

## Case Report

# Sequential changes of arterial spin-labeling perfusion MR images with dual postlabeling delay following reconstructive surgery for giant internal carotid artery aneurysm

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## Abstract

**Background:** Arterial spin-labeling magnetic resonance perfusion imaging (ASL-MRI) allows noninvasive measurement of cerebral blood flow (CBF) but depends on arterial transit time (ATT). To overcome this problem, we developed a simple ASL technique with dual postlabeling delay (PLD) settings. In addition to the routinely used PLD of 1.5 seconds, we selected another PLD of 2.5 seconds to assess slowly streaming blood flow and detect arterial transit artifacts (ATAs) resulting from stagnant intravascular magnetically labeled spins.

**Case Description:** We validated the dual PLD method with digital subtraction angiography (DSA) findings in a patient with an unruptured right giant internal carotid artery (ICA) aneurysm who underwent proximal ligation of the right cervical ICA followed by right superficial temporal artery–middle cerebral artery anastomosis. The giant aneurysm was detected as a strongly hyperintense signal area of ATA using both values of PLD. Decreased signal in the right hemisphere at PLD 1.5 seconds was somewhat improved at PLD 2.5 seconds. DSA revealed that this laterality resulted from the different ATT values between hemispheres due to stagnation of the labeled spin within the aneurysm. Postoperatively, with gradual but complete thrombosis and regression of the aneurysm, the size of the ASL hyperintense signal area decreased markedly. At postoperative 2 years, the aneurysm was not demonstrated as an ATA; furthermore, the decreased signals in the right hemisphere at PLD 1.5 seconds had mostly improved.

**Conclusion:** Serial ASL-MRI with dual PLDs could show dynamic changes of giant aneurysms and the associated hemodynamic state following the surgery.

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**Key Words:** Arterial spin-labeling perfusion MR imaging, arterial transit artifact, arterial transit time, giant aneurysm, postlabeling delay

## INTRODUCTION

Arterial spin-labeling magnetic resonance perfusion imaging (ASL-MRI) visualizes cerebral perfusion using magnetically labeled protons in arterial blood as an endogenous tracer.<sup>[1-7,13,15]</sup> Because ASL-MRI requires no exogenously administered tracer, it is an advanced, repeatable perfusion tool.<sup>[1-7,13,15]</sup> However, the technique has some drawbacks, the most prominent of which is that ASL is highly sensitive to the arrival time of labeled blood in tissue, namely the arterial transit time (ATT).<sup>[1,2,5,6,13]</sup> Acquisition of ASL-MRI has a time delay, the postlabeling delay (PLD), between inversion of blood spins passing through the labeling plane in the neck and brain image collection in any plane after tissue perfusion of labeled blood.<sup>[1-6,13]</sup> The fundamental tradeoff of ASL-MRI acquisition is that short PLDs do not allow complete delivery of labeled blood to the tissue, whereas long PLDs result in strong T1 decay and therefore reduced signal-to-noise ratio.<sup>[1,6]</sup> To resolve this tradeoff between allowing sufficient delay to visualize tissue perfusion and maintaining adequate diagnostic quality, PLDs of 1.5–2.0 seconds are routinely used in daily clinical practice.<sup>[1,6,7,9,13,15]</sup>

In patients with steno-occlusive cerebrovascular disease, including leptomeningeal anastomosis, labeled blood that travels via collateral pathways of the circle of Willis or secondary collateral pathways exhibits prolonged ATT.<sup>[1,6,9]</sup> Thus, ASL measurements that employ a conventional single PLD (e.g. 1.5 seconds) lead to underestimation of cerebral blood flow (CBF). To overcome this problem, we developed a simple ASL technique using two PLD settings. In addition to the routinely used PLD of 1.5 seconds, we selected another PLD of 2.5 seconds to assess the slowly streaming collateral pathway that maintains the cerebrovascular reserve.<sup>[1,6]</sup> We also validated the setting of the dual PLD values at 1.5 and 2.5 seconds by assessing the ATT and angiographic circulation, including the collateral network, in the target area using digital subtraction angiography (DSA) as a gold standard.<sup>[1,6]</sup> DSA revealed that the hypovascular area seen at 1.5 seconds was improved via the collateral circulation and delayed anterograde flow at 2.5 seconds after contrast medium injection at the cervical portion of the internal carotid artery (ICA) and vertebral artery (VA).<sup>[1,6]</sup>

Another drawback of ASL-MRI is that, in patients with well-developed collaterals, a single conventional PLD shows apparent hyperperfusion in territories where intravascular magnetically labeled protons is stagnant,

a condition termed “arterial transit artifact (ATA).”<sup>[1,16]</sup> In our previous report, we demonstrated another use of dual PLD method; they facilitate the differentiation of ATAs from focal hyperperfusion. ATAs appeared in nearly the same configuration in ASL-MRI with PLDs of both 1.5 and 2.5 seconds.<sup>[1]</sup> On DSA, the area corresponding to that affected by ATA is not demonstrated as a hypervascular area at 1.5 or 2.5 seconds but as a stagnant contrast in the vascular structure at 4.5 seconds during the late venous phase.<sup>[1]</sup>

In this study, we examined the usefulness of ASL-MRI with dual PLDs to elucidate sequential changes in response to thrombosis and regression of the giant aneurysm and alteration of the associated hemodynamic state following reconstructive surgery. These ASL findings were validated with DSA findings according to the methods of our previous reports.<sup>[1,6]</sup> To our knowledge, this is the first description of sequential ASL signal changes in response to thrombosis and regression of the giant aneurysm and alteration of the associated hemodynamic state.

## CASE REPORT

A woman aged 66 years presented with decreased right visual acuity over several months. On admission, her visual acuity was 0.04 on the right and 0.1 on the left. Right abducens palsy was noted. Conventional MRI and MR angiography (MRA) revealed a giant right ICA aneurysm (diameter 30 mm) and a left ICA aneurysm (5 mm) [Figure 1a-e]. T1-weighted MRI (T1WI) showed a mixed iso–low-intensity area in the lumen of the right giant ICA aneurysm, although a flow artifact originating from the aneurysm was present [Figure 1c]. T2-weighted MRI (T2WI) revealed an iso–high-intensity area at the center of the aneurysm [Figure 1d].

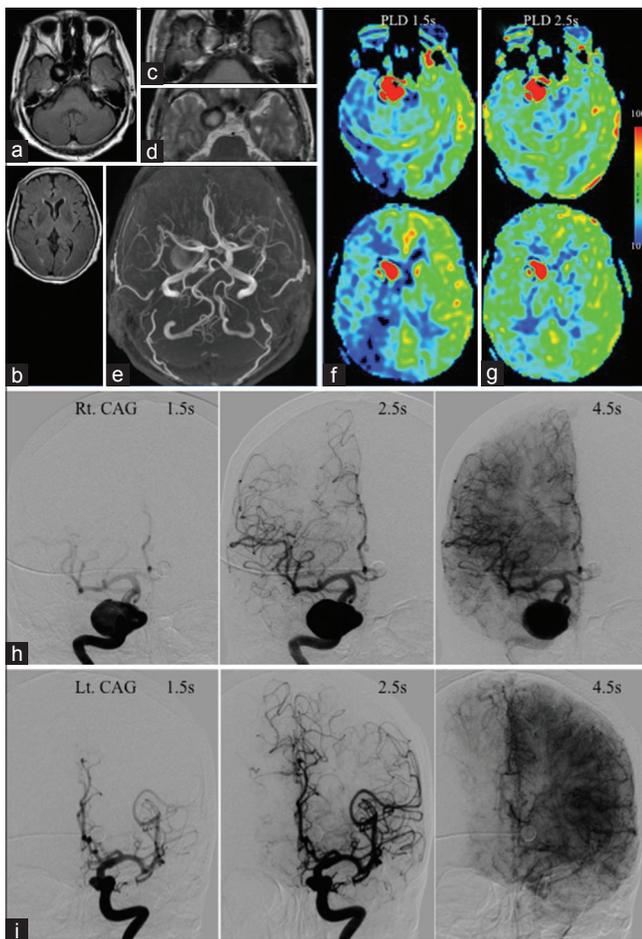
In ASL-MRI with PLDs of 1.5 and 2.5 seconds, although the left aneurysm was not demonstrated, the right ICA aneurysm was depicted as a hyperintense signal area in nearly the same configuration [Figure 1f and g]. This area was large enough to extend to the axial level of the basal ganglia [Figure 1f and g], while the aneurysm was not seen at this level in conventional MRI [Figure 1b]. Hyperintensity circles were also noted in a concentric arrangement central to the right aneurysm [Figure 1f and g]. Although there was no laterality in the bilateral middle cerebral artery (MCA) territories on MRA [Figure 1e], ASL-MRI with PLD 1.5 seconds demonstrated decreased signals in the right hemisphere, especially the right MCA territory [Figure 1f]. ASL-MRI with PLD 2.5 seconds showed improvement in

this decreased area, although a slight right laterality was still present [Figure 1g].

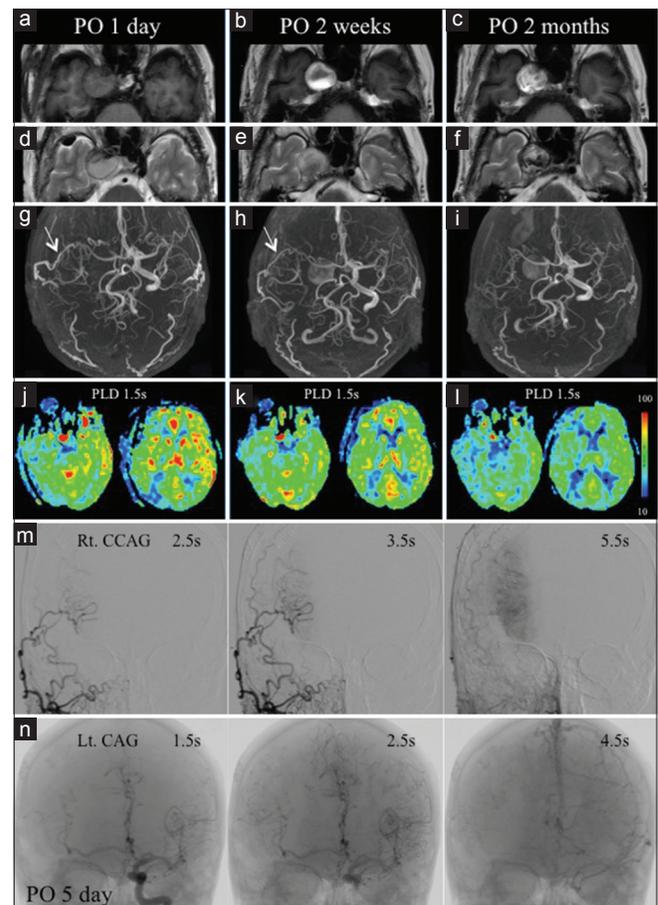
Carotid angiography (CAG) at 1.5 and 2.5 seconds after contrast medium injection into the right and left ICA, respectively, clearly demonstrated the nonthrombosed giant aneurysm at the cavernous portion of the right ICA [Figure 1h] and the aneurysm at the cavernous portion of the left ICA [Figure 1i], respectively. At 4.5 seconds PLD, the contrast in the right ICA aneurysm was still stagnant [Figure 1h, right], while the contrast in the left aneurysm had completely disappeared [Figure 1i, right]. In the left CAG at 1.5 seconds, the trunks of the left MCA and ACA were well opacified, and their peripheries had started to be visualized [Figure 1i, left]. In contrast, in the right CAG at 1.5 seconds, the trunks of the right MCA and ACA were barely visualized due to stagnation of the contrast in the

giant aneurysm [Figure 1h, left]. At 2.5 seconds, the trunks and peripheries of the right MCA and ACA were opacified [Figure 1h, middle] but not fully visualized compared with the left [Figure 1i, middle].

The balloon Matas and Allcock test revealed robust collateral flows through the anterior communicating artery (ACoA) and the right posterior communicating artery (PCoA), respectively. During 20 minutes of balloon test occlusion (BTO), her neurological findings and somatosensory evoked potentials (SEPs) following left median nerve stimulation did not show any decline. For the treatment of the “symptomatic” giant right IC aneurysm, proximal ligation of the right cervical ICA was indicated. The patient underwent right superficial temporal artery (STA)-MCA bypass just before the proximal ICA ligation on the same day with monitoring of SEPs and transcranial motor evoked potentials.



**Figure 1:** MRIs (a-d) and MRA (e) show right giant and left ICA aneurysms. Both on ASL with PLDs of 1.5 (f) and 2.5 s (g), the right aneurysm is depicted as hyperintense signal in the same configuration. ASL with PLD 1.5 s reveals decreased signal in the right MCA territory, and with 2.5 s improved. (h) Right CAG shows the contrast in the right aneurysm is stagnant at 4.5 s after injection. At 1.5 s, the trunks of the right MCA and ACA are barely visualized because of stagnation, and are opacified at 2.5 s. (i) Left CAG shows that the trunks of the left MCA and ACA are well opacified at 1.5 s



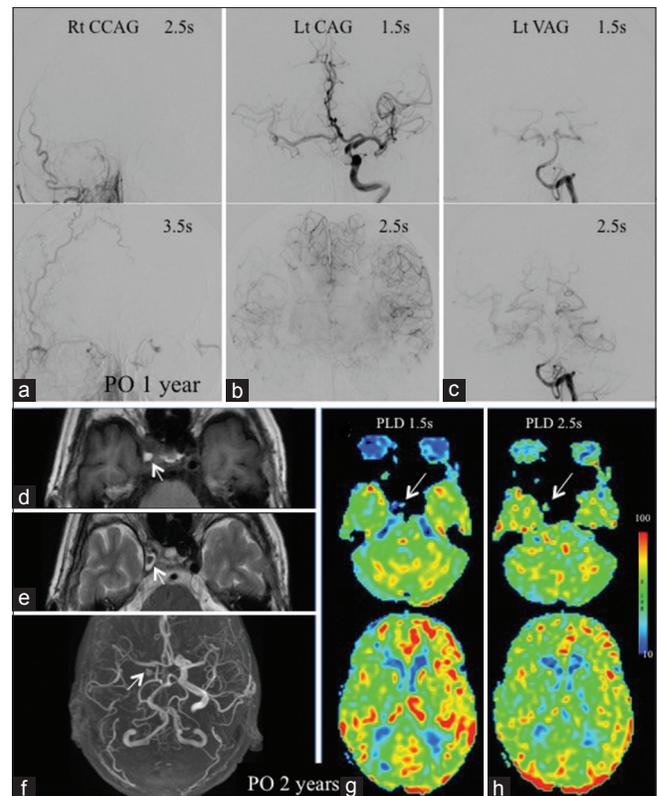
**Figure 2:** MRIs show gradual signal change in the right aneurysm, although the size is unchanged (a-f). The aneurysm is not demonstrable on MRA at postoperative (PO) 1 day (g), but reappears at PO 2 weeks and 2 months (h,i). The bypass is patent at PO 1 day and 2 weeks (g, h), but not at 2 months (i). Perioperative ASL (j-l) shows a gradual decrease in aneurysm size and improving ASL signals in the right MCA territory. Right common CAG at PO 5 days (m) shows part of the right MCA visualized at 2.5 and 3.5 s. Left CAG (n) reveals the trunk and periphery of the right MCA are visualized at 1.5 and 2.5 s

During postoperative (PO) 2 months, conventional MRI revealed a gradual signal change of the right aneurysm, although the aneurysm's size had not changed. T1WI depicted the aneurysm as homogenous and iso-low-intensity at PO 1 day [Figure 2a], iso-intensity surrounded by hyperintensity at PO 2 weeks [Figure 2b], and having an onion skin appearance with flow void signs at PO 2 months [Figure 2c]. In T2WI, the aneurysm was depicted as mixed iso-low-intensity with a low-intensity peripheral rim at PO 1 day [Figure 2d], mixed iso-hyperintensity at PO 2 weeks [Figure 2e], and having an onion skin appearance with flow void signs at PO 2 months [Figure 2f]. MRA did not demonstrate the aneurysm at PO 1 day [Figure 2g], but the reappearance of the aneurysm was noted at PO 2 weeks [Figure 2h] and 2 months [Figure 2i]. The STA-MCA bypass was patent at PO 1 day [Figure 2g] and 2 weeks [Figure 2h], but there was no visualization of the bypass at PO 2 months [Figure 2i].

Perioperative ASL-MRI with a PLD of 1.5 seconds demonstrated a gradual decrease in the size of the aneurysm. At PO 1 day, the size of the ASL hyperintense signal area had markedly decreased in size compared with that shown by preoperative ASL-MRI, and the hyperintense signal area was not demonstrated at the level of the basal ganglia [Figure 2j]. Furthermore, no concentric artifact was noted. ASL-MRI at PO 2 weeks [Figure 2k] and 2 months [Figure 2l] showed further size decreases of the aneurysm. At PO 1 day, ASL signals increased throughout both hemispheres compared with preoperative ASL-MRI [Figure 2j]. The decreased ASL signals on the right hemisphere were mostly improved, although there was still a slight laterality. At PO 2 weeks and 2 months, the increased ASL signals in both hemispheres showed gradual improvement, although the right side still showed slightly decreased ASL signals compared with the left side [Figure 2k and l].

DSA was performed at PO 5 days. Right common CAG (CCAG) demonstrated complete patency of the bypass, and part of the right MCA territory was visualized through this bypass at 2.5 and 3.5 seconds (equivalent to 1.5 and 2.5 seconds in CAG, respectively) [Figure 2m]. Through cross flow via the ACoA, left CAG revealed that the trunk of the right MCA was faintly visualized at 1.5 seconds, and the periphery of the right MCA was visualized at 2.5 seconds [Figure 2n]. DSA did not show opacity of the aneurysm in the right ICA.

At PO 1 year, the patient had completely recovered from her right visual disturbance and abducens palsy and underwent coil embolization of the left ICA aneurysm. At that time, right CCAG failed to reveal the patency of the bypass [Figure 3a]. Left CAG confirmed successful



**Figure 3: (a) Right common CAG at PO 1 year reveals no patency of the bypass. (b) The right MCA trunk and periphery are visualized at 1.5 and 2.5 s on left CAG. (c) Left vertebral angiography depicts right MCA periphery visualization at 2.5 s. MRIs (d-f) at PO 2 years reveal a marked size decrease of the right aneurysm. ASL shows the aneurysm as a tiny spot of low signal at 1.5 s (g) and iso at 2.5s (h). ASL with PLD 1.5 s shows the preoperative decreased ASL signals in the right MCA territory improving with slight laterality (g). ASL with PLD 2.5 s shows this laterality improving somewhat (h)**

embolization of the left ICA aneurysm [Figure 3b]. At 1.5 seconds, the trunk of the right MCA was visualized through cross flow via the ACoA, but it was not fully visualized compared with the left side. The aneurysm of the right ICA was not opacified. At 2.5 seconds, left CAG [Figure 3b] and left VAG [Figure 3c] revealed visualization of the right MCA periphery, but right laterality was still present.

At PO 2 years, conventional MRI and MRA demonstrated a marked size decrease of the right ICA aneurysm. The aneurysm was detected as a small hyperintensity surrounded by a low-intensity region in T1WI [Figure 3d] and a small low-intensity area surrounded by a hyperintensity in T2WI [Figure 3e]. MRA depicted the aneurysm as a small spot without any communication with the artery [Figure 3f]. There was no visualization of the STA-MCA bypass.

ASL-MRI with dual PLDs demonstrated the aneurysm as a tiny spot of low-intensity signal at PLD 1.5 seconds [Figure 3g] and an iso-intense signal

area at 2.5 seconds [Figure 3h]. The intensity and configuration of the spot were not identical between PLDs of 1.5 and 2.5 seconds. To compare with pre- and perioperative ASL-MRI findings, the intensity and size of the ASL signal was markedly decreased. Furthermore, preoperative decreased signals in the right hemisphere, especially in the right MCA territory, were markedly improved at PLD 1.5 seconds [Figure 3g]. Although there was a slight signal decrease in the right hemisphere, this laterality was somewhat improved at PLD 2.5 seconds [Figure 3h].

## DISCUSSION

### ASL signal changes of the giant aneurysm

The prominent finding of preoperative ASL-MRI was that the right giant ICA aneurysm was detected as a hyperintense signal area, while the aneurysm itself was generally not demonstrated on ASL-MRI (as seen for the left aneurysm). The hyperintense signal area of the right giant aneurysm remained in nearly the same configuration in ASL-MRI with PLDs of 1.5 and 2.5 seconds, indicating that the aneurysm demonstrated an ATA.<sup>[1]</sup> In accordance with previous reports,<sup>[1,17]</sup> in DSA, stagnant contrast with high concentration in the right giant aneurysm was still observed at 4.5 seconds during the late venous phase, while the contrast in the left aneurysm had completely disappeared by that time.

The giant aneurysm presented large ATAs resulting from the swirl of the strongly labeled spins in the stagnating blood inside the aneurysm, which extended to the axial level of the basal ganglia. We have also reported a patient with ICA stenosis in whom round-shaped ATAs of delayed and stagnant anterograde flow extended to the level of the basal ganglia.<sup>[1]</sup> Another notable finding was the hyperintense signal circles around the aneurysm. Because these circles were noted in a concentric arrangement, central to the aneurysm, they are also thought to be artifacts because of their strong magnitude and the multiple directions of labeled flow spins within the aneurysm.<sup>[2,5]</sup>

At PO 2 months, conventional MRI revealed gradual signal change of the aneurysm, although its size had not changed. According to previous reports,<sup>[8,14]</sup> these signal changes indicated a dramatic flow reduction and staged and multilayered thrombosis in the aneurysm, although DSA at PO 5 days failed to reveal the right ICA aneurysm. At PO 2 years, conventional MRI and MRA demonstrated a marked size decrease and characteristic intensity change in the right ICA aneurysm. According to a previous report,<sup>[10]</sup> these MRI findings imply complete intraluminal thrombosis and regression of the aneurysm.

In contrast to conventional MRI, ASL-MRI with PLD 1.5 seconds at PO 2 months showed a markedly and

gradually decreased size of the aneurysmal hyperintense signal area. Furthermore, no concentric artifact was noted. Without the availability of ASL-MRI data with PLD 2.5 seconds, whether the ASL-MRI's hyperintense signal is attributed to the ATA cannot be confirmed; however, it is speculated that labeled flow spins dramatically decreased in association with the flow reduction and staged aneurysmal thrombosis.

At PO 2 years, ASL-MRI with dual PLDs demonstrated the aneurysm as a tiny low-intensity spot at 1.5 seconds and an iso-signal region at 2.5 seconds. The intensity and configuration of the spot were not identical between PLDs of 1.5 and 2.5 seconds, indicating that this area did not present as ATA but as blood flow near the aneurysmal wall and vasa vasorum.<sup>[10]</sup> Because there were no available dual-PLD ASL-MRI data between PO 2 months and 2 years, unfortunately, the precise temporal course of these changes could not be demonstrated.

### ASL signals changes to associated hemodynamic states

Preoperative ASL-MRI with PLD 1.5 seconds demonstrated decreased signals in the right hemisphere, especially the right MCA territory. ASL-MRI with PLD 2.5 seconds showed improvement in this decreased-signal area. DSA revealed that this laterality of ASL signals resulted not from the different CBF values but from the different ATT values between hemispheres; this effect was caused by stagnation of contrast within the aneurysm and delayed anterograde flow, as demonstrated in our previous reports.<sup>[1,6]</sup>

At PO 1 day, ASL signals at PLD 1.5 seconds increased across both hemispheres compared with those shown in preoperative ASL-MRI; furthermore, at that time, the preoperative decreased ASL signals in the right hemisphere were markedly improved. Because no perioperative ASL-MRI data were available with dual PLDs, these findings are speculated to have resulted from the shortened ATT<sup>[13]</sup> produced by the abrupt disappearance of stagnant labeled spins within the aneurysm. Increased CBF to the right MCA territory caused by patent STA-MCA anastomosis, as demonstrated by DSA at PO 5 days, was another possible reason. However, these increased ASL signals across the both hemispheres were gradually improved at PO 2 weeks and 2 months, probably because of the obstruction of STA-MCA anastomosis.

At PO 2 years, the preoperative decreased signals in the right hemisphere were markedly improved at PLD 1.5 seconds, as stagnation of labeled spins within the aneurysm had disappeared. ASL-MRI with dual PLDs demonstrated a slightly decreased right ASL signal at 1.5 seconds, which was somewhat improved at 2.5 seconds. This was explained by the DSA findings at PO 1 year: with the obstruction of the bypass, right MCA

territory were opacified with primary collateral pathway via ACoA and PCoA at 2.5 seconds. Labeled blood that travels via collateral pathways of the circle of Willis exhibit prolonged ATT as long as 1 second.<sup>[1,6,9]</sup>

In this case, the bypass was spontaneously occluded in the postoperative course without any sequels. It implies that the patient was tolerant for ICA occlusion without bypass, as was expected by preoperative BTO findings. Since there have been reports describing the development of the postoperative ischemic complications without bypass even among patients with negative BTO findings,<sup>[11,12]</sup> we performed bypass just before the proximal ICA ligation. This may be related to the future impact of ASL-MRI with dual PLD methods on the surgical management of giant ICA aneurysm because there is a question if ASL-MRI can provide any information on postoperative compromise of CBF. As was demonstrated in our previous reports,<sup>[1,6]</sup> dual PLD method could evaluate CBF compromise, on the daily clinical practice, in cases with atherosclerotic steno-occlusive cerebrovascular disease. Further studies should be conducted on whether dual PLD method can be used as evaluation of CBF compromise in BTO.

## CONCLUSION

Although our experience is limited to a single case, serial ASL-MRI with dual PLDs showed dynamic changes in response to thrombosis and regression of the giant aneurysm and alteration of the associated hemodynamic state following reconstructive surgery.

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Nil.

## Conflicts of interest

There are no conflicts of interest.

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