

Most of the cerebral venous drainage is carried by the extracranial venous system in the neck. The main routes of drainage are the IJVs, the vertebral venous system, and the deep cervical veins, presenting a wide inter-individual variability both in the functional prevalence between them and in the postural effect [1–5].

These three routes of cerebral venous outflow have their multiple anastomoses in the neck, especially in the craniocervical junction [1, 3]. The IJV and VV can be easily identified and dynamically studied with ultrasound technique.

2.1 Jugular Veins

IJV is the vein of greater size in the cervical region and is considered the main cerebral venous outflow route, particularly in the supine position. The cerebral venous flow goes mainly from the superficial and deep venous system to the transverse sinus (TS) which in its turn continues in the sigmoid sinus (SyS), which drains into the IJV. The IJV joins the subclavian vein (SV) to form the BCV. The confluence of the two brachiocephalic veins gives rise to the superior vena cava (SVC), which drains the cerebral venous blood in the right atrium.

The IJV therefore begins at the level of the jugular foramen, after the junction of the inferior petrosal sinus (IPS) with the SyS, as a direct continuation of the latter. At this level, there is a slight expansion, called jugular bulb or gulf, which cannot be explored by ultrasound, and which continues relying on the anterior surface of the transverse process of the atlas [6]. The interaction between these two structures may obstruct the jugular venous outflow in some cases evidenced by neurosurgery. However, not even this segment can be investigated by ultrasound, while the next segment, at the level of epistropheus or C2, becomes explorable. In this segment, the relationships of contiguity of the IJV with the carotid axis are easily recognizable. The most common course of IJV is slightly anterior and lateral compared to the internal carotid artery (ICA), with a distance of about 1 mm from it in 69.5 % of examined cases. Variations in the anatomy of the IJV and its correlation to CCA are frequent [7]. The subsequent course of the IJV maintains this relationship with CCA, passing under the anterior edge of the sternocleidomastoid muscle to join the SV and converge into the BCV [8].

In a study performed with computed tomography angiography (CTA) aimed to evaluate the IJV anatomy and its relationship to

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the carotid artery, out of 176 IJV examined both from the right and from the left side compared to the CCA, 85.2 % of IJV were in a lateral position, 12.5 % in the anterior position, 1.1 % in the medial position, and 1.1 % in the posterior position [7]. Furthermore, in an ultrasonic study designed to evaluate the degree of overlap between the IJV and CCA in the position of the head suitable for IJV cannulation, in over 1,000 veins, the IJV covers even if only partially the CCA in 54 % of patients, predisposing them to the accidental puncture of the carotid artery [9]. The variability may be even greater if you consider the effect of the rotation of the head; in fact, the overlap between IJV and CCA increases passing from the neutral position of the head to a rightward rotation (23.3 vs. 39.2 %) and to a leftward one (35.3 vs. 52.8 %), so that the incidence of lateral positioning of the IJV compared to the CCA is significantly reduced with the rotation of the head (40 vs. 21 % at right, 26.5 vs. 10.5 % at left). The right side appears, however, associated with a minor overlap, whatever the position of the head [10].

An important and well-studied element of the IJV is its valve apparatus, located near the confluence with the SV, and present in 86–93 % of the veins in autopsy case studies [11].

From the ultrasound point of view, it is therefore possible to divide the IJV into three different segments:

- a rostral segment or J3, bounded below by the carotid bifurcation and corresponding to the IJV segment before receiving the confluence of the common facial vein.
- an intermediate segment or J2, between the carotid bifurcation and the supra-avalvular plan,
- a lower segment or J1, consisting of the valve plane and of the dilation immediately supra-avalvular.

Morphological anatomical abnormalities of IJV are considered rare; for example, duplication would have a ratio of 4/1000 unilateral cervical dissections [12].

2.2 Internal Jugular Vein Valves

The high-resolution ultrasound examination revealed the presence of a valve in one or both veins in 87 % of cases in the series of Lepori et al. [13] and in 72 % in the series of Macchi and Catini [14]; the series of Darge et al. [15] in a population of children and young adults has found instead a prevalence of 96 %. In autptic studies on adults, the 86–88 % of the examined subjects had a valve [16, 17]. Gender differences in the prevalence of the valvular apparatus of the IJV are not reported, and in the subjects with unilateral valve, it is more commonly located to the right side.

Murase et al. [18] in an autptic study judged as competent 88 % of the valves located on the right side and only 44 % of those located on the left one. Furthermore, it is known that the cerebral venous drainage is asymmetric, with the right side more frequently dominant than the left one. From these findings, it can be hypothesized that the dominant side is more frequently equipped with a valve.

The valve cusps are macroscopically described in anatomical studies as thin translucent structures; the majority of valves are composed of two cusps (66–90 %). Monocusp valves are the second most common form, while tricuspid valves account for 6–7 % [15].

The valves are located on the distal portion of the IJV (J1, in the ultrasound subdivision above suggested), proximal to the jugular bulb [13]. Physiologically, a complete closure of the valve occurs during diastole, in order to prevent the retrograde transmission of the right atrial pressure through the SVC and BCV into the IJV [19].

2.3 Size of the IJV and Cross-Sectional Area

There is a broad range of normality regarding the size (in terms of cross-sectional area—CSA) and the symmetry of the IJV. The limits of the

information available in the literature depend on the fact that most of the published studies have not been performed on normal subjects but on intensive care units patients, with the aim of evaluating the options and risks of a jugular venous catheterization. They are often hypo- or hypervolemic subjects with hemodynamic and respiratory diseases, thus making the data difficult to be exported to normal subjects. Furthermore, in the context of neuroradiological studies, for example CTA, there is not the possibility to assess the influence of breath dynamics on the IJV CSA. Under these restrictions, there are some ultrasonic studies that show, at the J2 level, how the normal venous diameter may vary from 9.1 to 10.2 mm, although a much smaller IJV, with diameter less than 5 mm, according to the evaluation of the authors, can be found in 13.5 % of the subjects on the right side and in 10.6 % on the left one [20]. In this category of patients, that is subjects with kidney disease for whom central venous catheterization was required so as to obtain access for dialysis, the angiographic study also indicated the presence of anatomical abnormalities of the central veins (IJV, SCV, BCV), including stenosis and/or angles, especially in those with a previous history of jugular catheterization with tunneled catheters (65 vs. 30 %) [21].

The use of CT angiography for the measurement of the diameter of the IJV bilaterally showed that 80.5 % of people have a dominant size of the right IJV [22, 23]. Furthermore, 7/176 IJV have been identified as hypoplastic, and in one case, such a condition was present bilaterally [22]. These considerations led the authors to suggest the priority of the right side for central venous catheterization.

Also for the IJV diameter, as well as for the presence of valves, there are no differences in gender and age [24].

The factors that can affect the size of the IJV are many, including the conditions of hydration, the cardiac and respiratory situation, which determine the intrathoracic pressure, the position of the head, and extrinsic compression by other structures in the neck, owing to the high compressibility of the venous vessels for the low

pressures within them [25]. Some positional maneuvers, such as the contralateral head rotation, may result in an increase in the area of the IJV examined with a consensual reduction in contralateral vein area, almost an occlusion. Similar increase in the area can be determined by the position of Trendelenburg [26, 27].

Another condition that can affect the area of the IJV is the occurrence of a phlebectasia, which is a focal dilatation of the terminal bulb of the IJV in the immediately subvalvular area; it is a benign condition, most frequently found in pediatric patients because it determines the appearance of a mass of the lower cervical region, most common on the right side for a more direct transmission of the intrathoracic pressure through the shortest innominate vein, also potentially equipped with valves [28, 29]. The ultrasound appearance of jugular phlebectasia is that of a fusiform dilation of the vessel, which, after execution of Valsalva maneuver, has a further considerable increase in size, both compared to the values of healthy control subjects and when compared to the contralateral IJV. The ratio of the diameter of the IJV at rest/Valsalva was calculated in 1:22 in normal subjects and 1:72 in patients [29].

2.4 Branches of the IJV

There are several venous branches that drain into the IJV in its cervical course. Among these, in the rostro-caudal direction, the most important are the facial vein, the lingual, the superior and middle thyroid veins. The first three can join in various ways, forming the thyreo-linguo-facial trunk, which is called facial or thyreo-facial vein before draining into the IJV. In addition, the main branches of the IJV of the two sides are connected by several midline anastomotic branches, helping to maintain an adequate venous outflow. Also, IJV branches are provided with valves, as demonstrated by an anatomical study [30]. The frequency (number of valves/cm of course) is variable: 0.24 ± 0.16 in the facial vein, 0.07 ± 0.15 in the lingual vein, $0.05 \pm$

0.10 in the superior thyroid vein, and 0.22 ± 0.40 in the media thyroid vein.

When the valves are present, they may be continent, thereby preventing retrograde venous flow, or incontinent, thus forming part of the circuit of regurgitation in case of retrograde transmission of venous hypertension [31].

The branches of the IJV may be identified by ultrasound, both in transverse scan and in longitudinal scan, B-mode and color mode, and similarly also the Doppler waveform can be sampled. During the cross-sectional scanning of the jugular axis, it is frequently possible to identify the terminal portion of IJV branches, as tributaries thereof, usually at the level of the cervical medium segment either J2 and J3 or rostral (sub-mandibular), less frequently at the caudal level, J1 segment. The Valsalva maneuver often facilitates the identification of the IJV branches, as well as allowing the identification of possible valve incontinence of the same or of the circuits of regurgitation. Once the branches of the IJV have been identified in this way, the transition to a longitudinal scan allows to follow a segment of greater length and also to identify the outflow into the IJV or the presence of any valves, as described also by some studies [32]. In longitudinal scanning, both in color mode and in Doppler mode, it is possible to identify the flow direction of a single branch of the IJV, as well as to apply the Valsalva maneuver to identify a possible reflux.

2.5 Superficial Veins of the Neck

The superficial veins of the neck and head are highly variable with a few fixed elements:

- The superficial temporal vein and the maxillary vein join to form the retromandibular vein, which branches as it crosses the parotid. The posterior branch, together with the posterior auricular vein, forms the external jugular vein (EJV), whereas the anterior branch joins the facial vein to form the common facial vein which flows into the IJV. The EJV crosses the sternocleidomastoid muscle in the superficial fascia, passes through the roof of the rear triangle, and then pierces the deep fascia 2.5 cm

above the clavicle to connect either in the confluence between IJV and SV (60 %), or in the SV (36 %), or in the IJV (4 %). It is not rarely duplicated [33]. Also, the EJV presents the valves, usually two, one in the end portion, near the confluence, and one approximately 4 cm above the level of the clavicle [34].

The anterior jugular vein (AJV) originates at the level of the hyoid bone from the confluence of blood from the superficial veins, from the branches of the EJV, from facial veins or from the same IJV. It runs alongside the neck midline, crossing the thyroid isthmus. It connects with the contralateral vein (jugular arc) just above the sternum, and subsequently, it deepens and flows into the SV (54 %) or into the EJV (46 %) [35]. There is sometimes the possibility of a single AJV in the midline instead of two peer structures [36].

2.6 Vertebral Veins

The vertebral venous system forms a network of vessels freely communicating, without valves either transverse or longitudinal. It consists of an inner part, the intraspinal epidural venous plexus, and of an outer part, paravertebral plexus, both of which continue for the entire length of the spinal cord. The system communicates with the deep thoracic and lumbar veins, the intercostals veins, the azygos and hemiazygos veins, as well as with the inferior vena cava.

The vertebral venous system presents a rather complex organization, since it is mainly constituted by two elements, the vertebral venous plexus and the VV (i.e., the venous plexus of the vertebral artery—VA) [3, 37, 38]. The vertebral venous plexus can be subdivided into an internal plexus (internal vertebral plexus, anterior and posterior) and an outer plexus (external vertebral plexus, anterior and posterior).

The VVs are the main longitudinal part of the external vertebral venous system. The VVs and the deep cervical veins, which are located within the muscle layers of the neck, receive flow from the marginal sinus and SyS through the condylar veins and their emissaries and from the venous

plexus surrounding the foramen magnum. In addition, there are several segmental connections between the internal and external parts of the vertebral venous system. The VVs, the deep cervical veins, and the EJV join the BCV.

The deep cervical veins and the VVs are considered to be the external component of the vertebral venous plexus. The intervertebral veins connect the VVs with the internal vertebral venous plexus within the spinal canal [39]. The VV exits the transverse foramen at the level of C7 as a single trunk, which flows into the back side of the BCV.

The complex connections of the vertebral venous outflow with the vertebral venous system at the skull cervical junction have been demonstrated both in anatomical and in angiographic studies [3, 41]. Among these, the most important and unvarying structure is the anterior condylar confluent (ACC), into which the lateral and anterior condylar veins, the IPS, and the IJV flow. The numerous anastomoses of the ACC make it an intersection between the cavernous sinus (CS), the dural sinuses of the posterior fossa, and the cervical posterior outflow tract (vertebral venous system and deep cervical veins).

The posterior and lateral condylar veins allow the connection with the external vertebral venous plexus, whereas the anterior condylar veins are linked to the internal vertebral venous plexus. There are anastomoses between the anterior external vertebral venous plexus, the VVs, and the deep cervical veins located in the region of the craniocervical junction.

The pterygoid plexus and the facial veins are other important ways of side extracranial outflow.

The pterygoid plexus communicates with the CS and finally drains into the EJV [37]. The facial vein can receive the venous flow from the superior ophthalmic vein, which reverses when the venous pressure in the CS is high [42, 43].

2.7 Doppler Waveform

The IJV and the VV have a largely similar Doppler waveform since they are affected by analogous hemodynamic parameters. However, the morphology of the Doppler waveform of the IJV is described in greater detail.

The heart contractions and the changes in the intrathoracic pressure are reflected in the Doppler waveform. During expiration or the Valsalva maneuver, the intrathoracic pressure increases, leading to a reduction in the venous return and to an increase in the diameter of the IJV. In this phase, we observe a poor or absent flow. During inspiration, the venous flow is increased as a result of negative intrathoracic pressure, and this produces a waveform of greater amplitude.

The typical Doppler waves, S, v, D, and a, at the level of the SCV can usually be identified also in the J1 segment of the IJV.

The normal venous flow is influenced by the retrograde pulsatility determined by cardiac movements and phasic changes associated with breathing.

The respiratory phase in the venous waveform depends on many factors, including the distance of the vein from the thorax. The venous spectrogram includes the S waves, v, D and a:

S: systolic wave, determined by the negative intra-atrial pressure with the movement of the atrioventricular septum toward the cardiac apex

v: is the result of the intra-atrial positive pressure created by overdistension of the right atrium during the filling phase.

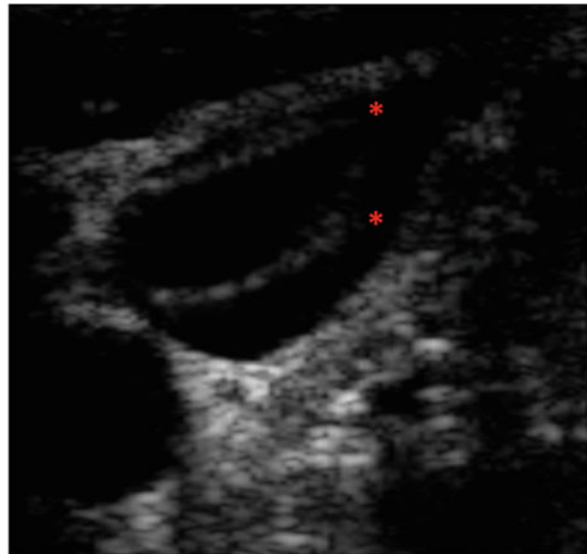
D: diastolic wave determined by the negative intra-atrial pressure, consequence of the opening of the tricuspid valve

a: reflects the intra-atrial positive pressure during the atrial.



Fig. 2.1 Schematic drawing of IJV and its segments. J1 or proximal segment, focused to the valve system. J2 or intermediate segment. J3 or distal segment, where the common facial vein ends into the IJV

Fig. 2.2 IJV in transverse scan at the level of the valve leaflets (J1) in B-mode. The valve system is well identifiable with two cusps in an intermediate position between the complete opening and the closure. The valve leaflets (see the *asterisks*) seem as *hyperechoic curve* and *tiny lines* coming from one side to the other of the vessel wall within the lumen. Movie 2.1 shows a dynamic example of the leaflets' movement



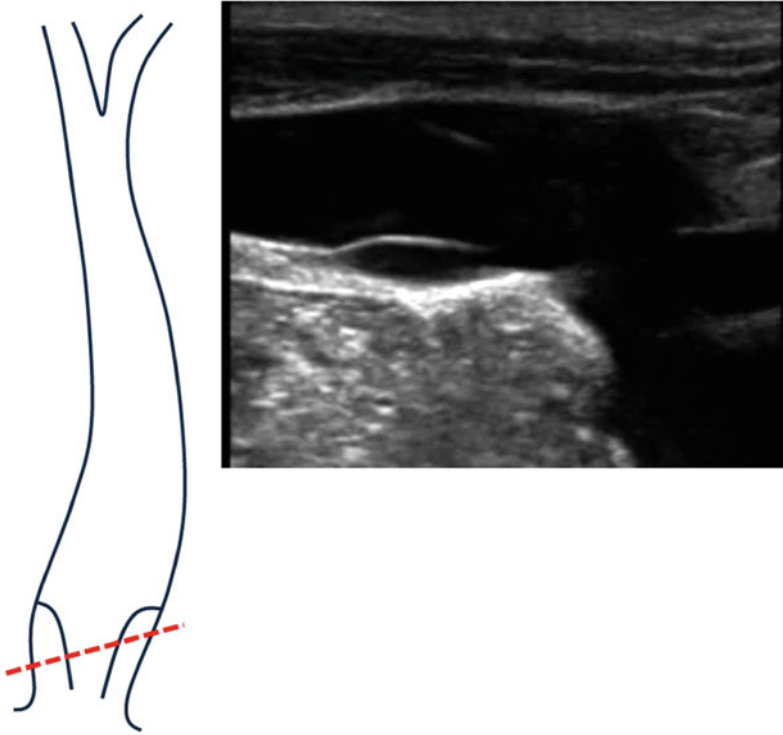


Fig. 2.3 Longitudinal scan of the IJV at the level of the valve system (J1) in B-mode. Also in this case are well evident the valve leaflets as two slightly *hyperechoic lines* into the IJV lumen, stopped in an intermediate

position during the opening–closing cycle. The valve cusps define the valve sinuses (*white asterisks*) at the IJV bulb. Movie 2.2 shows a dynamically view of the leaflets movement

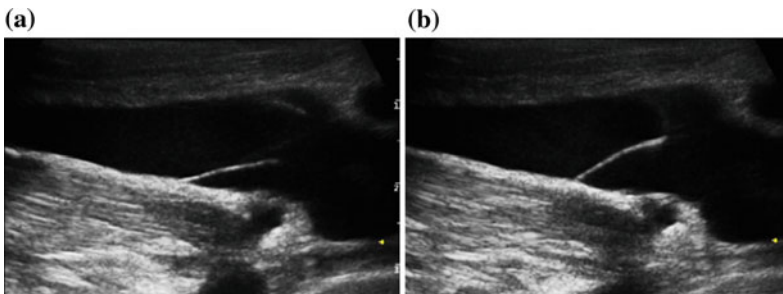


Fig. 2.4 Longitudinal scan of IJV at the valve level (J1) in B-mode, focusing on a particular aspect. In the *left side a*, the valve is totally open and has two well-identifiable separate leaflets; in the *right side b*, the valve is close and

the leaflets are adherent each to other into the IJV lumen near the *midline*. Pictures are oriented leaving the head of the examined subject on the *left* end and the heart on the *right* end

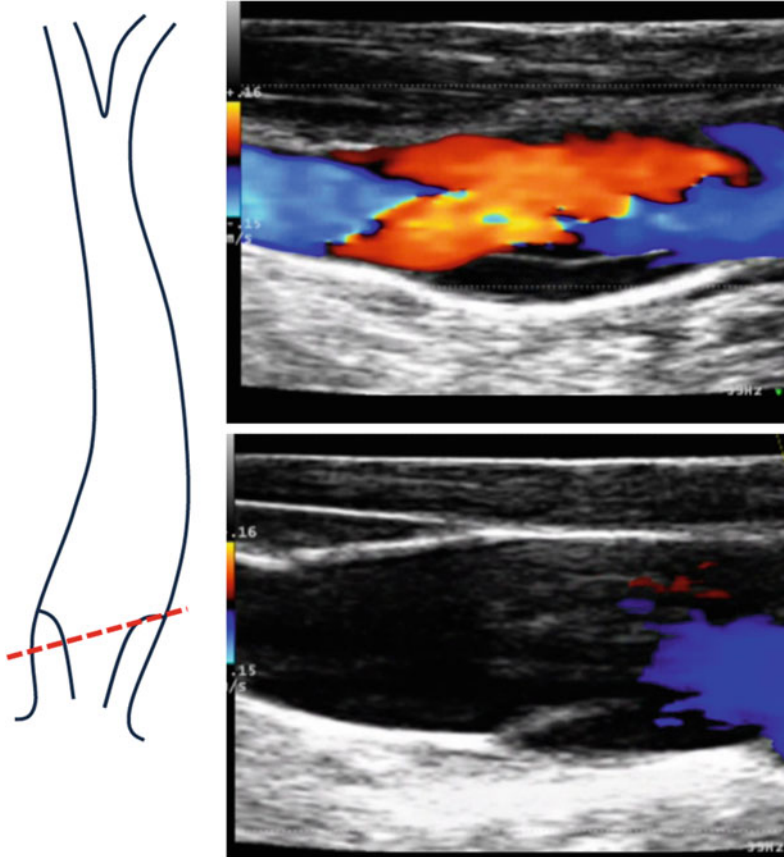


Fig. 2.5 Longitudinal scan of IJV at the valve level (J1) in color mode; the subject is the same as in Fig. 2.4. In the *left side* of the picture, there is the schematic drawing of the IJV with the level of insonation. In the *right side*, the two magnified pictures show the color-coded signal

of blood flowing through the open valve (*top image*) and the stopped color-coded signal of blood flow because of the valve closure. The pictures are oriented as detailed in the caption of the Fig. 2.4

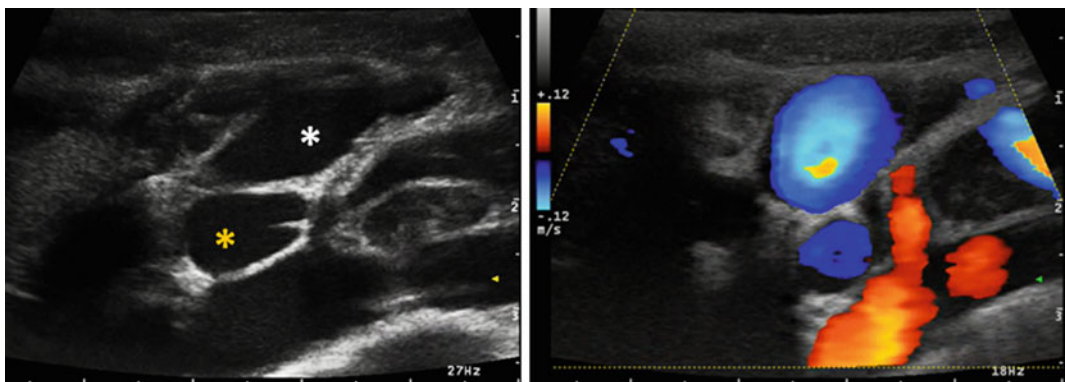


Fig. 2.6 Transverse scan of J1 IJV in B-mode (in the *left side*) and in color mode (in the *right side*). It is often possible to simultaneously visualize the IJV and VV valve system, as in present picture is exemplified. IJV

(*white asterisk*) and VV (*yellow asterisk*) are imaged in the same picture at the level of the valve system of both veins, See also the correspondent Movies 2.3 and 2.4

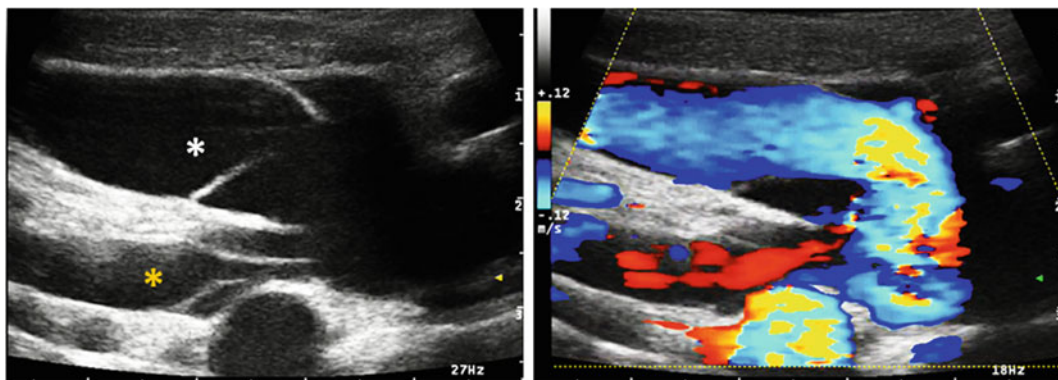


Fig. 2.7 Longitudinal scan of J1 IJV in B-mode (in the left side) and in color mode (in the right side). As in the Fig. 2.6, it is often possible to simultaneously visualize the IJV and VV valve system, as in present picture is

exemplified in longitudinal scan. IJV (white asterisk) and VV (yellow asterisk) are imaged at the valve level. The valve system seems composed from two leaflets for both veins. See also the correspondent Movie 2.5

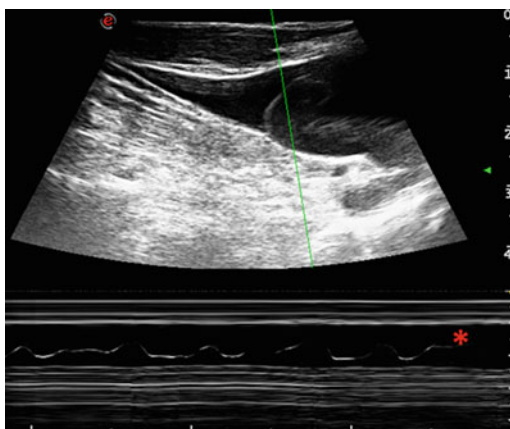


Fig. 2.8 Longitudinal scan of IJV at the valve level (J1) in M-mode. Another way of evaluate the valve leaflets movement is by using M-mode as echocardiographic evaluation of valve function. The M-mode allows to evaluate the movement of the structures at different depth levels along the sampling line (*M-line*). The *M-line* in the picture is green, and, in the lower part of the image, the asterisk indicates the line correspondent to the cycles of movement of one IJV leaflet. See also the Movie 2.6

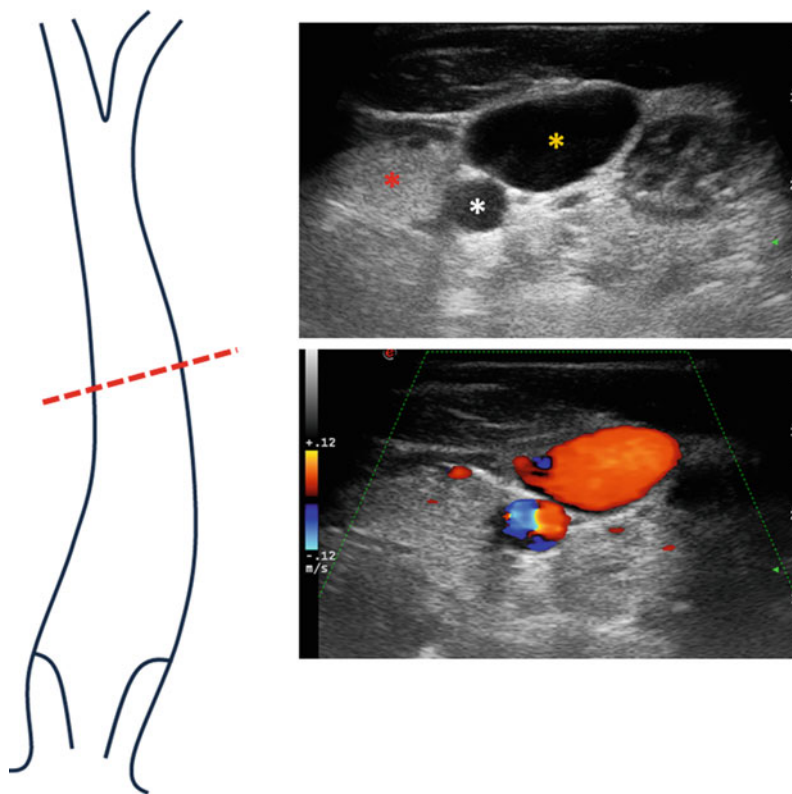


Fig. 2.9 Transverse scan of IJV at the level of the thyroid gland (J2) in B-mode (*upper part* of the picture) and in color mode (*lower part* of the picture). The *red asterisk*

indicates the thyroid gland, the *white* one the common carotid artery, and the *yellow* one indicates the IJV

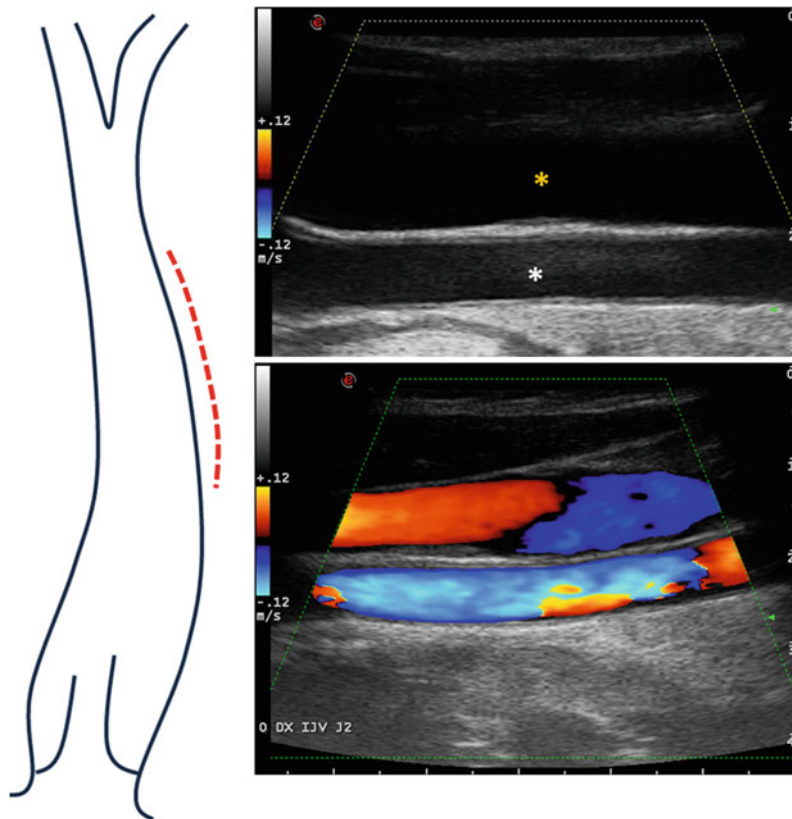


Fig. 2.10 Longitudinal scan of IJV at the level of the intermediate segment (J2), in B-mode (*upper part* of the picture) and in color mode (*lower part* of the picture). The *white asterisk* indicates the CCA and the *yellow* one the IJV, and upon the IJV course, the suprafacial

muscular planes of the neck are identifiable. In this example, IJV is parallel to the CCA within the same sheath and both vessels are visible in the same scanning plane but with opposite blood flow direction, as shown in color mode. See also the correspondent Movie 2.7

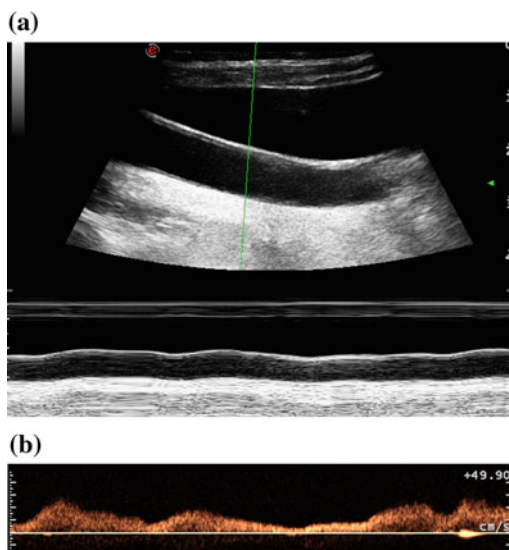


Fig. 2.11 **a** Longitudinal scan of IJV at the level of the intermediate segment (J2) in M-mode. By using this scanning mode, it is possible to evaluate the width of the movement of expansion–contraction of the IJV in comparison with the movements of the CCA, as reference for the heart cycle. It is noticeable that the variations in the IJV diameter are different in each heart cycle because of the superimposed effect of the breath cycle. It is sometimes difficult to differentiate one component from the other one, especially in some situations, as in the presence of IJV valve incontinence or pulmonary hypertension, where the breath-dependent variations can be much more accentuated. **b** This variability is expressed in the Doppler waveform that is affected by the same components, as in this example

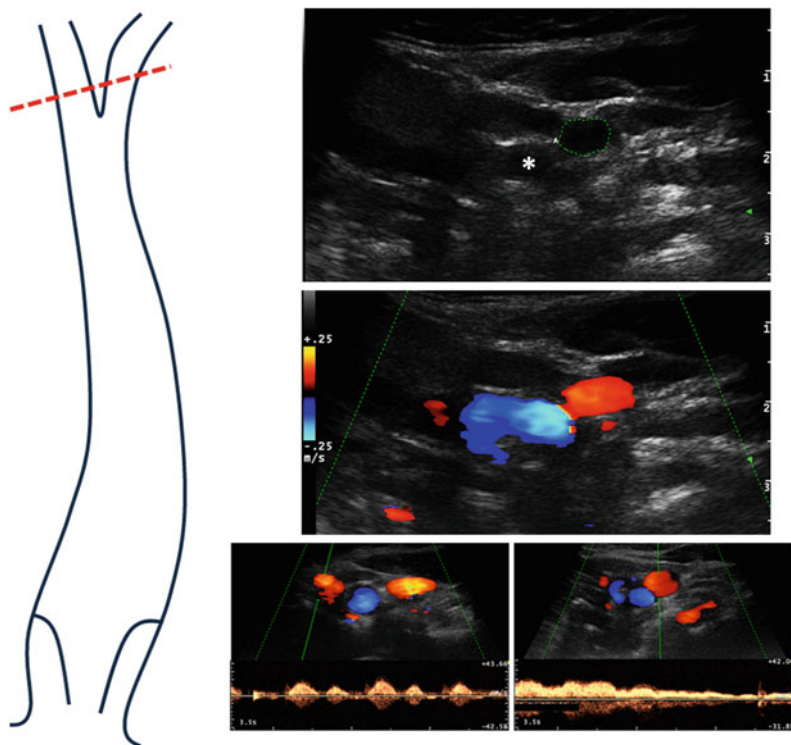


Fig. 2.12 Transverse scan of IJV at the level of the distal segment (J3) in B-mode and color mode. From up to bottom: (1) image in B-mode with manual tracking of J3 IJV CSA; on the *left side* (white asterisk), there are the CCA and the external carotid artery (ECA), slightly upon the carotid bifurcation, and besides there is the common

facial vein (see also the Movie 2.8). (2) Image in color mode of the same structures with the opposite direction of blood flow in arteries and veins showed by Doppler waveform. (3) Doppler waveform of the common facial vein (*left side*) and J3 IJV (*right side*)

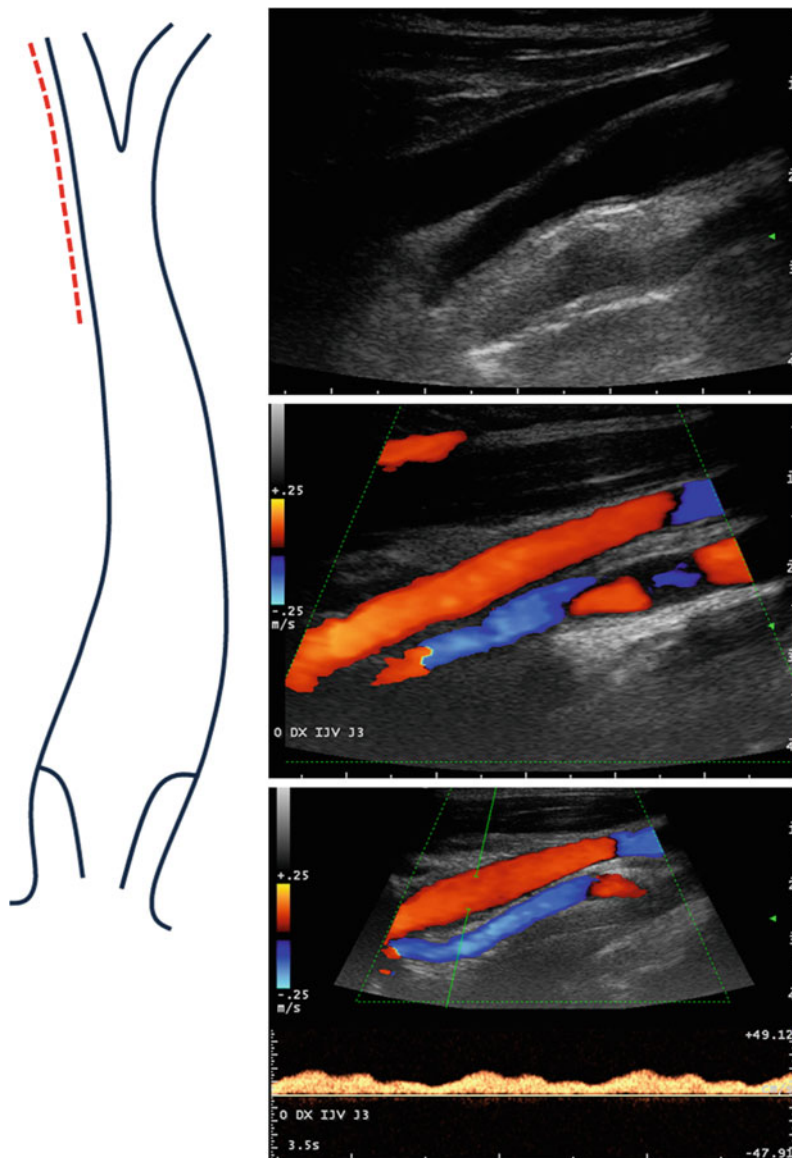


Fig. 2.13 Longitudinal scan of IJV at the level of the distal segment (J3). From *up to bottom*: (1) B-mode scan with J3 IJV (*yellow asterisk*) and carotid axis (*white asterisk*). (2) Image in color mode of the same structures,

with the identification of the opposite direction between arteries and veins in the Doppler waveform (see also Movie 2.9). (3) J3 IJV Doppler waveform

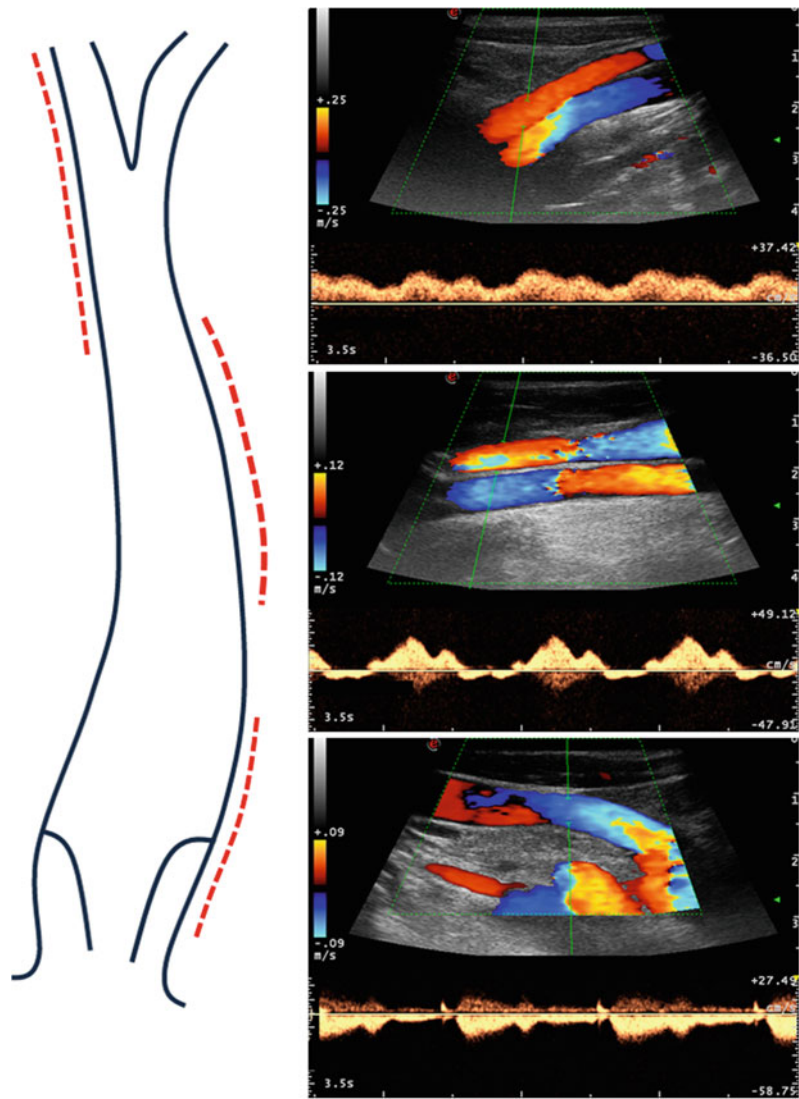


Fig. 2.14 Longitudinal scan of IJV at the level of J1, J2, and J3 in color mode and Doppler mode. From *top to bottom*, J1, J2, and J3 IJV are imaged; the variation of the Doppler waveform is showed, being similar to the

one of central veins in J1–J2 segments, nearer to the *right* atrium, and partially different in the J3 segment, more distant from the *right* atrium

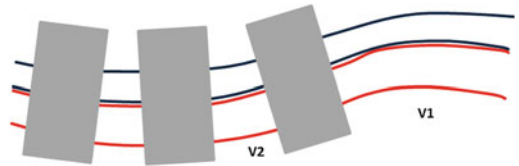


Fig. 2.15 Schematic drawing of the venous plexus of the VA at the V1 and V2 levels; VV is outlined in blue, and the vertebral artery is outlined in red; the gray boxes correspond to the shadows of the vertebral bones in the ultrasound image

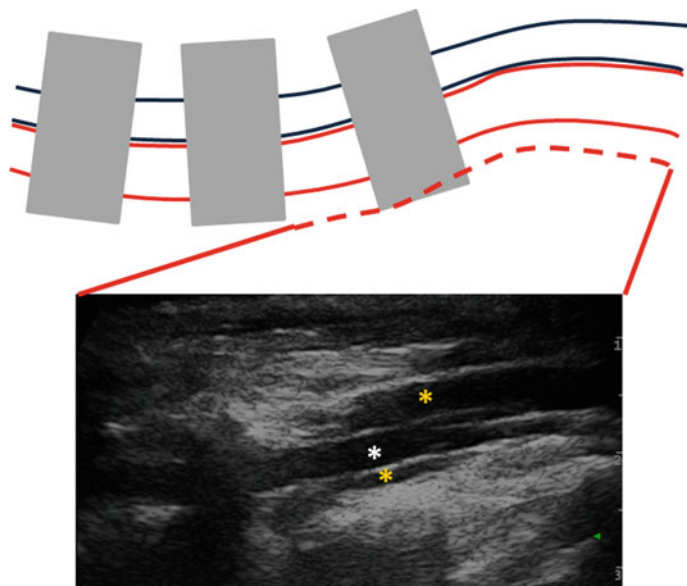


Fig. 2.16 Venous plexus of the vertebral artery at the level of V1 and proximal V2 segments in B-mode. The vertebral artery is indicated by the *white asterisk* and the

venous plexus surrounding it by the *yellow asterisk*. The Movie 2.10 shows the dynamic relation between these structures

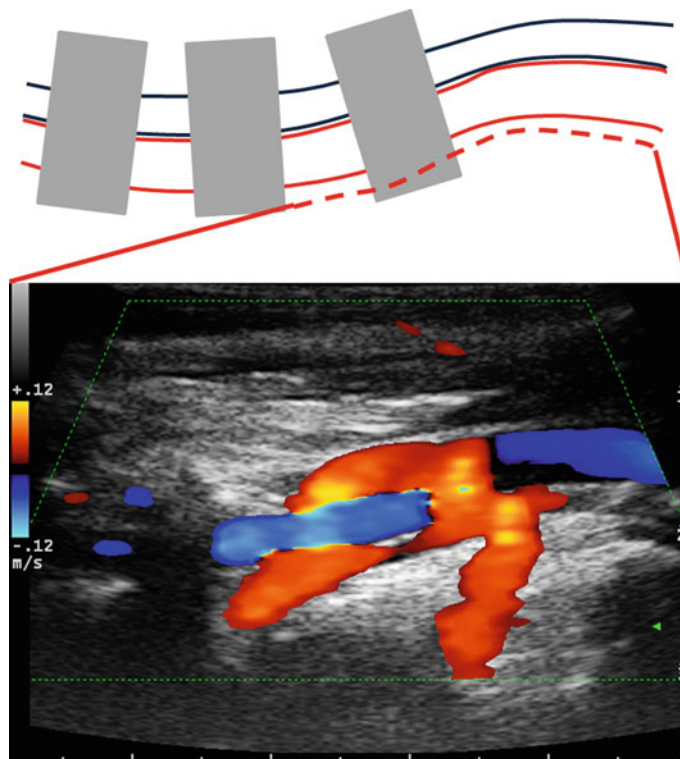


Fig. 2.17 VA venous plexus at the level of V1 and proximal V2 segments in color mode. The opposite color-coded signal of artery and vein corresponds to the different flow direction. It is evident the plexiform aspect of the vertebral venous outflow, surrounding the VA, and

the confluence of at least one deep cervical branch (*green asterisk*), frequently found at this level, where the main trunk of the VV collects the flow from plexi and deep cervical veins before to join the SV. See Movie 2.11 about the relation between arteries and veins

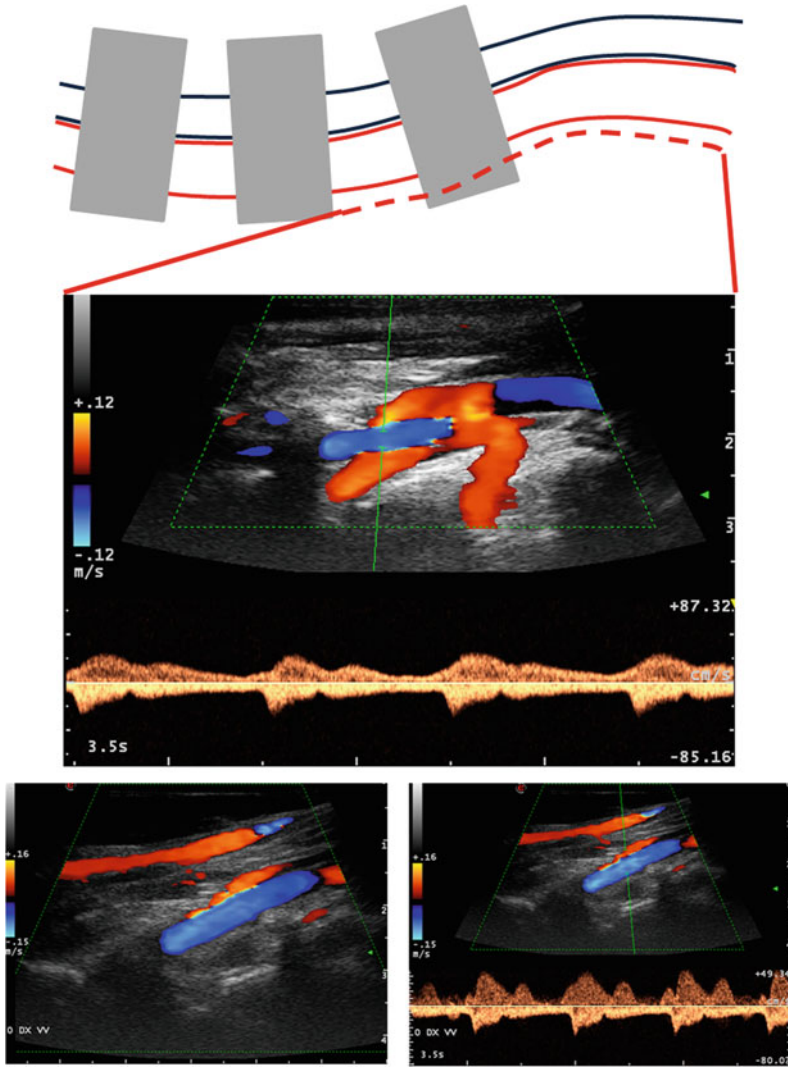


Fig. 2.18 Venous plexus of the VA at the level of V1 and proximal V2 segments in color mode and Doppler mode. In the examples, two features are represented: (1) the morphological variability of the plexus with more

(*top* image) or less (*bottom* image) evident venous network and deep cervical veins confluence. (2) The Doppler waveform variability, more (*bottom* image) or less (*top* image) similar to the one of central veins

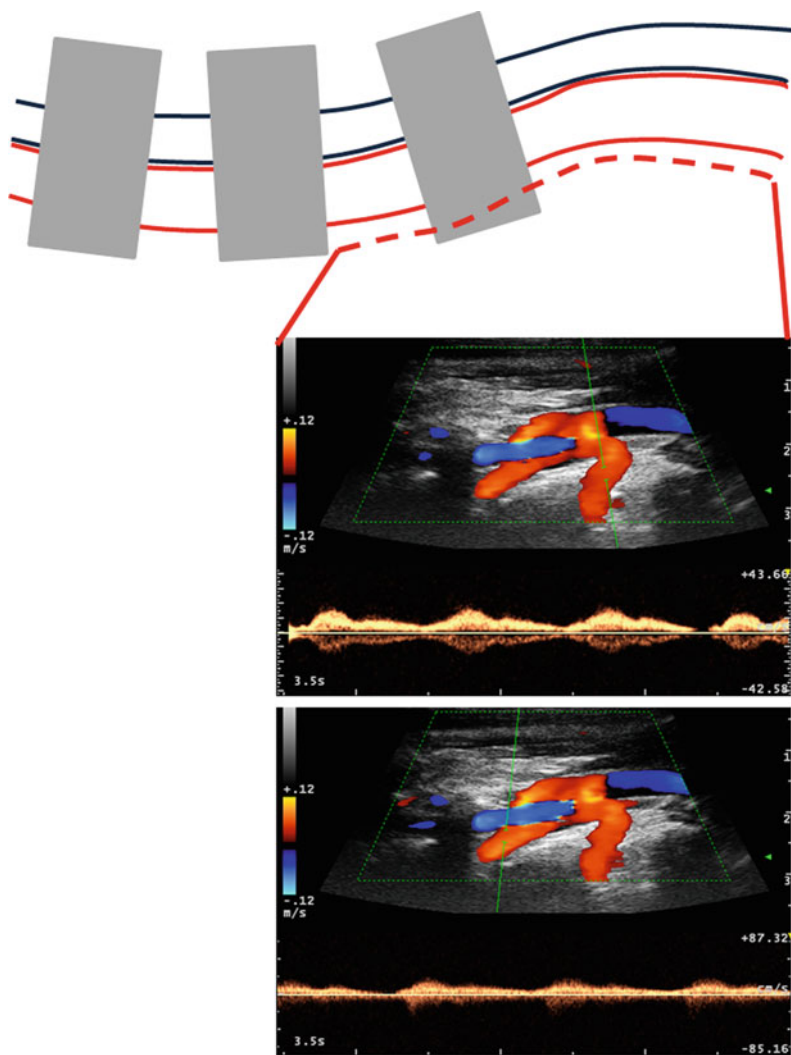


Fig. 2.19 VA venous plexus at the V1 and proximal V2 levels in color mode and Doppler mode. The entrance point of two deep cervical veins is identified and the

Doppler waveform sampled, showing the same variability as IJV one depending on heart and breath cycles

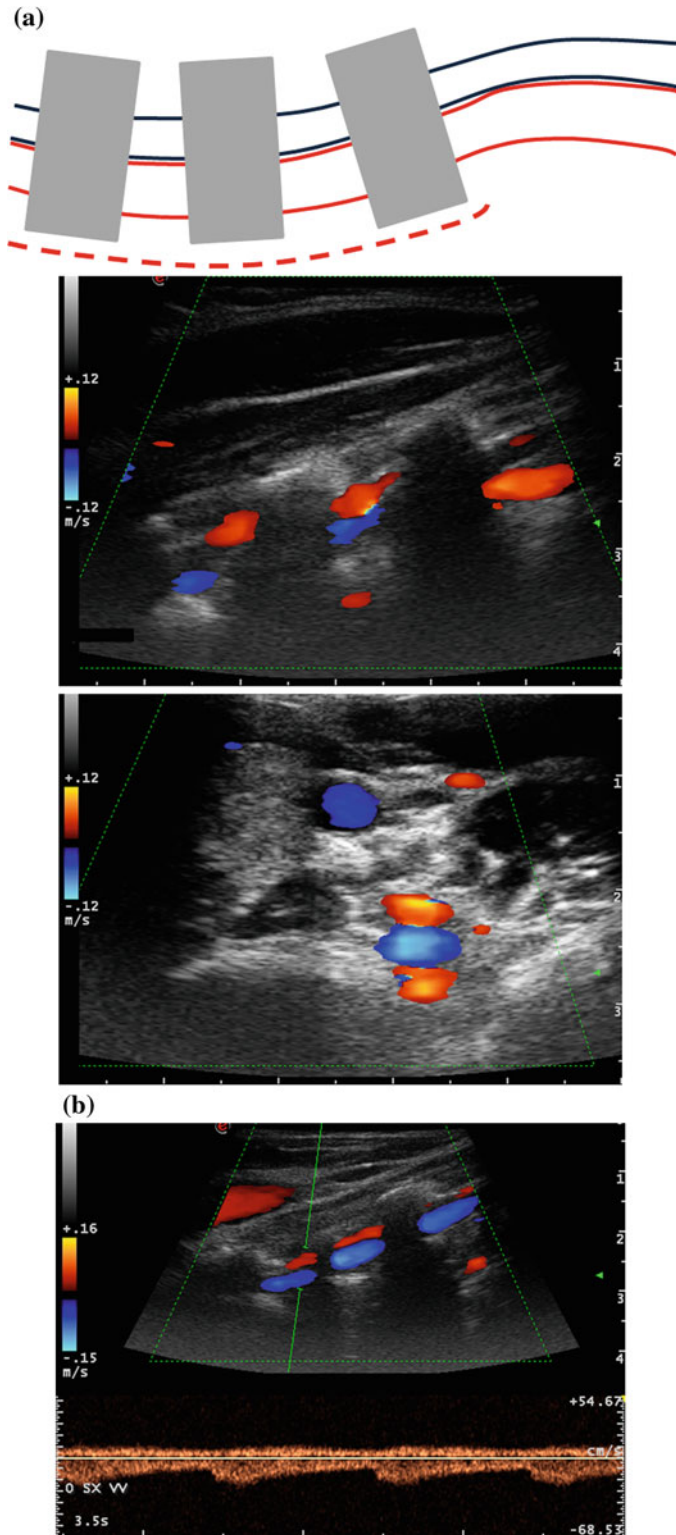


Fig. 2.20 VA venous plexus at the V2 level in color mode. **a** Longitudinal scan (*top image*) of the intertransverse channel along three sequential segments, where the VA and VV are recognizable, and transverse scan

(*bottom image*) (see also Movie 2.12), confirming the network organization of the vertebral venous outflow (see also Movie 2.13). **b** VA and VV Doppler waveform at the V2 level

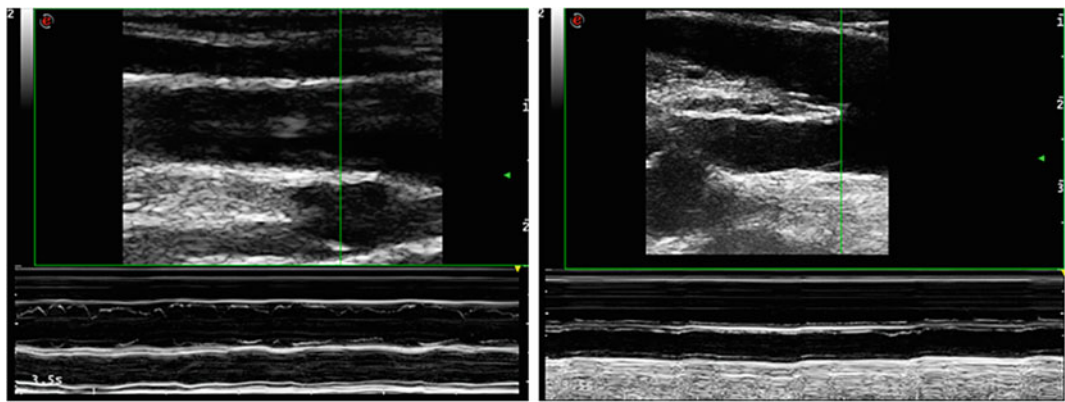


Fig. 2.21 VV valve in B-mode. As the IJV, also the VV has a valve system at the confluence into the SV and M-mode is as much suitable for its study

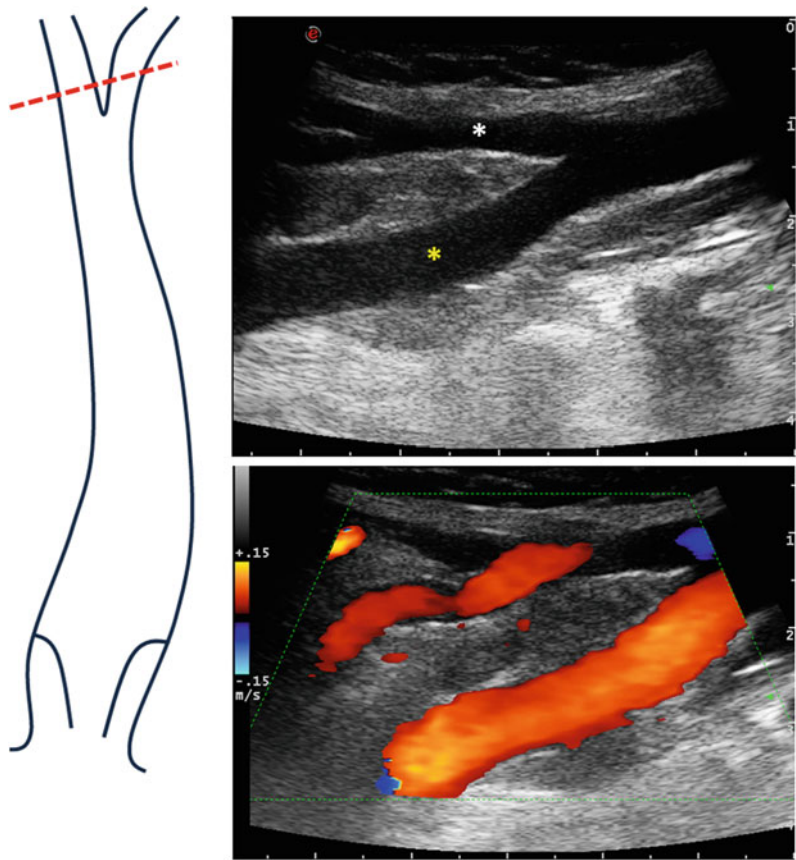


Fig. 2.22 IJV branches in longitudinal scan in B-mode and color mode. At the *top*, there is an image in B-mode with the lingual-facial trunk (*white asterisk*) and J3 IJV (*yellow asterisk*). In the *bottom* image, there is the correspondent structures in color mode (see also Movie 2.14)

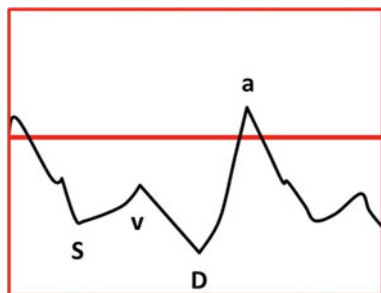


Fig. 2.23 Schematic drawing of the venous flow pattern in the *central* veins

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