Subclavian steal syndrome (SSS) involves changes in hemodynamics secondary to proximal subclavian artery stenosis and/or occlusion where the subclavian artery “drains” the blood from the vertebral artery. It sometimes induces neuromuscular symptoms, especially in cases with bilateral involvement.

We report the case of a 65-year-old symptomatic male with severe bilateral SSS with complete vertebral reversal. Doppler ultrasonography yielded inconclusive results because of a scar in the left lower neck region leading to poor acoustic windows. Subsequent magnetic resonance imaging with contrast-enhanced magnetic resonance angiography and velocity-encoded phase-contrast magnetic resonance imaging provided the vascular morphology and blood flow pattern which allowed subsequent interventions to be successfully performed.

**Key Words:** Angioplasty • Phase-contrast magnetic resonance imaging • Subclavian steal syndrome

**INTRODUCTION**

Subclavian steal syndrome (SSS) is a condition in which reversed blood flow is noted in the vertebral artery due to ipsilateral proximal subclavian artery stenosis and/or occlusion. Most cases are asymptomatic; however, inadequate brain and upper extremity perfusion may occur thereby leading to neuromuscular symptoms.

Doppler ultrasonography is the first tool of choice for diagnosing SSS, since it is non-invasive, quick, safe and cost-effective. However, the lack of adequate contact between the ultrasound probe and the body may limit its usage in cases with large skin scars. Magnetic resonance imaging (MRI), another non-invasive modality, can provide imaging of vascular structures, and it has been previously employed in unilateral SSS. MRI is less affected by the perivascular environment than Doppler ultrasonography, although MRI is more expensive and takes longer to perform. To the best of our knowledge, only a few cases of bilateral SSS have been reported, and they rarely involved MRI.

**CASE REPORT**

A 65-year-old male heavy smoker presented with a past medical history of an old cerebral vascular accident which occurred 3 years earlier, old coronary artery disease, dyslipidemia, and hypertension. The patient complained of numbness, soreness, and mild weakness of the upper extremities.
bilateral arms with poor wrist pulsation for the past 2 years. Left subclavian artery total occlusion was diagnosed, and he received surgical treatment with a left common carotid artery-left subclavian artery graft in another hospital.

Unfortunately, the symptom of bilateral arm weakness persisted after the operation, and progressive dizziness developed. He then came to our hospital for a second opinion.

Physical examination revealed obvious blood pressure difference between upper and lower limbs: 63/30 mmHg (left arm), 70/35 mmHg (right arm), 105/60 mmHg (left leg) and 95/60 mmHg (right leg). Doppler ultrasonography revealed right subclavian artery stenosis and an inconclusive result with regards the left subclavian artery and the graft vessel because of a large scar on the skin in the left lower neck leading to poor contact between the ultrasound probe and the skin.

MRI of the chest and neck was subsequently performed using a 1.5-Tesla scanner (Magnetom Sonata, Siemens Medical Solutions, Erlangen, Germany) with a gadolinium-based contrast agent injected into a left arm vein for a more complete study. Dynamic contrast-enhanced magnetic resonance angiography (CEMRA; TR/TE = 3/1 ms; flip angle = 30°) revealed total occlusion of the proximal segment of the left subclavian artery and severe vascular stenosis of the right subclavian artery on the early-phase images, and delayed contrast enhancement of the distal segments on late-phase images (Figure 1A-C). In addition, a vascular bulge about 0.5 cm at its largest dimension arising from the anterolateral aspect of the left common carotid artery with a blind end in the left supraclavicular fossa was also noted, which was consistent with a failed graft vessel (Figure 1B).

Velocity-encoded phase-contrast magnetic resonance imaging (VEPC-MRI; TR/TE = 28/3 ms; flip angle = 30°; venc = 150 cm/sec) through the level of the lower neck region showed complete retrograde (cranial-to-caudal direction) filling of the left and right vertebral arteries through the entire cardiac cycle (average blood flow = 1.03 ml/sec and 2.22 ml/sec, respectively) and pulsatile antegrade (caudal-to-cranial direction) filling of the left and right common carotid arteries (average blood flow = 11.06 ml/sec and 13.20 ml/sec, respectively) (Figure 1D). CEMRA also revealed patent bilateral posterior communicating arteries, which supplied blood to the bilateral posterior cerebral arteries, the basilar artery, and bilateral vertebral arteries (Figure 1E). Thus, severe bilateral SSS with complete vertebral reversal was considered.

The patient received a catheter-based angiography study via the right femoral approach which showed 95% stenosis of the right subclavian artery (Figure 2A), total occlusion of the left subclavian artery (Figure 2C), and complete retrograde blood flow of bilateral vertebral arteries, which were compatible with the MRI findings.

Percutaneous transluminal angioplasty (PTA) was then performed. The right subclavian artery was engaged by a 9 Fr JR4 guiding catheter (Cordis Corporation), and the lesion was crossed by a 0.89 mm × 150 cm guidewire (Terumo Corporation). We used a 7.0 × 40 mm balloon (Wanda, Boston Scientific) to dilate the stenosis with a maximal balloon pressure of 10 atm. A 9.0 × 338

Figure 1. (A) The early-phase coronal maximum-intensity projection (MIP) image of dynamic contrast-enhanced magnetic resonance angiography (CEMRA) revealed total occlusion of the left subclavian artery (arrow). (B) The early-phase oblique coronal MIP image of dynamic CEMRA showed a failed graft arising from the anterolateral aspect of the left common carotid artery with a blind end in the left supraclavicular fossa (arrow). Severe stenosis of the right subclavian artery (arrowhead) was also found. (C) The late-phase coronal MIP image of dynamic CEMRA revealed delayed contrast enhancement of bilateral vertebral arteries (arrows). (D) The time-flow curve of VEPC-MRI showed antegrade blood flow of the left common carotid artery (L’t CCA) and the right common carotid artery (R’t CCA), which were above the baseline. The left vertebral artery (L’t VA) and right vertebral artery (R’t VA), however, had completely retrograde flow through the entire cardiac cycle and were below the baseline. (E) The early-phase axial MIP image of dynamic CEMRA through the circle of Willis revealed patent bilateral posterior communicating arteries (arrows).
25 mm stent (Express LD, Boston Scientific) was deployed with a maximal pressure of 11 atm. Post-procedure angiography revealed no residual stenosis of the right subclavian artery and antegrade flow of the right vertebral artery (Figure 2B).

Six months later, PTA for the left subclavian artery lesion was performed using a similar method. We used a 3.0 x 20 mm balloon (Smash, Boston Scientific) with a maximal balloon pressure of 10 atm, followed by a 6.0 x 40 mm balloon (Wanda, Boston Scientific) with a maximal balloon pressure of 10 atm to re-construct the native lumen of the left subclavian artery. A 7.0 x 37 mm stent (Express LD, Boston Scientific) was deployed with a maximal pressure of 12 atm, followed by in-stent dilatation by an 8.0 x 20 mm balloon (Wanda, Boston Scientific) with a maximal pressure of 12 atm. Post-procedure angiography revealed no residual stenosis of the left subclavian artery and antegrade flow of the left vertebral artery (Figure 2D). The patient’s neuromuscular symptoms subsided after the procedures.

DISCUSSION

Bilateral subclavian steal syndrome

Subclavian steal syndrome was first described by Contorni in 1960. It is a condition in which reversed blood flow is noted in the vertebral artery due to ipsilateral proximal subclavian artery stenosis and/or occlusion. Bilateral SSS is rare, and it was first reported in 1965 by Coder et al. In cases of bilateral SSS, retrograde flow in the vertebral arteries is accomplished by stealing flow from the carotid artery and the circle of Willis. Bilateral SSS presents more frequently with neuromuscular symptoms. Upon physical examination, a blood pressure difference may not present between bilateral upper extremities, but rather between upper and lower extremities. Bilateral SSS comprises about 5% of all cases with subclavian steal.

Doppler ultrasonography for diagnosing SSS

Based on Doppler ultrasonography, von Reutern and Pourcelot reported three vertebral blood flow patterns in SSS: mild, systolic deceleration without any retrograde flow; moderate, alternating flow with a retrograde flow in systole; severe, complete flow reversal during the entire cardiac cycle. However, as in our case, some situations limit the use of Doppler ultrasonography in the neck. Examples of this include poor acoustic windows due to dressings covering a wound, granulation artifacts in cases with previous surgery or radiotherapy, a lack of adequate contact between the ultrasound probe and the skin with a large scar, and severe tortuous vessels leading to difficulty in sampling.

Magnetic resonance imaging for diagnosing SSS

Other non-invasive diagnostic tools can be used to evaluate SSS such as computerized tomography (CT) and MRI. Unlike CT, MRI does not use ionizing radiation and is generally a very safe procedure, although it takes longer to perform than CT. Both CT and MRI can reliably define the underline etiology of SSS, which may be missed by Doppler ultrasound. Magnetic metal implantations are a major contraindication for MRI, and patients with acute or chronic severe renal insufficiency or allergic reactions to gadolinium-based contrast...
agents increase the risks in CEMRA.

With an adequate injection of contrast agent, CEMRA enables the visualization of vascular disease based on morphological changes of the diseased vessel. In VEPC-MRI, the operator can choose target vessels and calculate the vector of blood flow. This information provides evidence of the hemodynamic changes of the target vessels. With the combination of CEMRA and VEPC-MRI, the morphological vascular condition and information on quantitative blood flow can be clearly demonstrated, even if the target vessels are hidden deep in the body or surrounded by complex perivascular structures as in our case. This technique is therefore an alternative choice for our case and provides the definite indication for further intervention.

To our knowledge, this is the first case report that combines the CEMRA and VEPC-MRI on a symptomatic bilateral subclavian steal syndrome patient with serious limitation of Doppler ultrasonography. Besides, the quantitative data of the bilateral complete vertebral reversal have never been mentioned in previous reports.

In our case, due to the inconclusive carotid Doppler ultrasonography result, combination of the CEMRA and VEPC-MRI confirmed the diagnosis of bilateral complete vertebral reversal. Therefore, it provided persuasive evidence for us and further encouraged the patient to receive PTA to treat his disease.

PTA for treating symptomatic bilateral SSS

In 1994, Horst et al. presented the first case of symptomatic bilateral SSS successfully treated by bilateral PTA with a unilateral stent in the left side. The patient was symptom-free without recurrent stenosis during 6 months of follow-up. Because of the low incidence of bilateral SSS, the treatment of bilateral SSS with simultaneous or sequential PTA remains controversial. In our case, because we were concerned that dramatic flow changes after the intervention may have altered brain perfusion, PTA was performed sequentially. Neuromuscular symptoms improved gradually and no adverse event was detected. No clinical evidence of recurrent stenosis during 12 months of follow-up was noted.

CONCLUSIONS

We reported a symptomatic case of severe bilateral SSS with complete vertebral reversal. Doppler ultrasonography yielded inconclusive results, whereas CEMRA and VEPC-MRI provided us with information about the vascular morphology and the blood flow patterns necessary to make an accurate diagnosis. We suggest that a comprehensive understanding of MRI techniques may enhance patient care and outcomes.

REFERENCES