



Title	Intraoperative Identification of the Shunt Point of Spinal Arteriovenous Malformations by a Selective Arterial Injection of Saline to Subtract Signals of Indocyanine Green : Technical Note
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Title page

Title: Intraoperative identification of the shunt point of spinal arteriovenous malformations by a selective arterial injection of saline to subtract signals of indocyanine green (3S-ICG): technical note

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Short Title: Shunt point identification of spinal AVM by 3S-ICG

1 **Title:** Intraoperative identification of the shunt point of spinal arteriovenous malformations by
2 a selective arterial injection of saline to subtract signals of indocyanine green (3S-ICG):
3 technical note

4
5 **Abstract**

6 *Background:* It is crucial to identify a shunt point for a spinal arteriovenous malformation
7 (AVM) treatment. For this purpose, some intraoperative supports have been reported—the
8 intravenous injection of indocyanine green (ICG), selective arterial injection of ICG (SAI-ICG),
9 and selective arterial injection of saline with a high frame rate digital camera. However, there
10 are difficulties in accurately identifying the shunt point, especially if the lesion has multiple
11 feeders. We here report a novel method, the selective arterial injection of saline to subtract
12 signals of ICG (3S-ICG), to precisely identify the perimedullary arteriovenous fistula shunt
13 points having multiple feeding arteries

14 *Methods:* After exposing the lesion, a 4-Fr catheter was cannulated into the origins of the
15 segmental artery. ICG was injected intravenously as a first step, and then, heparinized saline
16 solution was flushed from the catheter.

17 *Results:* Compared with other methods, this method could point out the exact shunt point and
18 was effective for certain shunt point obliterations.

19 *Conclusion:* Though having similar invasiveness, 3S-ICG is superior to previously described

- 1 techniques, such as SAI-ICG. Therefore, it will be useful when spinal AVM surgical treatment
- 2 is performed.

1 **Introduction**

2 The spinal arteriovenous malformations (AVMs), being rare pathologies, have occasionally
3 challenging surgical interventions, especially in complicated vascular structures. For their
4 treatment, understanding precisely their vascular structures is extremely important since the
5 proximal side obliteration of a feeding artery will result in a recurrence and the inadequate
6 occlusion of the draining veins may lead to neurological deterioration due to normal spinal cord
7 perfusion obstruction.¹ Identifying the architecture of spinal dural arteriovenous fistulas (AVFs)
8 and perimedullary AVFs with a single feeder is relatively easy. On the other hand, the complex
9 structures of the perimedullary AVFs with multiple feeding arteries or intramedullary AVMs are
10 more difficult to ascertain.

11 The intravenous and selective arterial injections of indocyanine green (ICG), and the
12 combination of a high frame rate digital camera and selective arterial injection of saline have
13 been reported to be effective for the intraoperative appreciation of vascular structures,²⁻⁵ useful
14 in identifying the whole lesion structure, but less helpful in knowing the accurate shunt point.

15 In this article, we present a novel method for intraoperative identification of the shunt point
16 which connects feeding arteries with draining veins with a selective arterial injection of saline
17 to subtract signals of ICG (3S-ICG).

18

19 **Methods**

1 We performed the following procedures for the surgical treatment of a patient with a spinal
2 perimedullary AVF having two feeding arteries: the anterior spinal artery (ASA) derived from
3 the left T9 segmental artery (Fig. 1A and B) and the posterior spinal artery (PSA) derived from
4 the right T10 segmental artery (Fig. 1C and D). Their draining veins were the anterior and
5 posterior spinal vein (ASV, PSV) —the common draining routes for both feeding arteries. The
6 shunt point seemed to exist on the left lateral side of the spinal cord, although it was difficult to
7 identify precisely by preoperative angiography and computed tomography angiography.

8

9 *Surgical procedure*

10 All procedures were performed in the hybrid operating room at the Hokkaido University
11 Hospital. After general anesthesia induction, a 5-Fr metallic kink-resistant sheath (Super Allow-
12 Flex Sheath; Teleflex Inc., NC, USA) was inserted via the left femoral artery to manipulate the
13 catheter with ease in the prone position, was sutured to the skin, and was kept sterile with a
14 surgical drape. Then, the patient was turned to the prone position. After confirming the vertebral
15 level using a fluoroscope, a midline skin incision and laminectomy from the lower side of T10
16 to the upper side of T12 were performed. The dura mater and arachnoid membrane were opened,
17 and the spinal cord was mobilized by towing the dentate ligament.

18 Digital subtraction angiography (DSA), selective arterial injection of ICG (SAI-ICG), and 3S-
19 ICG were carried out from the right T10 and left T9 segmental arteries. After identifying the

1 entire vascular structure and shunt points, the shunt point obliteration was done.

2

3 *Angiographic procedures*

4 A 4-Fr catheter (HS1; Gadelius, Tokyo, Japan) was inserted into the 5-Fr sheath introduced
5 beforehand and cannulated into the origins of the right T10 and the left T9 segmental arteries,
6 respectively. We often use a microcatheter when the 4-Fr catheter gets out of place by injecting
7 a contrast medium,⁴ although not necessary in the present case. For DSA, approximately 5 ml
8 of contrast medium was injected through the catheter by hand.

9 When SAI-ICG and 3S-ICG were performed, the fluoroscope was withdrawn from the
10 operative field and the surgical microscope (OPMI PENTERO 900; Carl Zeiss Meditec,
11 Oberkochen, Germany) was positioned. To detect a near-infrared ray, the near-infrared mode
12 (INFRARED 800) was activated. For SAI-ICG, approximately 5 ml of ICG diluted with saline
13 (1:1000, 5 µg/ml) was gently flushed from the 4-Fr catheter. Regarding 3S-ICG, 1 ml of
14 undiluted ICG (5 mg/ml) was injected intravenously as a first step. After approximately 1
15 minute, ICG had passed into the patient's whole circulation. Then, approximately 5 ml of
16 heparinized saline solution was slowly flushed from the 4-Fr catheter. The series of procedures
17 were recorded in both the near-infrared and bright field modes. The former represented 3S-ICG,
18 whereas the latter was the same as the selective arterial injection of saline (SAI-S) reported by
19 Hamauchi et al.⁵

1

2 **Results**

3 After exposing and rotating the spinal cord, a titanium alloy clip was applied to the dentate
4 ligament around the suspicious vascular structure, confirming it as a genuine lesion using a
5 fluoroscope. DSA was performed, corroborating it to be the target lesion (Fig. 2A and B). Then,
6 SAI-ICG and 3S-ICG were performed from the right T10 segmental artery. SAI-ICG showed
7 the dilated feeding artery—the left PSA—, tortuous, fine vessels, and the dilated draining veins
8 toward ASV and PSV (Fig. 3A). However, the exact shunt point could not be revealed. SAI-S,
9 a 3S-ICG by-product, showed the feeding artery to be transparent and the distal side of the
10 draining veins to be constant. The feeding artery color change was partially difficult to observe
11 due to the thickened connective tissue, obscuring the boundary between the feeding artery and
12 the draining veins, or the shunt point (Fig. 3B and C). In contrast, 3S-ICG succeeded to point
13 out the shunt point. The feeding artery lost the ICG signal due to the flushed saline, whereas
14 the draining veins had a constant signal by blood from the other feeding artery, having a clearer
15 boundary than that of SAI-S (Fig. 3D and E and Video 1).

16 Similarly, they were performed from the left T9 segmental artery. SAI-ICG showed the dilated
17 feeding artery—the pial branch of ASA—, tortuous, fine vessels, and dilated draining veins
18 (Fig. 3F), clarifying the entire lesion structure. The feeding artery was difficult to differentiate
19 from the draining veins with just this finding. SAI-S finding gave rough information to where

1 the shunt point was, although did not give an exact one (Fig. 3G and H), while 3S-ICG provided
2 more accurate shunt point information (Fig. 3I and J and Video 2). After all examinations were
3 completed, the shunt points were obliterated, where DSA showed no residual shunt evidence
4 (Fig. 2C and D). A schematic illustration of the vascular structure based on angiographic
5 procedures is shown in Fig. 4.

6

7 **Discussion**

8 In this technical note, we described a novel method for detecting accurate shunting points of
9 the perimedullary AVF. By this method, the shunt points could be identified more accurately
10 than the intraoperative support methods described previously. Additionally, since the saline
11 administration has only been added to SAI-ICG, the 3S-ICG invasiveness is the same as the
12 SAI-ICG.

13 3S-ICG facilitated shunt identification is the most important factor in spinal AVF surgical
14 treatment. The treatment difficulty of spinal AVMs differs depending on their type. Takai et al.
15 proposed a classification system of the spinal AVMs as follows: dural AVF (type I),
16 intramedullary glomus AVM (type II), intramedullary juvenile AVM (type III), perimedullary
17 AVF (type IV), and extradural AVF (type V).⁶ They subdivided type IV into three subtypes
18 based on Mourier's classification⁷: type IVa with a single feeder and small AVF, type IVb with
19 multiple feeders and medium AVFs, and type IVc with multiple feeders and a giant AVF. Among

1 them, type I treatment strategy is often simple—they can be cured by draining vein obliteration,
2 which passes through the dura mater.⁸ However, when the lesions have multiple feeders as types
3 II, III, IVb, and IVc, their treatments get more difficult due to their complexity. Especially,
4 accurate identification of the shunt point is important and necessary for types IVb and IVc.
5 Some authors reported intraoperative supports to achieve shunt points identification. The ICG
6 intravenous injection is the representative one, generally used in many hospitals,^{2,8} convenient,
7 and require nothing special. However, it has a weak point for the lesion with multiple feeding
8 arteries because it simultaneously shows the signals from all feeding arteries. Additionally,
9 washing out ICG requires time; therefore, it takes much time if repeated injections are needed.
10 Our group has previously reported the efficacy of SAI-ICG and SAI-S combined with a high
11 frame rate digital camera. SAI-ICG is superior to intravenous ICG regarding the prehension of
12 each vascular structure, although it cannot distinguish the feeding arteries from the draining
13 veins. SAI-S with a high frame rate camera having a high temporal resolution is suitable for a
14 high flow shunt, with the advantage of being repeatedly performed in the bright field. This
15 method theoretically can identify the shunt point since injected saline will be mixed with the
16 blood from the other feeding arteries in the distal area of the shunt point. However, its sensitivity
17 is inferior to that of ICG. Hence, identifying the exact shunt point is difficult. Moreover, the
18 vessel color change observation becomes difficult, when there are thickened connective tissues
19 or adhesions around the vessels. Hence, this method requires the separation of connective

1 tissues around the lesion, which may include some unrelated field for shunt point disconnection.
2 By contrast, this method could identify more accurately, owing to ICG sensitivity. In our
3 method, the feeding artery lost the ICG signal due to the injected saline. The signal around the
4 shunt point also decreases but does not vanish because minimum amount of ICG can be detected
5 in the drainage veins. Consequently, their boundary can be recognized. 3S-ICG was considered
6 as invasive as the intraoperative support method described previously, such as SAI-ICG.
7 Therefore, we can gather much information from the novel method without increasing risk. The
8 characteristics of each intraoperative support are summarized in Table 1.

9

10 **Conclusions**

11 We reported 3S-ICG during a surgery for spinal AVMs with multiple feeders. This method is
12 superior to the other methods regarding the accurate shunt point identification, contributing safe
13 and certain obliteration of the shunt points. We believe that this novel method will provide
14 useful information for surgeons without increasing a risk.

15

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- 7

1 **Figure Legends**

2 **Figure 1: Preoperative digital subtraction angiography (DSA) findings**

3 The anteroposterior (AP) view of the conventional DSA (A) and the left anterior oblique (LAO)
4 view of the three-dimensional (3D) DSA (B) from the left T9 segmental artery showed the
5 arteriovenous shunt (AVS) at the T11 level. The feeding artery (dotted arrow), which could be
6 recognized only in 3D DSA, was branched from the anterior spinal artery (arrow). The draining
7 veins were the anterior spinal vein (ASV, single arrow head) and posterior spinal vein (PSV,
8 double arrow heads).

9 The AP view of the conventional DSA (C) and the LAO view of the 3D DSA (D) from the right
10 T10 segmental artery also showed the AVS at the T11 level. The feeding artery (double-dotted
11 arrows) was the left posterior spinal artery (PSA), which was supplied from the right PSA
12 (double arrows) via the vasa corona, could be recognized only in the 3D DSA and was branched
13 from the anterior spinal artery (arrow). The draining veins were also the ASV (single arrow
14 head) and PSV (double arrow heads). Both shunt points seemed to exist on the left lateral side
15 of the spinal cord, although precise identification was difficult.

16

17 **Figure 2: Intraoperative DSA findings**

18 Before shunt obliteration, DSA from the right T10 (A) and the left T9 (B) segmental arteries
19 were performed. A titanium alloy clip (arrow) applied to the dentate ligament around the

1 suspicious vascular structure became a mark, confirming it as a genuine lesion. After shunt
2 obliteration, DSA from the right T10 (C) and the left T9 (D) segmental arteries were performed
3 again. Both of them showed no residual shunt evidence.

4

5 Figure 3: Intraoperative findings of the selective arterial injection of indocyanine green (SAI-
6 ICG), the selective arterial injection of saline (SAI-S), and the selective arterial injection of
7 saline to subtract signals of ICG (3S-ICG)
8 SAI-ICG from the right T10 segmental artery showed the dilated feeding artery (double-dotted
9 arrows), tortuous vessels, and dilated draining veins (arrow head). However, it could not reveal
10 the shunt point (A). SAI-S from the right T10 segmental artery showed a feeding artery color
11 change (double-dotted arrows) from red (B) to transparent (C) and the distal side of the draining
12 veins (arrow head) to be constant. Nevertheless, the shunt point was obscure. 3S-ICG from the
13 right T10 segmental artery also showed a feeding artery signal change (double-dotted arrows)
14 from a high signal (D) to little signal (E) and the draining veins (arrow head) to have a constant
15 signal. The boundary (single asterisk and double asterisks) was clearer than that of SAI-S.
16 SAI-ICG from the left T9 segmental artery showed the dilated feeding artery (dotted arrow),
17 tortuous vessels, and dilated draining veins (arrow head). However, it was also difficult to
18 identify the shunt point (F). SAI-S from the left T9 segmental artery showed a feeding artery
19 color change (dotted arrow) from red (G) to transparent (H) and the distal side of the draining

1 veins (arrow head) to be constant. In this method, the shunt point was also unclear. 3S-ICG
2 from the left T9 segmental artery showed a feeding artery signal change (dotted arrow) from a
3 high signal (I) to little signal (J) and the draining vein (arrow head) to have a contrast signal. It
4 could point out the shunt point (pound).

5

6 Figure 4: A schematic illustration of the vascular structure based on angiographic procedures.

7 The feeding artery from the left PSA (double arrows) shunted at single asterisk and double
8 asterisks. The feeding artery from the ASA (single arrow) shunted at a pound.

9

10 **Video Legends**

11 Video 1: 3S-ICG from the right T10 segmental artery.

12 A feeding artery signal was changed from a high signal to little signal by injecting saline,
13 whereas draining veins signals were constant.

14

15 Video 2: 3S-ICG from the left T9 segmental artery.

16 A feeding artery signal was changed from a high signal to little signal by injecting saline,
17 whereas draining veins signals were constant.

Table 1. The characteristics of each intraoperative support.

	Convenience	For multiple feeders	Repeatable use	Temporal resolution	Identification of shunt point
Intravenous ICG	○	△	△	△	△
SAI-ICG	△	○	○	△	△
SAI-S with HFR camera	△	○	◎	○	○
3S-ICG	△	○	◎	△	◎

ICG, indocyanine green; SAI-ICG, selective arterial injection of ICG; SAI-S, selective arterial injection of saline; HFR, high frame rate; 3S-ICG, selective arterial injection of saline to subtract signals of ICG

Triangle (△) means that the corresponded method (line) is inferior to the method rated as circle on the corresponded item (column).

Circle (○) means that the corresponded method (line) is superior to the method rated as triangle on the corresponded item (column).

Double circles (◎) means that the corresponded method (line) is particularly superior to the other methods on the corresponded item (column).

Abbreviations list

ASA, anterior spinal artery; ASV, anterior spinal vein; AVF, arteriovenous fistula; AVM, arteriovenous malformation; DSA, digital subtraction angiography; ICG, indocyanine green; PSA, posterior spinal artery; PSV, posterior spinal vein; SAI, selective arterial injection; SAI-S, selective arterial injection of saline; 3S-ICG, selective arterial injection of saline to subtract signals of ICG