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Natalie Kosnik et al., Review of the internal jugular vein

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ABSTRACT

The internal jugular veins (IJV) are the primary venous outflow channels of the head and neck. The IJV is of clinical interest since it is often used for central venous access. This literature aims at presenting an overview of the anatomical variations, morphometrics based on various imaging modalities, cadaveric and surgical findings, and the clinical anatomy of IJV cannulation. Additionally, the anatomical basis of complications, techniques to avoid complications, and cannulation in special instances are also included in the review.

The review was performed by a detailed literature search and review of relevant articles. A total of 141 articles were included and organized into anatomical variations, morphometrics, and clinical anatomy of IJV cannulation.

The IJV is next to important structures such as the arteries, nerve plexus, and pleura, which puts them at risk of injury during cannulation. Anatomical variations such as duplications, fenestrations, agenesis, tributaries, and valves, may lead to an increased failure rate and complications during the procedure, if unnoticed. The morphometrics of IJV, such as the cross-sectional area (CSA), diameter, and distance from the skin-to-cavo-atrial junction may assist in choosing the appropriate cannulation techniques and hence reduce the incidence of complications. Age, gender, and side-related differences explained variations in the IJV-common carotid artery relationship, CSA, and diameter. Accurate knowledge of anatomical variations in special considerations such as pediatrics and obesity may help prevent complications and facilitate successful cannulation.

Key words: internal jugular vein, anatomical variations, morphometrics, cannulation, imaging, landmarks

INTRODUCTION

The internal jugular vein (IJV) is the main venous drainage of the head and neck and is the continuation of the sigmoid sinus [92]. It travels down the neck through the carotid sheath, along with the common carotid artery (CCA), the internal carotid artery (ICA), the vagus nerve, and the deep cervical lymph nodes [82]. The IJV joins with the subclavian vein posterior to the sternal end of the clavicle and forms the brachiocephalic vein [83]. The IJV typically runs anterolaterally to the ICA and CCA before joining the subclavian vein [135]. Deviations from the normal anatomy due to embryological dysgenesis cause a variety of clinically significant anatomical variations. The IJV serves as a major surgical landmark for structures such as the spinal accessory nerve (SAN), the carotid artery, and cervical lymph nodes [33]. Hence, the altered anatomy of the IJV is of significance as the landmark may be misinterpreted if not identified correctly.

Besides anatomical variations, dimensions of IJV are of significant clinical interest; hence, various imaging modalities are used to measure IJV dimensions. Color doppler ultrasonography (USG), magnetic resonance imaging (MRI), and computed tomography (CT) are the most common non-invasive techniques used to measure dimensions, identify variations, and diagnose pathologies [113, 141]. Variables such as head positioning and respiratory changes are known to alter the dimensions [117]. In addition, age, population demographics, and external compression may account for the varying measurements reported in the literature [63, 117, 141]. Some of the commonly reported dimensions include cross-sectional area (CSA) and diameter of the IJV. The CSA is significant since a low CSA may indicate stenosis or an underlying pathology [63]. Variations in CSA at different cervical levels, head rotations, and positions provide options that are most favorable for successful IJV cannulation [19, 49, 66, 95].

The dimensions and anatomical relationships alter through the normal aging process, differ between genders, and are influenced by pathologies such as increased body mass index (BMI) [40, 44, 70, 74, 75, 81, 99, 106, 123]. It is important to be aware of these possible changes in varying patient populations, especially in IJV cannulation. Traditionally, the anatomical landmark technique was utilized to perform cannulation of the IJV [21, 67, 115]. However, considering the highly variable nature of the IJV, the USG-guided procedure has added benefits [17].

There are numerous cadaveric and clinical reports on anatomical variations, dimensions, relations, age-related differences, and the anatomical aspects of IJV cannulation and stenosis. Currently, there is not a comprehensive review of the IJV available. The aim of this study was to review the anatomic variations of the IJV with special reference to the clinical anatomy of IJV cannulation, including special considerations in pediatrics and obese patients.

MATERIALS AND METHODS

The aim of this research was to perform a narrative review of the internal jugular vein. The literature search was conducted using the databases, Pubmed and Google Scholar. The

Medical Subject headings (MeSH) used were Jugular Veins/abnormalities and Jugular Veins/diagnostic Imaging. The keywords internal jugular vein, anatomical variations, morphometrics, cannulation, imaging, and landmarks were used. Several cross-references were utilized and compared to identify the most up-to-date information. The references utilized for this review ranged from imaging studies, case reports, cadaveric studies, literature reviews, and textbooks. There were no exclusions based on publication date.

RESULTS

The electronic search yielded a total of 3,237 results. The authors analyzed the results and selected 141 articles as relevant to this review. These references were grouped into categories of anatomic variations, morphometrics, differences in the IJV based on sex and age, and special considerations such as IJV cannulation in pediatric and obese patients. A summary of the resources used is outlined (Table I).

DISCUSSION

Cadaveric, surgical, and radiological findings helped understand the anatomy of IJVs. Due to their non-invasive approach, color doppler USG and MRI are commonly used [141]. The benefits of USG include its ability to provide real-time images of structure and display the hemodynamics, while drawbacks are primarily due to the accuracy and reproducibility of USG being dependent on the skill of the operator [141]. A disadvantage of both USG and MRI is that they require the operator to apply external pressure to vessels with a probe or collar, which could lead to inaccurate measurements of IJV characteristics, such as shape, thickness, diameter, CSA, and flow [53, 113, 117, 141]. Advantages of MRI and magnetic resonance venography (MRV) include the ability to view structural abnormalities, quantify venous blood flow compared to arterial flow, track progression of diseases over time, and provide images used by interventionalists when planning for treatment [141]. A computerized tomography (CT) scan can be used to non-invasively assess IJV's relation to surrounding structures, dimensions, and detect abnormalities not revealed by USG [70, 113]. There is no gold standard for the diagnosis of IJV pathologies, but a combination of various imaging modalities and criteria are commonly used to assess these conditions [141.

ANATOMICAL VARIATIONS

Embryologically, the IJV develops from the right and left cardinal veins at eight weeks of gestation [83]. Developmental abnormalities may result in a variety of anatomical variations, which range from complete agenesis to duplication [120]. In a study of 1197 patients, there were 40 total variations found, which included bifurcation (4), duplication (14), fenestration (16), trifurcation (1), and posterior tributary (5) [83].

Agenesis

Congenital agenesis or complete absence of the IJV is a rare condition, and only eight cases have been reported in the literature. It may result from abnormally formed channels lined by quiescent endothelium [59]. Four cases of agenesis of the right IJV were detected during attempted cannulations and all of them were cannulated into the left IJV or the axillary vein [4, 61, 79, 96]. A 55-year-old patient showed right IJV agenesis, and a detailed study on venous anatomy revealed left IJV phlebectasia and collateral channel that drained the right IJV into the left IJV [43]. The venous return may also be taken over by the external jugular vein (EJV) [120]. A case of left IJV agenesis was incidentally found in a 62-year-old male during neck dissection for oral carcinoma, and the neck collaterals and EJV were enlarged [10]. Besides failed and complicated cannulation, there is a spectrum of symptoms with agenesis of the IJV [96]. In a case of right IJV agenesis, the left IJV wall was thickened as a compensatory mechanism that resulted in a rare complication of IJV thrombosis [59]. Due to inadequate drainage from the cranium into the neck, cerebral venous insufficiency has been implicated in patients with IJV agenesis [4]. The agenesis of IJV may be associated with malformations in the intracranial venous system [24]. A summary of the cases with IJV agenesis is listed (Table II).

Hypoplasia

Hypoplasia of IJV indicates a narrowing of its lumen. Hypoplasia possibly occurs due to truncal venous malformations arising from developmental arrest in a late embryonic stage [65]. Typically, the IJV is double the size of the CCA, measuring 9.1-10.2 mm in diameter [71]. There is no standard dimension of IJV that indicates it to be hypoplastic; however, it was either difficult or impossible to cannulate when the IJV diameter was less than half its normal size [11]. In an USG-based study, 8.7% of the 104 uremic patients had an IJV diameter measuring under 5 mm [71]. In a study, 9.5% (47 of 493) patients were found to have IJV diameter less than 7 mm; 14.9% of them had failure of IJV cannulation while 8.5% had complicated cannulation [77] In a cadaveric study, three out of 93 dissections showed a narrowing of the IJV with an increase in ipsilateral EJV magnitude [11]. A pediatric study found the IJV to be hypoplastic in 4% of individuals, and this group measured under 5 mm and 3 mm in children and infants, respectively [5]. Due to considerable difficulty with cannulating a hypoplastic IJV, pre-cannulation imaging and cannulating a different vein may be beneficial.

Duplication

Duplication and fenestration comprise the commonly reported variations and are found in 0.4% of cases [92]. The terms duplication, bifurcation, and fenestrations are often confused. A duplication is defined as a split in the IJV, with each branch having its own attachment to the subclavian vein [33, 132]. If the IJV splits at or superior to the omohyoid muscle, that is considered a bifurcation [83]. However, if the IJV splits inferior to the omohyoid muscle, it is considered a duplication [83]. Fenestration is defined as a split in the IJV that reunites before merging with the subclavian vein [132]. There are three embryonic hypotheses considered for IJV duplication: the vascular hypothesis, the neuronal hypothesis, and the bony hypothesis [92]. The vascular hypothesis argues that the persistence of two venous channels during the process of IJV development forms the duplication. The neuronal hypothesis argues that the SAN is trapped in the venous capillary plexuses during development, which can lead to an anterior and posterior portion of the IJV. The bony hypothesis contributes the embryogenesis of this variation to duplication of the jugular foramen [86]. The vascular theory of duplication is the most widely accepted of these hypotheses [48].

A review of 22 cases from cadaveric, surgical, and radiological reports classified three morphological patterns of duplication: Type A, Type B, and Type C [86]. Type A duplication, found in 15 of the 22 cases, had the IJV split superior to the lower border of the posterior belly of the digastric; the two veins then rejoined at the omohyoid central tendon, and the SAN ran in between them. This description has been referred to as a fenestration [33, 122], partial duplication [98], or incomplete duplication [110]. In 295 patients, who underwent surgical neck dissections, only 2 cases were reported to have fenestration [33]. An incidental finding of a fenestrated IJV was noted in another patient admitted following a motor vehicle accident [12].

Type B duplication, found in 2 of the 22 cases, was the true or complete duplication in which the IJV split superior to the digastric and continued inferiorly to drain into the subclavian separately [86]. This type was associated with difficulty preserving the vein during neck dissections, [86]. Type C duplication, found in 5 of the 22 cases, had the IJV split at a lower level around the hyoid bone, and the veins drained separately into the subclavian vein. In all 5 cases, the lateral of the two veins was partly outside the carotid sheath [86].

Type C duplications caused the most difficulty in surgery and imaging interpretation. A rare case of bilateral type C duplication was associated with a bulbous jugulo-vertebro-subclavian venous sinus [39]. A rare case of bilateral duplication had both vessels draining separately into the subclavian vein on the right, while they drained into the jugulo-vertebro-subclavian sinus on the left [39].

The SAN is superficial to the IJV, divides the deep and superficial cervical lymph node, and needs to be considered in IJV duplications [35]. In a meta-analysis of 1491 hemi-necks dissection, the relationship between the SAN and an IJV duplication was classified into four types [35]. Type 1 (79.7%) had the SAN superficial to the duplicated IJV; type 2 (16.6%) had the SAN posterior to the split vein; type 3 (0.7%) had the SAN between the split veins; type 4, which was never reported, had the nerve pass around the branches of the vein [35]. Another study showed that in two of the three patients, SAN bisected the fenestration, while one SAN ran medial to the fenestration [33]. Surgeons must consider the variant relationship and determine the location of the SAN in relation to the variant IJV preoperatively by USG to avoid damage to the SAN during neck dissections [1, 3].

Duplication has not been reported to have physiological implications, but there are certain clinical implications such as plebectasias and aneurysms. An aneurysm is a vessel dilation that involves degeneration of all layers of the venous wall, while phlebectasia involves thinning of tunica media [6, 15]. Duplications were found to be associated with phlebectasia in 46% of cases [86, 116]. IJV phlebectasia is a fusiform, soft, non-pulsating swelling of the vein which increases in size during the Valsalva maneuver [57]. Aneurysms were commonly reported at a vessel bifurcation, as there is a weakening at the proximal and distal end of the split [118]. There are two proposed hypotheses for these pathologies: turbulent flow at the bifurcation [118], or an incomplete formation of the tunica media [34]. The right jugular bulb is positioned superiorly to the left jugular bulb, which can be a predisposing factor to phlebectasia [56]. Phlebectasia could complicate choosing an appropriate vein for free-flap reconstructions [86]. This can be avoided by a preoperative diagnosis using venography, arteriography, and USG [110].

Valves

The IJV has a single valve located near the inferior jugular bulb, and it regulates the transmission of intrapleural pressure to the brain [52]. However, conflicting reports on the presence and competency of the IJV have been reported in the literature. Dissection and USG-based clinical studies on 75 cadavers and 75 adult patients found the valves bilaterally in 84% and 60% respectively [68] while an USG-based study on 120 children showed bilateral valves in 74% of cases [36]. Almost 80% of cases with unilateral valves were found to have valves on the right IJV [36, 68]. Anatomical studies showed a higher incidence of valves than imaging since the thinness of valves allowed a better direct visualization due to the thinness of valve leaflets [36]. Cadaveric findings showed bicuspid valves in 98.5% while USG-based studies reported only 42% [36, 68]. Another study using color doppler showed two-leaflet valves in 75%, single-leaflet in 14%, and three-leaflet in 11% of the 462 IJVs examined [126]. Besides the valve thinness, difficulty in accessing the lower left IJV due to its position behind the clavicle probably caused these differential findings.

The IJV valve was found at an average distance of 28 mm and 9.2 mm from the jugulo-subclavian junction in adults and children respectively [36]. However, an atypical location of the valve in the mid-neck far from the clavicle was found during an IJV cannulation [80]. The IJV valvular motion is likely a protective factor against cerebral venous engorgement; it was noted that 90% of the valves were incompetent and 29 out of 41 competent valves were bicuspid, and the researchers proposed that incompetent valves seemed to be a normal phenomenon [126]. In contrast to this finding, a recent study that explored the valve competency using hydrostatic pressure technique and found them to be competent in all the 25 living subjects and 93% of the 30 cadavers examined in the study [108]. Damage to the IJV valves at cannulation may destroy the leaflets and secondarily lead to an increased cerebrospinal pressure; hence it is important for clinicians to be aware of the valvular anatomical variants [52]. A real-time USG may be helpful in avoiding damage to a high positioned valve or a valve with abnormal cusps.

Tributaries

The typical tributaries of the IJV, the inferior petrosal sinus, the facial, lingual, pharyngeal, and superior and middle thyroid veins enter the IJV anteriorly; hence, surgical approach is easier from posterior to anterior because the posterior triangle has no tributaries of the IJV [130]. However, rare instances of posterior tributaries have been reported. A case showed a posterior tributary that joined with the IJV from the medial aspect of the sternocleidomastoid (SCM) and in another case, the tributary arose from under the SCM and drained into the lower third of the IJV [83]. In another case, the EJV was found to drain into the IJV instead of the subclavian vein, hence grouped as a posterior tributary [8]. In two instances, posterior tributaries of IJV were found during surgical dissection, one of which coursed deep to the posterior belly of the digastric, and another that coursed above the inferior belly of omohyoid

[37]. Although the author called it an additional tributary, the description mimics a duplicated IJV. A lateral tributary was reported during a neck dissection, and it was found to drain into the lower part of the right IJV [78]. In a cadaveric case report, a vein, 4 mm in diameter, formed from the junction of the common facial vein and IJV ran parallel to the IJV for 3 cm and then rejoined with the IJV [85]. It is imperative that variant tributaries are considered while performing surgical and interventional radiology procedures in this region.

Congenital arterio-venous fistulas

Congenital arterio-venous fistulas of IJV are vascular malformations that involve abnormal communication between IJV and a carotid artery [20]. It may result due to arrested venous development and abnormal arterio-venous differentiation during embryogenesis [41]. Acquired fistulas are usually traumatic in origin and often a complication of IJV cannulation [41]. Fistulas demonstrate progressive growth, which then may present clinically as localized swelling, bruit, or a pulsating mass or with neurological symptoms and often warrant treatment by embolization [20, 50]. Reported cases of an external carotid artery (ECA) and IJV fistula included a 15-year-old-female and a 2-year-old male who presented with a pulsatile swelling in the neck [2, 20], and a 27-year-old-male with neurological manifestations besides a neck swelling [50]. A fistula between the ICA and IJV was reported in a 64-year-old female with a pulsating swelling and bruit [131]. Lagos also reported a fistula between the ICA/IJV in a 7-year-old patient who presented with status epilepticus [64]. Two cases of spontaneous IJV-CCA fistulas were reported and they were likely related to collagen vascular diseases [94, 103]. A case of fetal IJV-carotid fistula was diagnosed during 27 weeks of gestation, in which case the fistula was accompanied by tricuspid regurgitation and pericardial effusion due to high flow through the fistula, but the report did not specify if it was IJV-ECA or ICA or CCA fistula [51]. An IJV fistula should be recognized before attempting IJV cannulation to avoid an arterial injury during the procedure.

Arterio-venous relations

Several studies have found anatomical variations in the relationship between IJV and CCA in 9.4-29% of patients [93]. A study on 120 healthy adults showed that the IJV is mostly anterolateral to the CCA; it was lateral to the CCA in approximately 6% and anterior to the CCA in approximately 15% of sides [92]. Another study on 100 adults also found an anterolateral IJV as the most common positioning; while an anterior IJV was found in 15% on the right, the frequency was higher (28%) on the left side [88] a lateral IJV was less common than the earlier study (4% on the right and 1% on the left). Another study found that the IJV was commonly located lateral to the CCA (85.2%) with anterior next (12.5%) [70]. This study did not include an anterolateral classification which explains why the findings were different from other studies. Anterior IJV is the most dangerous location since it puts the CCA at risk of injury and USG-guided cannulation may help prevent this complication.

Age-related differences

The relationship of the IJV to CCA was shown to vary with age. Two studies on neonates found the lateral IJV as the most common position [81, 124]. Two pediatric studies found the IJV to be anterolateral to the CCA when the head position was 30° contralateral rotation and neutral [40, 99]. Another study on pediatrics found the majority of IJV to be anterolateral or anterior to CCA, with position changing after insertion of a laryngeal mask airway [84]. A study including both neonates and pediatrics found that the IJV was lateral to CCA in 51.3% and anterolateral in 42.9% with a head rotation of 45° contralaterally [123]. Thus, neonates have a more lateral IJV in relationship to the CCA, which progresses to an anterolateral position in pediatrics. However, since these studies all have varying head rotations, it could also be argued that lesser degrees of head rotation (30° contralateral and less) favor an anterolateral IJV relationship to the CCA, whereas a larger rotation of 45° contralateral head rotation may push the IJV into a slightly more lateral position with respect to the CCA. A study on age-related differences in the IJV-CCA relation showed that the subset with anterolateral IJV (87.9%), had a mean age of 41.6 years while the lateral IJV (10.3%), had a mean age of 59.4 years [106]. Knowledge of relatively more common lateral IJV in older individuals is clinically useful information while attempting IJV cannulation.

MORPHOMETRICS

The dimensions of IJV are variable since it is a compliant structure, and its measurements can change with the positioning of the patient, respiration, and cardiac function [63, 117]. Since IJVs are the primary extracranial venous drainage pathways, variations or changes in dimensions will likely have an impact on the drainage of the cerebrospinal nervous system [141].

Cross sectional area (CSA)

The CSA is a commonly measured dimension of the IJV. A larger CSA is the target for the IJV cannulation [112]. Additionally, a significant change in IJV CSA could underlie an elevated BMI [63]. Due to venous structures having rapid responses to changes in blood pressure, an increase in IJV CSA suggests an increase in venous blood pressure which corresponds to impaired venous flow and sometimes an increased intrathoracic pressure [74]. Hence, several studies have aimed at finding the normal ranges of IJV CSA in various populations and age groups.

The findings obtained from several studies that used radiological modalities to measure the IJV CSA are shown (Table III). USG typically measured the CSA at the middle segment of the IJV at the level of the thyroid gland and facial vein [141]. This middle segment is commonly referred to as J2, as compared to the inferior (J1) and superior (J3) portions [141]. The table shows a wide difference between the CSA values provided by each imaging modality and is likely due to several reasons: IJV dimensions are highly variable due to the individual's cardiac function, heart rate, volume status, respiratory function, and posture [117]. Therefore, it is important to take into consideration the positioning of the patients while images were obtained. Aging, as described in further detail below, is associated with an increase in CSA. Notably, the studies that used MRI-imaged individuals of an older age group than those imaged in the CT studies. Other demographics, such as country of origin, play a role in dimensions, as well [63]. Most MRI analytical software, such as time-of-flight (TOF), differs from that of CT and likely contributed to the difference [63]. Both MRI and USG require external compression, thereby altering IJV dimensions [117, 141]. The CSA tends to increase moving caudally, making the level of measurement another important aspect differentiating published results [18]. Given the variability of normal CSA values, a recent study used an interesting technique by using each IJV as its own internal control to measure the level of stenosis in the vessel with MRV [117].

Diameter

The diameter of the IJV is of similar significance as the CSA; interestingly, the IJV is not a perfect circle and hence has varying diameters in different planes. A summary of findings from several studies is shown (Table III). The CT-based studies determined the maximal diameter while USG measured the anteroposterior, transverse, or lateral diameters [32, 87, 113]. The average diameter obtained from USG showed a smaller average than CT, which was likely related to compression of the IJV during the procedure. A cadaveric study found a similar average diameter to those by USG [45]. Besides knowing the normal range of IJV diameter, this dimension has a clinically significant correlation to right atrial pressure (RAP). An USG-based study on 72 adults found that IJV anteroposterior diameter showed a significant positive correlation with RAP [125]. The mean maximum IJV diameter for $RAP < 10$ mmHg was 7 ± 3 mm, and for $RAP \geq 10$ mmHg, it was 10 ± 2 mm [125]. Additionally, a correlation between the RAP and respiratory variations in IJV diameter was noted; the variations of 14% and 40% were noted for $RAP \geq 10$ mmHg and $RAP < 10$ mmHg, respectively [125]. This is a new area of correlation and needs further research.

Variations in cross-sectional area and diameter

Side differences

The right and left IJVs are often asymmetrical due to asymmetries in the drainage of blood through the dural venous sinuses, favoring the right transverse sinus and IJV over the left [100]. Lim et al. found that the mean right IJV diameter was 14.1 mm compared to the mean left IJV diameter of 11.74 mm [70]. Other studies that measured the IJV diameters found a similar difference [45, 70, 88, 113]. Beggs et al. found a mean difference in CSA of 15.64 mm^2 at the C2-C3 level and 26.31 mm^2 at the C7-T1 levels, and the right IJV was larger than the left at both levels [18]. Other studies on CSA concurred with these findings [63, 113, 137]. The overall larger size of the right IJV is likely why it is favored to be used in cannulation over the left IJV.

Differences in cervical levels

Differences in dimensions of IJV have been noted at various cervical levels. Magnano et al. measured average CSA values larger at the lower cervical levels as compared to upper cervical levels [74]. Higher CSA at lower cervical levels was likely due to increased flow into the lower portion of IJV [18, 63, 74]. There was also more variability noted in the CSA at lower cervical levels [63], which was postulated to be due to breathing artifacts. Research findings support the IJV having a conical structure with an increasing area at a lower level [18, 46, 63, 74], and therefore recommend cannulation to be attempted at lower levels of the IJV where there is a larger CSA to target. However, a recent study supported a rhomboid shape of the IJV and found that the middle IJV (level of cricoid) was larger than the upper and lower IJV and therefore recommended cannulation near the level of the cricoid cartilage, which may also help to avoid unnecessary complications, such as pneumothorax [54]. However, this retrospective study did not account for variables such as patients' physiological state or underlying diseases; hence further prospective research is needed to confirm the findings.

Age-related differences

Studies have shown differences in IJV dimensions with age. A significantly larger CSA (at mid-cervical levels) was associated with increasing age [54] and the difference was primarily observed in patients over 40 years of age [74]. The difference was likely due to a lower velocity and lower outflow volume in the IJV and reduced atrial emptying [30]. Another study on 462 IJVs of patients in the 21-92 years age group reported a similar difference, but it was not statistically significant [126]. It is important to remember that while the larger CSA with increasing age may favor IJV cannulation, other cardiac factors such as lower blood flow and increased RAP may influence the procedure.

Gender differences

A study using 2-dimensional MRV found the CSA of IJV in males to be larger than in females, with this difference being even more obvious on the right side and in older males [74]. The findings are consistent with other studies on IJV dimensions like any other blood vessel in the body [126]. On the other hand, a CT-based study showed a larger CSA in males compared to females, which was not statistically significant [54]. A possible explanation for this difference is due to the difference between the type of imaging used in these two studies.

Distance between skin and atrio-caval junction

A study on 100 patients using USG-guided catheterization revealed that the mean distance from the skin puncture (or access) sites to the superior vena cavo-atrial junction (CAJ) was 18.3 cm and 16 cm for the left and right IJV cannulation, respectively [7]. The mean distance was 1.7 cm higher in males than in females for the right IJV approach ($p < 0.1$) [7]. A prospective study on 239 patients correlated catheter tip position and catheter length with the patients' recorded heights and found that most catheters having their tips in the SVC had a length described by the following formula (where 'H' is patient height in centimeters): from the right IJV, (H/10) cm for right IJV cannulation [91]. However, Andrews et al. found gender to be a better predictor of the access site to CAJ distance rather than height [7].

The depth of IJV from the skin influences the cannulation technique and dimensions of the catheter used for cannulation. The right IJV runs more superficially to the skin compared to the left IJV since the mean skin to IJV distance was found to be 17.4 mm on the right compared to 18.7 mm on the left [53]. Parmer et al. concurred with this finding; however, the average thickness on the right side measured 9.75 mm, and the left measured 10.3 mm [88]. Another study yielded the mean depths on the right and left as 14 and 14.5 mm when measured in the transverse plane from the skin [70]. The differences are possibly due to differences in study techniques and the population studied.

INTERNAL JUGULAR VEIN CANNULATION

Cannulation of the IJV is performed for administering medications, fluids, and monitoring pressures, and in cardiac surgery patients for hemodynamic monitoring and measuring cardiac filling pressures [27, 115]. The goal is to have a successful first attempt at cannulation because increased attempts increase the risk of complications [115]. It is important to remember the normal and variant anatomy of the IJV and surrounding structures to prevent complications such as arterial puncture or hemothorax [22].

Clinical Anatomy of IJV cannulation

The IJV is preferred for central venous cannulation due to the easily accessible external landmarks such as the carotid artery, decreased risk of pneumothorax in comparison to subclavian vein access, easier management of bleeding, relatively fewer chances of a mispositioned catheter, and higher chances of cannulation under USG-guidance [97]. Besides, the IJV is preferred during emergency venous access because cardiopulmonary resuscitation can still be performed [97]. The right IJV is preferred because it has a larger CSA than the left and is in a straight line with the innominate veins and SVC, which allows for improved placement of the catheter [22, 42]. The right IJV is mostly chosen because of its accessibility and safety for right-handed anesthesiologists [44]. Also, the right-sided approach avoids injury to the thoracic duct, which is a possibility with left IJV cannulation [22, 53].

Cannulation techniques

IJV cannulation can be done by the landmark technique or the USG technique, but it is important to be comfortable utilizing the landmark technique in cases when USG is not available [115].

Currently, three techniques are used for IJV cannulation: central, anterior, and posterior (Figure 1). The location of the carotid artery is felt by palpation in the space between the trachea and SCM, and then the IJV is found lateral to the carotid pulse [22]. The central/ middle approach utilizes Sedillot's triangle, which is a triangle formed by the sternal and clavicular heads of the SCM, and the needle is inserted at the apex of the triangle [97]. The puncture site is the same as the alternative technique described earlier. In the anterior approach, the needle is inserted along the medial border of SCM, 2-3 finger breadths superior to the clavicle. This approach accesses the IJV at a slightly higher level than the low approach described earlier; in the posterior approach, the needle is inserted along the lateral border of the SCM, halfway between the mastoid process and the clavicle [97]. Some authors used the terms anterior and central interchangeably [22, 23]. Two studies used the point where the EJV crosses over the SCM, at a point just lateral to the SCM, around one-third of the distance between the clavicle and mastoid process for the posterior approach [22, 76].

A randomized study of 104 patients compared the central approach with the posterior approach and reported more complications such as interruption of blood flow with the posterior approach [76]. The central or middle approach was the preferred approach in other studies [16, 140]. The posterior approach was recommended for patients with scoliosis and pathologies of the lower neck when the central approach could not be performed [29, 76]. On the contrary, Babu et al. recommended the posterior approach due to fewer attempts required to successfully cannulate since 80% of the cannulations were successful on the first attempt compared to 57% with the anterior approach [13]. Since the posterior approach involved needle insertion higher up in the neck, allowing a longer vein length, the study reported fewer cases of hemothorax, pneumothorax, and arterial puncture [13]. In obese, critically ill, or short-necked patients, the posterior approach is preferred to prevent complications [29].

Complications

When performing IJV cannulation, it is important to be aware of the complications associated with the procedure as well as variations in each patient that may complicate the procedure. A study evaluated the structures near the IJV that are susceptible to transfixion during IJV cannulation [26]. When using USG-guided cannulation, it is possible to puncture the posterior wall of the vein because low-pressure veins can collapse [26]**.** When carotid artery puncture results in a hematoma, finding the IJV can be difficult because of the compression caused by arterial leakage and pseudo-aneurysms [9, 73]. Near the puncture site of the IJV, at the level of the cricoid cartilage, the upper trunk of the brachial plexus is posterior to the IJV, so utilizing the posterior approach for IJV cannulation may result in injury to the upper trunk of the brachial plexus [89].

The catheter tip may be positioned incorrectly, which is more common on the left IJV because the left brachiocephalic vein is longer and has more tributaries [127, 133]. Abnormal positioning of the catheter tip may predispose to thrombosis, infection, vessel or cardiac perforation, and valvular injury [109]. An angle of a tip to vessel wall greater than 40° was found to be more likely to lead to SVC wall perforation, which was shown in a laboratory [111].

Techniques to reduce complications and increase success rate

An understanding of the normal anatomy of the IJV and its relations is essential to prevent injury to surrounding structures, and an experienced clinician can help aid successful cannulation. Recognition of anatomical variations such as agenesis and duplication may help minimize the complications due to multiple failed attempts. Anatomical variations of the size and positions of the IJVs should be assessed when using the landmark technique or USG to reduce complications [14, 97]. IJV cannulation using the landmark technique in a patient with an absent IJV may be related to a higher incidence of complications such as arterial puncture and pneumothorax [96]. Detecting variations before the procedure was recommended to allow a preoperative discussion between the patient and surgeon on alternative cannulation sites and monitoring strategies [61]. Although a meta-analysis reported that real-time USG-guided IJV placement was not beneficial, USG imaging prior to IJV insertion was found to lower cannulation failure and injury to the carotid artery [107].

To avoid mechanical complications and ensure accurate monitoring of CVP, it is important to ensure that the tip of the catheter lies in the SVC (at its junction with the right atrium), in line with its long axis, right above the pericardial reflection, and the angle of the catheter to vessel wall should be less than 40 degrees [62]. As a surface marking, the atrio-caval junction corresponds to the level of sternal angle [16]. A study explored the radiological landmark to confirm the catheter tip position after cannulation since it should always lie above the pericardial reflection [111]. The upper limit of the pericardial reflection is below the carina, and the tip position varies based on left and right-sided cannulation [111]. Radiologically, zone A corresponds to the lower SVC, and upper right atrium, zone B, the area around the junction of the left and right innominate veins and the upper SVC, and zone C represents the left innominate vein proximal to the SVC (Figure 2) [111]. The study concluded that right-sided central venous catheters should be sited above the carina and left-sided should be sited in the SVC with the tip at a shallow angle to the vessel wall [111].

Many studies have identified an increase in IJV CSA with contralateral head rotation, making this a useful maneuver during cannulation [19, 49, 87, 97]. An USG-based study found that the right IJV CSA decreased from 14.2 mm^2 to 8.7 mm^2 when transitioning from a >30° contralateral rotation to <30° ipsilateral rotation [87]. Rotating the patient’s head also alters the location of the IJV’s relation to the carotid artery, yielding a 95% to 57.5% decrease in CCA overlap with this rotation [87]. While a decreased overlapping is preferred for cannulation, it was determined that a greater CSA was more important in performing successful cannulation under optimum conditions [87]. An USG-guided simulation on volunteers showed the risk of injury to CCA was lower with less than 45° contralateral head rotation [69].

The Trendelenburg position or head-down tilt is recommended in central venous cannulation, as it increases CSA due to greater central blood volume and venous return, causing distention of the vessel [134]. In this position, the patient's supine body is placed at an angle to the horizontal with the lower extremities at an elevation compared to the head [55]. A 15° head-down tilt increased IJV CSA compared to neutral positioning, reverse Trendelenburg positioning, and passive leg elevation [60] (Table III). Increased tilt over 15° increases CSA further but has been shown to increase intracranial pressure [32]. Therefore, IJV cannulation is recommended to be performed at a Trendelenburg position of 5° to 10° with 45° contralateral head rotation, allowing a significant increase in IJV CSA without a significant displacement of the IJV location [49].

Passive leg raising while maintaining the torso in a horizontal plane, has also been shown to increase IJV CSA. One study in mechanically ventilated patients showed that both Trendelenburg position and passive leg raising significantly increased right IJV CSA, 26% and 23%, respectively, as well as both vertical and transverse diameters of the IJV [47]. If Trendelenburg position is contraindicated or not possible, passive leg raising may be considered during cannulation [47, 60].

Special considerations

IJV cannulation in obese patients

A BMI over 30 kg/m^2 is considered true obesity, and these patients are often at risk of difficult cannulation [105]. The thick subcutaneous layer is likely to hide surface landmarks and requires more pressure and acute angulation to insert the needle [38]. An MRV-based study on 193 individuals showed that elevated BMI correlated with an increased IJV CSA at lower cervical levels, especially at C7/T1, while no such correlation was observed at upper cervical levels [75]. The larger IJV CSA measurements seen with high BMI patients were likely due to these patients having an increased intrathoracic pressure leading to the IJV enlargement [74].

There is a higher incidence of successful cannulation by the posterior approach (97%) in the higher weight group/obese patients compared to the anterior approach (75%), and there is a significant decrease in arterial puncture using the posterior approach (3.1%) in comparison to the anterior approach (16.6%) [29]. The study did not find a significant difference in procedure difficulty or complication rates between weight groups or approaches [29].

Although USG showed a greater incidence of CCA and IJV overlapping in obese patients compared to non-obese patients (which was especially significant at 30° or greater of head rotation), there was no statistically significant difference seen between the two groups regarding CCA puncture during the cannulation attempts under USG guidance [44, 69, 119]. USG guidance and head rotation less than 30° for central venous cannulation in obese patients may help avoid or quickly address any complications of the procedure and minimize overlapping of the IJV and CCA [25, 44, 69, 121, 137].

While the Trendelenburg position is helpful in non-obese patients, the outcome may be detrimental in obese patients. It is hypothesized that placing an obese patient in the Trendelenburg position exacerbates the risk of procedural complications due to an increase in pressure, compression, and stretch on the patient from weight [139]. Therefore, Trendelenburg positioning is not recommended in obese patients during cannulation.

IJV cannulation in pediatrics

Several studies in infants and children found that USG-guided cannulation was superior to the anatomical landmark method [28, 101, 128, 129]. The USG-guided cannulation was associated with increased success rates, fewer attempts at cannulation, fewer arterial punctures [28, 128]. In infants and pediatric populations, USG-guided cannulation seems to be the most effective and efficient.

IJV cannulation is technically challenging in infants, especially when using the traditional landmarks technique [136]. In a new landmark technique, the carotid artery was marked at the level of the cricoid cartilage, as well as the apex of the triangle formed by the clavicle and two heads of the SCM then the needle was inserted between the marks, towards the ipsilateral nipple [136]. If the first attempt was not successful, the needle was inserted more laterally for the second attempt, and if that attempt was unsuccessful, then the needle was inserted more medially [136]. Results found the new landmark technique to reduce complications such as carotid artery puncture, the duration of the procedure was shorter, and this new technique had an overall higher success rate [136].

A clinically relevant correlation between a patient's height and depth of catheter placement was found by researchers if the patient's height was between 40 and 140 cm [138]. This study used an anterior approach to insert the catheter in the right IJV and then confirmed placement with transesophageal echocardiography [138]. The final equation that was produced is as follows: optimal depth (cm) = 1.7 + (0.7 x height) [138]. This finding is very clinically relevant and helps in planning catheter insertion in children.

The vertebral artery (VA) was at risk of transfixation in pediatric patients based on the extent of overlap of VA with IJV; assessed by the width of VA, the distance between the VA and IJV/skin [58]. Thirteen percent of patients were at high risk, and hence the VA should be found by USG before cannulation [58].

CONCLUSIONS

Anatomic variations in the IJV are to be looked for when utilizing the IJV for central venous access and can be assessed by imaging modalities to view the IJV. The CSA and diameter of the IJV are variable per patient and can be changed based on patient position and breathing patterns. The dimensions and position of the IJV in relation to the CCA change with aging, with neonates having a more lateral position and pediatrics and adults having a more anterolateral position. A detailed understanding of the neck anatomy surrounding the IJV, complications associated with IJV cannulation, and the best approach and imaging modality aid in successful cannulation. While cannulation can be done by the landmark technique or the USG-guided technique, it is important to be comfortable utilizing the landmark technique in cases when USG is not available. Special considerations such as high BMI and age must be assessed before cannulation to employ techniques to increase successful cannulation rates and avoid complications.

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Table I. Summary of search results

Manuscript section	**Sub-section**	**Number of resources**
Anatomical Variations	Agenesis	10
	Hypoplasia	5
	Duplication	20
	Valves	6

	Tributaries	6
	Congenital Fistulas	9
	Arterio-venous Relation	4
Morphometrics	Cross- sectional area (CSA)	21
	Diameter	5
	Variations in CSA and Diameter	13
	Distance between skin and atrio-caval junction	5
IJV Cannulation	Clinical anatomy of IJV cannulation & Cannulation techniques	12
	Complications	24
Special Considerations	BMI	11
	Pediatrics	7

IJV — internal jugular vein (Subsections are listed in the order they appear in the manuscript. Some references are included in more than one section listed in the table).

Table II. Agenesis of the internal jugular vein

Study	**Age and Gender**	**Side of Agenesis**	**Mode of Discovery**	**Clinical Scenario**	**Salient Features**
B.R. Miller, 2011 [79]	12 Years Not reported	Right	Ultrasound, Doppler Imaging	Recognized during pre-cannulation ultrasound	Left IJV was enlarged and was the of same diameter as the left

					common carotid artery
Kayiran et al., 2015 [59]	17 Years Female	Right	CT, Doppler USG, and dynamic MRI indicated absence of right IJV	Diagnosed when investigated for painless left sided mass	Enlarged left IJV presented as a mass in the neck
Alagöz et al., 2015 [4]	66 Years Female	Right	Ultrasound indicated the absence of the right IJV, confirmed with Color Doppler	Identified during attempted cannulation for acute respiratory failure	None reported
Tejada et al., 2015 [114]	16 Years Not reported	Right	Ultrasound	Identified during attempted cannulation for laparotomy	Enlarged collaterals (thyro-lingual-facial trunk and middle thyroid vein)
Rewari et al., 2015 [96]	65 Years Male	Right	Ultrasound	Failed right IJV cannulation	None reported
Kong et al., 2017 [61]	43 Years Female	Right	Ultrasound, Doppler Imaging, CT	Recognized during pre-cannulation ultrasound	None reported
Filograna et al., 2019 [43]	52 Years Male	Right	Non-contrast CT	Recognized during staging of colon carcinoma	Collateral venous circulation that drained from the right anterior IJV and right retromandibular vein into the left IJV
Aroor et al., 2020	62 Years	Left	CT, Confirmed with	Misdiagnosed as IJV thrombosis	Enlarged neck collateral veins

[10]	Male	Histopathology	while investigated for oral carcinoma

CT — Computed Tomography; IJV — Internal Jugular Vein; USG — Ultrasound; MRI — Magnetic resonance imaging

Table III. Dimensions of the internal jugular vein

Imaging Modality	Study	Average CSA (mm^2)	Diameter (mm)	Patient's Position	Average Age (years)	Population Demographics
USG	Clenaghan et al., 2005 [32]	n/a	R 13.5 (Lat)	Su	22-57 (range)	Ireland 10 M/10 F
			R 15.5 (Lat)	10° T		
			R 15.5 (Lat)	15° T		
			R 16.4 (Lat)	20° T		
			R 16.7 (Lat)	25° T		
			R 16.7 (Lat)	30° T		
	Kim et al., 2008 [60]	R 11.2 ± 0.8	n/a	Su	27.6 ± 1.9	South Korea 20 M/0 F
		R 16.6 ± 6.70		15° T		
		R 3.80 ± 2.30		15° RT		
		R 14.0 ± 6.40		50° PLR		
	Sayin et al.,	R 2.9 ±	R 5.2 (0-1 y)	Su, cricoid	2.7	Turkey

2008 [102]	2.2 (0-1 y) R 4.3 ± 1.8 (1-2 y) R 5.4 ± 3.4 (2-6 y) R 5 ± 2.6 (6-15 y)	R 6.6 (1-2 y) R 7.5 (2-6 y) R 7.2 (6-15 y)	cartilage level		
	n/a	R 5.3 (0-1 y) R 6.4 (1-2 y) R 7.0 (2-6 y) R 7.6 (6-15 y)	Su, sterno-clavicular junction level		
	R 2.5 ± 1.2 (0-1 y) R 4.5 ± 2.2 (1-2) R 5.9 ± 4.1 (2-6 y) R 6.2 ± 3.7 (6-15 y)	n/a	T, cricoid cartilage		
Bellazzini et al., 2009 [19]	R 9.0 ± 5.6	n/a	Su, 20-30° CLR	37 ± 11	United States 23 M/29 F
	R 12.6 ± 6.9		T, 20-30° CLR		
	R 15.8 ± 6.5		Su, V, 20-30° CLR		
	R 17.0 ± 7.9		T, V, 20-30° CLR		
Ozbek et al.,	R 10.8 ±	R 13.6 ± 0.4	Su, 15-20°	37.8 ±	Turkey

	2013 [87]	0.6	(Tr) R 9.7 ± 0.3 (AP)	T, neutral head positioning	13.3	25 M/14 F
		R 12.7 ± 0.7	R 14.4 ± 0.4 (Tr) R 10.9 ± 0.3 (AP)	Su, 15-20° T, < 30° CLR		
		R 14.2 ± 0.8	R 15.0 ± 0.4 (Tr) R 10.9 ± 0.3 (AP)	Su, 15-20° T, > 30° CLR		
		R 8.7 ± 0.6	R 12.9 ± 0.5 (Tr) R 7.9 ± 0.3 (AP)	Su, 15-20° T, < 30° ILR		
	Parmar et al., 2013 [88]	n/a	R 13.23 ± 2.52 L 10.25 ± 2.29	15° T, 45° CLR	27.12 ± 4.41	India 50 M/50 F
	Ciuti et al., 2013 [31]	R 4.2 ± 4.0	n/a	Su	27	Italy 12 M/13 F
		R 0.70 ± 0.60		Si		
	Seong et al., 2016 [104]	R 10.6 ± 3.60	n/a	Su	28.15 ± 2.85	South Korea 26 M/15 F
		R 13.4 ± 4.50		Su, V		
		R 12.6 ± 4.10		Su, EDC		
		R 14.1 ± 4.70		Su, V, EDC		

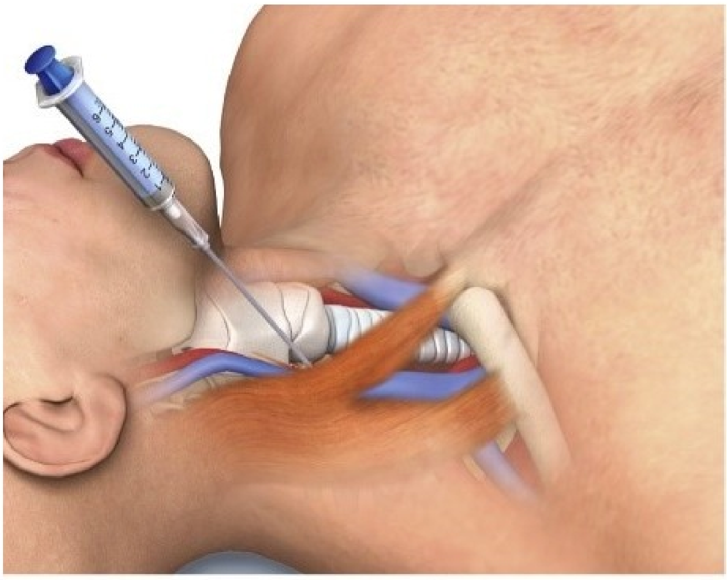
	López Álvarez et al., 2017 [72]	n/a	5.9 ± 2.3 (AP)	Su, 10-15° CLR	5.5 ± 5.2	Spain 70 M/55F
MRI	Laganà et al., 2016 [63]	R 63.26 ± 31.51 L 53.52 ± 25.58	n/a	Su	31.22 ± 9.29	Italy 13 M/23 F
	Magnano et al., 2016 [74]	R 68.7 ± 53.7 L 49.3 ± 37.5	n/a	Su; C7/T1 level	43 ± 17.5	United States 63 M/130 F
		R 55.4 ± 38.0 L 42.1 ± 30.6		Su; C5/C6 level		
		R 52.5 ± 28.2 L 38.8 ± 23.5		Su; C4 level		
		R 39.2 ± 24.1 L 27.5 ± 18.0		Su; C2/C3 level		
	Pelizzari et al., 2018 [90]	R 46.6 (median) L 24.4 (median)	n/a	Su	30.9 ± 9.0	Finland 1 M/8 F
CT	Lim et al., 2006 [70]	n/a	R 14.1 L 11.74	Su	Adults	Australia

	Tartière et al., 2009 [113]	R 181 ± 111 L 120 ± 81	R 17 ± 5 L 14 ± 5	Su	60 ± 15	France 132 M/58 F
	Yoon et al., 2013 [137]	R 165 ± 81 L 119 ± 57	R 16.7 ± 3.8 (Tr) R 12.6 ± 3.7 (AP) L 13.7 ± 3.5 (Tr) L 11.1 ± 2.6 (AP)	Su	48 ± 14	South Korea 34 M/46 F
	Jeon et al., 2020 [54]	R 124.3 L 89.1	R 14.3 L 12.0	Su; Upper (Hyoid)	65 (median)	South Korea 160 M/153 F
		R 190.8 L 127.0	R 17.6 L 14.4	Su; Middle (Cricoid)		
		R 183.1 L 94.5	R 16.5 L 11.8	Su; Lower (T1)		
Autopsy Dissection	Furukawa et al., 2010 [45]	n/a	R 13.4 L 9.4	n/a	54.4	Japan 18 M/12 F

USG — Ultrasonography; MRI — Magnetic Resonance Imaging; CT — Computed Tomography; R — Right IJV; L — Left IJV; Lat — Lateral; AP — Anteroposterior; Tr — Transverse; Su — Supine; Si — Sitting; T — Trendelenburg; RT — Reverse Trendelenburg; V — Valsalva; M — Male; F — Female; PLR — Passive Leg Raising; CLR — Contralateral Rotation; ILR — Ipsilateral Rotation; ECD — External Digital Compression

Figure 1. Approaches to the internal jugular vein. IJ — Internal jugular; SCM — sternocleidomastoid [97]. (Reprinted from Roberts and Hedges' Clinical Procedures in Emergency Medicine and Acute Care, Seventh Edition, Salim R. Rezaie, E.C. Coffey, Christopher R. McNeil, Central Venous Catheterization and Central Venous Pressure Monitoring, 405-438.e3., 2019, with permission from Elsevier).

Figure 2. Stylized anatomical figure dividing the great veins and upper RA into three zones (A–C), representing different areas of significance for placement of CVCs. Zone A, upper RA and lower SVC; Zone B, upper SVC and junction of left and right innominate veins; Zone C, left innominate vein [111]. (Reprinted from British Journal of Anaesthesia, vol. 96, P.A. Stonelake, A.R. Bodenham, The carina as a radiological landmark for central venous catheter tip position, 335-340, 2006 with permission from Elsevier).



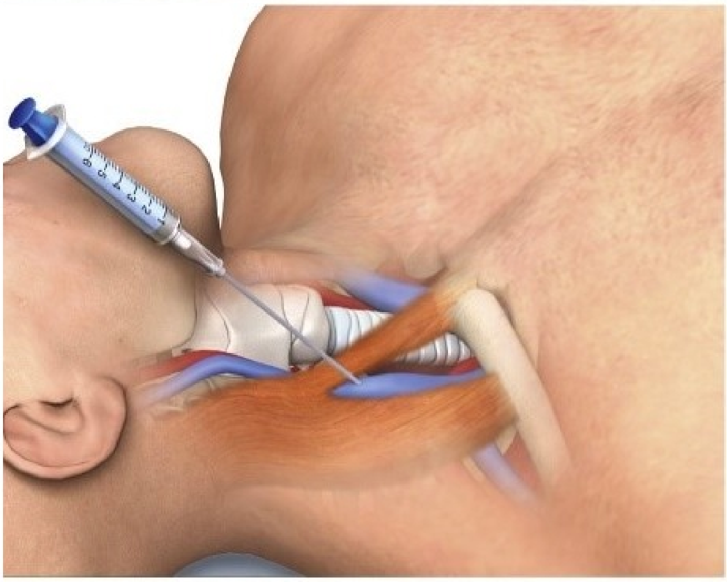
Anterior Approach

Insert needle along the medial edge of the sternocleidomastoid, 2-3 fingerbreadths above the clavicle.

Entry angle = 30° to 45°.

Aim toward the ipsilateral nipple.

Note: palpate the carotid artery during venipuncture. The artery may be slightly retracted medially.



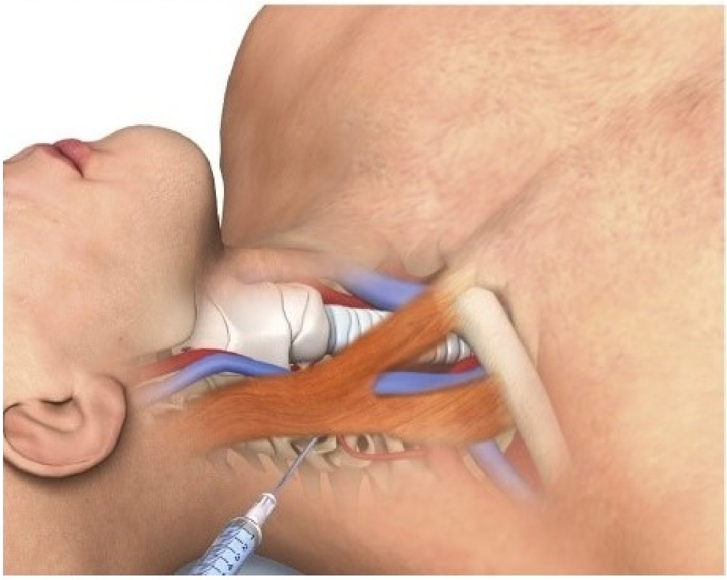
Central Approach

Insert needle at the apex of the triangle formed by the heads of the sternocleidomastoid muscle and the clavicle.

Entry angle = 30°.

Aim toward the ipsilateral nipple.

Note: estimate the course of the IJ vein by placing three fingers lightly over the carotid artery as it runs parallel to the vein. The vein lies just lateral to the artery, albeit often minimally so.



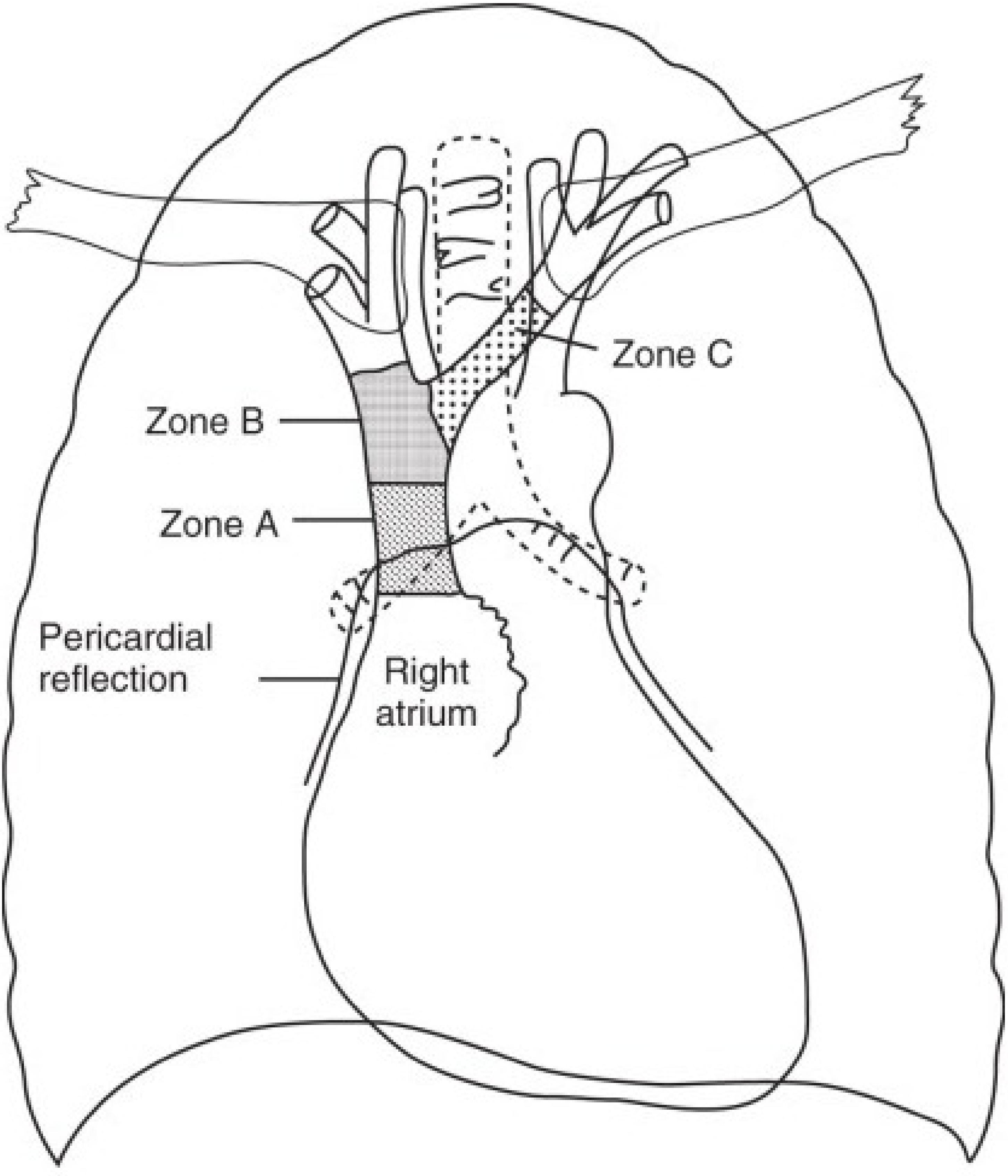
Posterior Approach

Insert needle at the posterior (lateral) edge of the sternocleidomastoid, midway between the mastoid process and the clavicle.

Entry angle = 45°.

Aim toward the suprasternal notch.

Note: avoid the external jugular vein, which crosses the posterior SCM border. During needle advancement, apply pressure to the SCM to lift the body of the muscle. The vein is usually reached at a depth of 7 cm.



Zone C
Zone B
Zone A
Pericardial reflection
Right atrium