGV was performed as described previously (Fig. 2). During phase 1, filling of venous and arterial medullary vessels was observed, whereas no filling was observed in the SVN. In phase 2 (1 min after the administration of ICG), after removal of the temporary clip, a rapid filling of the SVN typical of this pathology was observed. After identifying this vessel as pathological, we proceeded toward coagulation and cutting, showing darkening of the SVN. After washing the first infusion of ICG, conventional IGV (CIGV) was performed to confirm exclusion of the fistula. During intraoperative monitoring, no changes were observed. The patient experienced a significant motor improvement. Immediate postoperative DSA ruled out the existence of dAVFs.

Fig. 1 Case 1. **a** Sagittal T2-weighted magnetic resonance imaging of the thoracic spine shows flow voids (white arrow head) representing dilated veins. **b** DSA shows the dural arteriovenous fistula: the afferent right T6 segmentary artery (black arrow head), the arterialized medullary vein (white arrow head) and the dilated serpiginous venous network (black arrow)

Fig. 2 Case 1 operative procedure. **a** Intradural exposure shows a venous vessel piercing the dura (white arrow head) and the SVN (black arrow heads). **b** Clipping of medullary vein suggestive of arterialization (white arrow head). **c** INIGV phase 1 showing the arterial and venous medullary vessels filling (white broken arrow) and the no enhanced SVN (white arrows); transient clip on the medullary vein (white arrow head). **d** INIGV phase 2 showing the rapid filling of the SVN (white arrow heads) after removing the temporary clip

Case 2

A 61-year-old woman presented with 2 years history of thoracic back pain. On examination, the patient did not show any deficit. T2-weighted MRI showed signal changes with serpiginous flow voids in the spinal canal without intramedullary hyperintensity, suggestive of spinal dAVF. Selective spinal DSA confirmed the diagnosis and showed the fistula being fed by the right T7 artery, but the arteriovenous shunt was located in the upper level, T6 T7 (Fig. 3). Adamkiewicz artery was located at the left T11 level. The surgical treatment was performed in prone

position under general anesthesia with motor evoked potentials monitoring. After patient consent, T6T7T8 right laminectomy and midline durotomy were performed. The right T6 and T7 nerve roots and arterial periradicular network were identified extradurally. Intradurally, at the T7 level pedicle, a venous vessel on the dura mater, that was lost in the subarachnoid space near the SVN, was observed. This vessel was temporarily clipped and an INIGV was performed. In phase 1, typical SVN was filled. In phase 2, no significant changes are observed with respect to phase 1. This pattern rules out the fact that the clipped vessel matches the AMV that feeds the SVN. The durotomy was extended superiorly where another venous vessel hung from the dura mater (Fig. 4). The procedure was repeated after this new vessel temporarily occluded. In this occasion, during phase 1, arterial and venous medullary vessel filling was observed, whereas no filling of the SVN was observed. In phase 2 (1 min after administration of ICG) after removal of the temporary clip, a rapid filling of the SVN, typical of this pathology, was observed (Fig. 5). After identifying this vessel as pathological, we proceeded to coagulation and cutting and darkening of the SVN was observed. After washing the first infusion of ICG, CIGV was performed to confirm exclusion of the fistula. During intraoperative monitoring, no changes were observed. The patient did not experience any postoperative deficits. Immediate postoperative DSA ruled out the existence of dAVFs.

Discussion

The spinal dAVF or dorsal intradural AVF [26] and, by extension, intracranial AVFs type 3 of Borden et al. [6] consist of one or more arteriovenous shunts located within dural arteries (in case of dAVFs, at the level of the radicular dural sleeve) and one or more leptomeningeal veins (in case of dAVFs, a medullary vein) that are dilated and follow a winding and abnormally dilated path. The shunt point is at the dural level and its direct exposure is complex, assuming radicular and/or medullary damage; therefore, the treatment consists of the coagulation and cutting of the medullary vein (intradural), avoiding arterialization and secondary hypertension in the venous system [26]. Other treatments have been defined, such as the resection of serpiginous venous pathway and it was concluded that postoperative morbidity was increased [1, 4, 13, 19, 23]. Therefore, in our center, the treatment of choice is surgical interruption of the AMV [16]. An alternative approach that has also been raised is the endovascular treatment for its occlusion [8, 11, 25] with different materials such as *N*-butyl 2-cyanoacrylate and Onyx [15, 24, 26].

Fig. 3 Case 2. **a** Sagittal T2-weighted magnetic resonance imaging of the thoracic spine shows flow voids (*black arrow heads*) representing dilated veins typical of this pathological entity. **b** DSA shows the afferent arterial vessel (*black circle*) at T7/T8 segment, the

efferent dilated venous network (*broken white circle*) and the fistulous point at the level of dural sleeve of right T6 nervous root (*white circle*). **c** DSA with the representation of vertebral bodies

Fig. 4 Case 2 operative procedure part 1. **a** Intradurally, at the T7 level pedicle, a venous vessel depending on the dura mater (*black arrow*), that was lost in the subarachnoid space near the SVN (*black arrow head*), was observed. **b** This vessel was temporarily clipped (*white arrow*) and an INIGV was performed. In phase 1, typical SVN was filled (*black arrow head*). **c** In phase 2, after removing transient clipping, no significant changes were observed with respect to phase 1. This pattern rules out the fact that the clipped vessel matches the AMV that feeds the SVN

Fig. 5 Case 2 operative procedure part 2. **a** The durotomy was extended until achieving the T6 pedicle where another venous vessel hung from the dura mater (*black arrow*). **b** INIGV was repeated after this new vessel temporarily occluded (*white arrow*). In this occasion, during phase 1, arterial and venous medullary vessel filling was observed (*black arrow head*), whereas no filling of the SVN was evidenced. **c** In phase 2 (1 min after administration of ICG) after removal of the temporary clip, a rapid filling of the SVN was observed, confirming the fistula at this level

Several authors have defined the usefulness of CIGV in dAVFs [9]. Schuette et al. [22] assessed the effectiveness of CIGV in 25 patients with cranial and spinal dAVFs,

demonstrating the fistula in all the cases and documenting its obliteration. In our opinion, the term “fistula location” is confusingly treated in the literature, as the difference between the fistulous point and the arterialized vein should be defined. Location of the arterialized vein does not mean the fistulous point is visualized. According to our experience, assessment of CIGV is highly difficult, as the direct point of the shunt is not evident because it is anatomically at the dural sleeve level. Some authors [14] have proposed a preoperative coil marking that allows exact intraoperative localization of spinal dural arteriovenous fistulas, thus, surgery at erroneous spinal levels is avoided, and it is feasible to perform a straightforward, minimally invasive surgical approach. Surgical exploration of the dural sleeve is meaningless, given the possible radicular compromise due to the radicular branch damage and in the case of being the level of origin of the Adamkiewicz artery, risk of spinal cord injury. Moreover, regarding the location of the afferent artery, in many occasions, it can be viewed, under direct microscopic vision, an arterial network at the periradicular level, but this vascularization does not insure that it is the affected level since the segmental artery, branch of the aorta artery, irrigates the nervous root (radicular branch), dural sleeve (dural branch) and depending on the level to the spinal cord (medullary branch), not necessarily contributing to the fistula [26]. Visualization of a rapid filling of the dilated venous system in apparent continuity with the medullary vein, after CIGV, does not establish unequivocally the affected level, as demonstrated in case 2 presented in the present work. Although some authors [22] have defined that the interpretation of the rapid and retrograde filling of the venous system typical of these injuries are easily identified by the CIGV, according to our experience and literature, where several authors have defined recurrence of the fistula after surgery, difficulties to localize the fistula or appearance of another fistula at different levels [10, 20], this is not so simple and may lead to errors as stated in case 2. Therefore, any of the components of the fistula, arterial afference, fistulous point and arterialized vein efference cannot be defined unequivocally by the CIGV. The concept of dAVF has a dynamic component of arterialization of the venous system, which clearly defines the DSA [28], but not the CIGV, since in the latter, the venous phase is superimposed to the arterial without washing of the first as it happens in the DSA, making impossible in many cases or at least hinders to identify the arterialized venous system. Vascular filling is quite erratic and often highlights arterial and venous subarachnoid vessels that confound the identification of the shunt and force to repeat videoangiography sequences several times, leading to a tedious and sometimes unsuccessful and erroneous procedure. It is therefore essential to establish guidelines for the performance of the IGV to achieve a

non-speculative and unequivocal interpretation of the venous system arterialization. Thus, we have defined IGV in negative, so called because the first phase is performed with the vessel suggestive of being pathological occluded. Such concept is easy to interpret when the arteriovenous shunt is unique, that is, only one efferent vein suspected of arterialization, since the opening of the transient occlusion and the rapid filling of the venous system can only be performed in one vessel and not simultaneously in several.

Therefore, according to our experience, cranial dAVFs in which arterialized leptomenigeal veins are usually multiple, or when spinal dAVFs have multiple shunt, will require clipping of suspected vessels and sequential opening of each of them with an ICG infusion for each vessel assessed and timing of complete washing of ICG among each of them, leading to longer occlusion time of the venous system with the risk of infarction if any of those veins is not pathological. In such cases, angioarchitecture configuration of dAVF defined by preoperative DSA is fundamental to simplify the procedure, being INIGV only required in those vessels with greater intraoperative doubt. Although limitations such as the difficulty to interpret venous arterialization referred to above and the need of exposure of the vascular network to be visualized arise, according to our experience, in cases of unique shunt presented in this work, the procedure performed “in negative” shortens the operative time and requires less administrations of ICG versus CIGV. Recently Killory et al. [12] have reported the usefulness of the CIGV in the treatment of angiographically occult dAVFs in a series of 3 cases. In the presented cases, the technique used and intraoperative findings are described in a very illustrative manner. In some of the displayed images, the direct point of the arteriovenous shunt is intradurally visualized and not at the dural sleeve level, thus we believe that the diagnosis may be that of perimedullary AVF and not strictly dAVF, although they could be included in the type intradural dorsal AVF of Spetzler classification [26]. It is an AVF between a radiculomedullary artery (not dural artery) and a medullary vein. These cases may be highly difficult if the shunt point is multiple, because the confirmation by CIGV that the SVN depends on the suspected arterialized veins would entail the need to locate all the shunt points. Given that they are at the subarachnoid space and at multiple levels, it could be really complex. The use of the INIGV could be helpful to confirm said arterialization since it is not required to locate the direct shunt point and it could be performed at the level of the venous vessels suspected of arterialization.

There are other procedures for intraoperative assessment of intracranial and spinal pathology like the microvascular Doppler [5, 17]. In accordance with our experience, taking into account the diameter of doppler catheters that we

usually use, the small caliber of spinal vessels and the scarce dural opening performed, contamination of this test by arterial flows of nearby arteries can lead us to error, therefore in recent operated cases, in which we had IGV, we were not required to use it. Intraoperative angiography is the gold standard test, but it has some drawbacks [2, 7, 21, 22, 27], such as the infrequent availability in neurovascular surgery units given its high cost, the time involved in the procedure and the necessary expertise to perform and interpret it in prone position [3]. The finding of darkening of the arterialized venous system after occlusion of the fistula is not always evident and immediate so it may help to confirm the disappearance of the arterialization only in some cases. For the time being, we confirm the fistula occlusion in all cases by postoperative DSA, but in the future, the INIGV may reduce this need.

Applications of CIGV have been established also in the field of intracranial vascular surgery, as well as in aneurysmatic pathology [19], cerebral AVMs surgery [12] and the cerebral revascularization surgery to corroborate the bypass patency. Apart from the already established usefulness of the INIGV in arteriovenous fistulae defined in this work, another field of application of this technique applied “in negative” could be the location of the adequate recipient cortical artery, during cerebral revascularization of the middle cerebral artery (MCA) territory, such as Rodríguez-Hernández and Lawton [18] described recently. The temporary clipping of one of the main trunks of the MCA and its further opening after the infusion of ICG enhances and confirms cortical vessels from the trunk to be revascularized and simplifies the procedure of location.

The main limitation of this study lies in the short case series and the absence of a control group.

Conclusion

The INIGV confers a greater dynamic potential to the CIGV, facilitating the recognition of the pathological vessel, arterialized vein, thus making the procedure less speculative. The definition of a systematic procedure that is rapid and easy to interpret provides great advantages to the treatment. Nevertheless, further studies are needed with a larger sample size to determine if INIGV may reduce the need to perform immediate postoperative DSA.

Conflict of interest The authors report no financial disclosures.

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