Collateral venous pathways in superior vena cava syndrome - a systematic analysis

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Learning objectives

The purpose of our educational exhibit is to:

1. give a systematic overview of collateral pathways occurring in case of superior vena cava syndrome (SVCS);
2. to highlight clinically relevant imaging appearances of collateral pathways in SVCS on contrast enhanced computed tomography (CECT) with its associated pitfalls.
SVCS describes a partial or complete occlusion of the superior vena cava (SVC) with variable clinical symptoms such as edema, cyanosis, enlarged venous vessels, cough, stridor, dyspnea, or even coma. Reduced or stopped blood flow via the physiological main route decreases cardiac output and forces blood to develop detours in order to compensate for the diminished minute volume. CECT is the modality of choice for clarification, for it is widely available and offers confirmation and morphologic depiction of the extent of obstruction as well as the underlying pathology. The main causes of SVCS are tumors, radiotherapy and iatrogenic interventions. Hematoma, infection and long-term hemodialysis are less common causes of SVCS.
Findings and procedure details

The authors reviewed CT angiography studies with known SVCS. Based on the analysis of these examinations, we could identify seven venous collateral pathways. An overview is displayed in Table 1. We will describe each of these pathways individually from an anatomical perspective with a pathophysiological background and point out the clinical relevance.

1. Lateral thoracic route

The lateral thoracic vein runs diagonally along the bony thorax from the anterior to the lateral wall as a continuation of the thoracoepigastric vein, and physiological blood flow is directed upwards into the axillary vein. Hereby, the lateral thoracic vein drains blood from the anterior serratus muscle and from the pectoral muscles. In the reverse direction, the thoracoepigastric vein provides a connection to the superficial epigastric vein (Image 1 a+b).

A thoracic inlet venous obstruction that extends as far as to the axillary vein results in a stream inversion of the lateral thoracic route. Now blood flows in a downward direction into the thoracoepigastric vein and from here either to the paraumbilical / umbilical veins and the portal venous system, or into the superficial epigastric vein and the femoral vein eventually returning via the inferior vena cava (IVC) to the right atrium. To this effect, the lateral thoracic vein provides an additional collateral pathway between the SVC and the IVC, also referred to as cavo-caval anastomosis.

In case of SVCS, blood may be redirected via superficial epigastric veins and the remnant of the umbilical vein back into the portal venous system, potentially leading to focal liver enhancement that may be misinterpreted as being pathologic (Image 2).

2. Internal thoracic route

The internal thoracic veins (also known as the internal mammary veins) accompany the internal thoracic artery on each side. They drain blood upwards from the superior epigastric vein, the intercostal veins and variably also from the pericardiophrenic veins. They run parallel to the sternum upwards along the internal thoracic wall and terminate in the corresponding brachiocephalic vein (Image 3a+b). Among each other, they are connected through small branches.
An obstruction of the brachiocephalic vein after of the confluence with the internal thoracic vein or the SVC leads to a stream inversion. And because venous drainage of the sternum consists of an intramedullary network that is connected to the internal thoracic veins via so called transcortical veins, a pseudo pathologic enhancement - similar to the liver - in case of SVCS can be found in the sternum as well. The reason for this is most likely due to elevated pressure resulting in reversed flow in the internal thoracic veins and backflow into the venous capillary network of the sternum. Pseudo pathologic enhancement of the sternum can be mistaken for osteoblastic metastases, classically from prostate cancer or breast cancer. Therefore, knowledge of this pseudo enhancement in the sternum in case of inlet thoracic venous obstruction is important for avoiding false interpretation of osseous lesions.

3. The azogos route

The azygos venous system (AVS) consists of the azygos vein, the hemiazygos vein, and the accessory azygos vein. These vessels are building an H-shaped formation anteriorly to the vertebral column. The azygos vein normally takes its course on the right side of the vertebral column. It is collecting blood from the posterior wall of the abdomen via lumbar veins, crosses the diaphragm through the aortic hiatus, receiving more influx from intercostal veins (Th5 to Th12) and in a variable amount from bronchial, pericardial and thoracic veins, eventually draining into the SVC. On its way, the hemiazygos vein flows into the azygos vein at the level of the thoracic vertebra 9 and the accessory hemiazygos vein at the level of the right thoracic vertebra (Image 4 a+b). It is important to note that the AVS communicates with the vertebral venous plexus, which is described in more detail below.

As the AVS connects the IVC with the SVC, it provides another collateral pathway to the right atrium in case of either IVC or SVC obstruction. Depending on the level of obstruction, blood flow is either anterograde (obstruction level lies above the influx of the azygos vein) or retrograde (obstruction level lies between the influx of the azygos vein and the right atrium).

The establishment of the azygos venous route is paralleled by vessel enlargement. In case of chronic SVCS, the vessel diameter grows slowly over time and most patients remain asymptomatic. In conventional chest radiography, such an enlargement can easily be mistaken as a mediastinal mass. Here, contrast-enhanced cross sectional imaging usually allows for ruling-out malignancy and for correct interpretation of the imaging finding.

4. Vertebral venous route
Three main networks are building the vertebral venous system, which are all are interconnected with each other: the intraosseous venous drainage, the epidural venous plexuses, and the paravertebral veins. Each vertebral body has its own intraosseous venous drainage: blood is collected in the venous sinus and passes through the nutrient foramen at the back of the vertebral body into the epidural venous plexus, consisting of an anterior and a posterior part. The paravertebral veins are named after their location: vertebral veins in the neck, azygos, accessory hemiazygos, and hemiazygos vein in the chest, ascending lumbar veins in the abdomen and internal iliac veins in the pelvis (Image 5 a+b).

There is often is seen an enhancement in vertebral bodies in patients with obstruction of the SVC and/or the brachiocephalic veins (Image 6a). This type of enhancement can be readily misinterpreted as osteoplastic vertebral metastases, previously also called "vanishing metastases" because follow-up imaging studies with different routes of contrast media injection show that this enhancement is no longer present (Image 6b).

5. Anterior cervical venous route

The veins of the neck consist of the deep cervical veins (described in the vertebral venous route) and the superficial cervical veins. These two systems are interconnected through various anastomoses. The external jugular vein conducts blood mainly from the superficial part of the forehead and scalp, and to a lesser extent from deeper tissue. It originates behind the angle of the mandible as a result of unification of the posterior auricular with the retromandibular vein, runs underneath the platysma and the superficial fascia and receives tributaries dorsally from the posterior external jugular, transverse cervical, and the suprascapular vein, and anteriorly from the anterior jugular vein, where it is connected with its contralateral twin. The external jugular veins drains finally into the subclavian vein. The internal jugular vein however collects blood from deeper parts of the face, neck, skull, and brain. It results from the junction of the sigmoid sinus with the inferior petrosal sinus at the level of the skull base and takes its course in the carotid sheath and flows into the subclavian vein. The main tributaries to the internal jugular vein in cranio-caudal direction are the maxillary vein, sometimes the retromandibular vein, then usually in a common trunk with the fascial and lingual vein. The thyroid veins exist on three levels: superior, middle and inferior. The former two ends in the internal jugular vein, the lesser one of this network ends in the brachiocephalic vein or sometimes in a common trunk directly in the SVC (Image 7 a+b).

In case of SVCS, venous return is granted by efflux via the aforementioned collateral pathways depending on the location of obstruction, preferential via the lateral thoracic route, the vertebral venous route, or by channeling a connection to the AVS or via numerous smaller, irregular formed venous networks in the head and neck region.
This variability is of clinical relevance and a profound knowledge about standard anatomy and its variations is vital, particularly for anesthesiologists or interventional radiologists as it provides a common access for intravenous catheterization, as well as for surgical interventions in this anatomical region.

6. Periscapular venous route

The union of the brachial with the cephalic vein at the lower margin of the teres minor muscle represents the beginning of the axillary vein. At the level of the first rib, it becomes the subclavian vein. The subclavian vein then unites with the internal jugular vein behind the anterior scalene muscle to form the brachiocephalic vein. Other tributaries to the axillary vein are the basilic, subscapular, circumflex humeral, lateral thoracic and the thoraco-acromial vein. Normally, blood from the periscapular musculature drains via the dorsal scapular vein, which runs with the concomitant artery, and ends either in the subclavian vein or in the external jugular vein. However, there are numerous smaller venous vessels around the scapula with a variable drainage, depending on pressure ratios and established collaterals (Image 8 a+b).

Similar to the internal thoracic route, the periscapular venous route serves as collateral pathway in in SVCS, and CT images then show backflow of contrast agent into this venous plexus. In most cases, the periscapular venous route does not build a single collateral pathway itself, but a pathway that is included among others.

7. Esophageal / periesophageal and pericardiophrenic venous route

Standard venous anatomy of the esophagus includes periesophageal and paraesophageal veins. The smaller periesophageal veins build an inner plexus that is connected with a larger, outer plexus via so called perforaters. Drainage is divided into three sections: from the proximal third of the esophagus into the brachiocephalic vein or directly into the SVC, from the middle third into the AVS and to the IVC, and from the distal third into the azygos vein and via the left gastric vein into the portal venous system.

In SVCS, the level of obstruction is the determining factor and gives direction to collateral pathway development. If the occlusion is located above the influx of the azygos vein, blood can flow back to the SVC via the AVS and there is no or little backflow into the IVC or the portal venous system. In case of obstruction below the entry of the azygos vein, a stream inversion may result and blood returns in a craniocaudal direction via AVS and the peri-/ paraesophageal collaterals eventually draining into the IVC and right atrium. When blood flows retrograde through these valveless vessels, varices develop from elevated pressure in about 30% of patients with SVCS. Because of this reversed craniocaudal flow direction, the term "downhill varices" was introduced. In distinction, increased portal
venous pressure leading to increased blood flow in a caudocranial direction in peri- and paraesophageal veins results in varices which sometimes are called "uphill varices".

The pericardiophrenic veins drain the pericardium and the diaphragm. They accompany the corresponding arteries andtribute to the brachiocephalic vein, either directly or via internal thoracic veins. Particularly on non-enhanced CT examinations, varicose dilation of the pericardiophrenic veins can be misinterpreted as pulmonary or pericardial mass. Thus, knowledge of this pericardiophrenic collateral pathway is important for a correct interpretation of the imaging findings (Figure 9 a+b).
**Fig. 1:** CT angiography examination of a 68-year-old male patient with lung cancer and SVCS due to complete obstruction of the SVC. Intravenous contrast media was administered in an antecubital vein of the right arm. Thick maximum intensity projection (MIP) reformation (a) and cinematic rendering (b) shows venous collateral pathways via dilated lateral thoracic veins (arrow) and intercostal veins to the internal mammary vein (arrowhead) and to contralateral thoracoepigastric veins (asterisk).

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Fig. 2: Axial CT angiography (arterial phase) of a 72-year-old patient with SVCS due to advanced stage pleural mesothelioma causing obstruction of the SVC. Intravenous contrast media was administered via an antecubital vein of the right arm. Pseudo pathologic liver enhancement (circle) due to reversed flow from the lateral thoracic route into the portal venous system is shown. Note opacification of the vertebral venous route (arrow) as an additional collateral pathway.

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Fig. 3: CT angiography examination of a 39-year-old male patient with SVCS due to left pectoral pacemaker, with administration of intravenous contrast media in an antecubital vein on the right arm. Thick maximum intensity projection (MIP) reformation (a) and cinematic rendering (b) showing dilated internal thoracic veins (white arrows) fed by intercostal veins (arrowhead) with drainage via diaphragmatic veins (asterisk).

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Fig. 4: CT angiography examination of an 18-year-old male patient with SVCS due to acute lymphoblastic leukemia with a large mediastinal mass with an near complete, slit-shaped compression of the SVC, after administration of contrast media through an
antecubital vein of the left arm. Thick maximum intensity projection (MIP) reformation (a) and cinematic rendering (b) showing venous collateral pathways through the azygos route, with a dilated azygos (white arrow) and hemiazygos vein (arrowhead). Note the opacification of the vertebral venous route (asterisk) as an additional pathway.

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Fig. 5: CT angiography examination of a 59-year-old male patient with thoracic stent graft placement (asterisk), supra-aortic debranching, and embolization of the brachial trunk due to aortic dissection, with administration of intravenous contrast media through an antecubital vein of the right arm. Thick maximum intensity projection (MIP) reformation (a) and cinematic rendering (b) showing the vertebral venous route with dilated paravertebral veins (white arrow) and posterior external venous plexus (arrowhead).

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Fig. 6: CT angiography examination of a 69-year-old male patient with numerous collateral pathways due to lymphoma. Sagittal CT reformation of the thoracic vertebral column (a) shows enhancement of the seventh cervical vertebra, that easily can be misinterpreted as osteoplastic metastasis. Sagittal CT reformation of the cervical spine (b) acquired 3 minutes later shows considerably lower attenuation of the vertebra, indicating pseudopathologic enhancement. Note prominent venous vessels (arrow) dorsal to the spinous process representing collateral circulation.

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**Fig. 7:** CT angiography examination of a 76-year-old male patient with high-grade compression of the SVC and the left brachiocephalic vein after cardiovascular surgery with thoracic stent graft placement, supra-aortic debranching due to aortic dissection Stanford type A, with administration of contrast media through an antecubital vein of the left arm. Thick maximum intensity projection (MIP) reformation (a) and cinematic rendering (b). Note the venous collateral pathways through the anterior cervical route with dilated left internal jugular (white arrow), middle thyroid (asterisk), and inferior thyroid (arrowhead) veins.

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**Fig. 8:** CT angiography examination of a 72-year-old male patient with lung cancer and consecutive SVCS with complete obstruction of the SVC, the left brachiocephalic vein as well as bilateral thrombosis of internal jugular and subclavian veins, with administration of contrast media through an antecubital vein of the right arm. Thick sagittal maximum intensity projection (MIP) reformation (a) and cinematic rendering (b). Note the venous collateral pathways with dilated periscapular (white arrows), supraclavicular (arrowhead) and intercostal (asterisk) veins.

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**Fig. 9:** CT angiography examination of a 75-year-old female patient with obstruction of the SVC and the right brachiocephalic vein due to a large right sided mediastinal mass, with administration of contrast media through an antecubital vein of the left arm. Thick maximum intensity projection (MIP) reformation (a) and cinematic rendering (b). Note the venous collateral pathways through the periscapular and the pericardiophrenic route, showing dilated periscapular (arrow) and pericardiophrenic (arrowheads) veins.

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**Table 1:** The seven collateral pathways and their key radiological features as well as pathologic conditions and pitfalls.

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Conclusion

Collateral venous pathways are a typically finding in patients with superior thoracic inlet obstruction. In the majority of cases, more than a single collateral pathway is developing for detours of the blood flow to the systemic circulation. Several of these collateral pathways may play a critical role also in radiologic imaging because pseudo pathologic enhancement of bony structures and parenchymal organs may occur. Considering these imaging findings in the presence of collateral pathways may help in the correct interpretation and for avoiding unnecessary follow up examinations.
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