Research paper

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Anatomical variations of the cervical vagus nerve on ultrasonography: a cross-sectional study

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Keywords

cervical vagus nerve, anatomical variation, ultrasonography, carotid sheath, thyroid gland

Abstract

Aim: To identify anatomical variations in the cervical vagus nerve using ultrasonography and assess their relationship with age, sex, side, site, and proximity to the thyroid gland. **Materials and methods:** A cross-sectional observational study was conducted on 347 patients undergoing routine or clinically indicated neck ultrasonography. High-frequency linear ultrasound probes were used to scan the cervical region bilaterally. The cervical vagus nerve was identified relative to the common carotid artery and internal jugular vein, and its anatomical course was classified using a reference C-I axis. Anatomical variation types and proximity to the thyroid gland in potentially vulnerable configurations were recorded. Demographic factors, including age and sex, were analyzed in association with variation prevalence. **Results:** Anatomical variations of the cervical vagus nerve were observed in 132 of 347 participants (38%). There was a statistically significant left-sided predominance (67.1%) compared to right-sided variations (6%) (p <0.001). Eight patients had bilateral variations. The most common type was the anteromiddle variation, followed by anterolateral, anteromedial, and medial types. Variation prevalence increased with age and was higher in males than in females (46.6% vs. 34.4%, p = 0.033). In 69 cases, the cervical vagus nerve was located less than 2 mm from the thyroid gland, with 13 abutting it directly. **Conclusion:** Ultrasonography is a valuable, non-invasive imaging modality for identifying anatomical variations of the cervical vagus nerve. Awareness of these variations is essential for surgical planning and for preventing iatrogenic nerve injury, especially during procedures like thyroidectomy, vagus nerve stimulation, and radiofrequency ablation, particularly in older patients and on the left side of the neck. Preoperative mapping of the nerve using ultrasonography could, therefore, be considered as a routine measure.

Introduction

The vagus nerve (VN), also known as cranial nerve X, is a mixed nerve that carries parasympathetic, motor, and sensory fibers. It originates from the medulla oblongata and descends through the neck and thorax into the abdomen. In the cervical region, it is enclosed within the carotid sheath alongside the common carotid artery (CCA) and the internal jugular vein (IJV). Classically, the VN is positioned posterolateral to the CCA and posteromedial to the IJV. However, emerging evidence suggests that this positional relationship is not consistent across all individuals[1–4].

Anatomical variations in the course of the cervical vagus nerve (CVN) are increasingly recognized and hold significant clinical relevance. Deviations from the classical pathway may increase the risk of inadvertent nerve injury during surgical or interventional procedures. With the growing adoption of minimally invasive surgeries, fine-needle aspirations, and image-guided therapies in the neck, accurate preoperative knowledge of vascular and neural anatomy has become indispensable.

Surgical and interventional procedures involving the cervical region – such as thyroidectomy, anterior cervical discectomy, vagus nerve stimulation (VNS), and radiofrequency ablation (RFA) – may be complicated by anatomical variants of the CVN[5–7]. These variations may increase the susceptibility of the nerve to injury, especially if they are situated anterior or medial to the CCA, or in close proximity to the thyroid gland. Preoperative identification of these anomalies can help mitigate risk and guide surgical planning.

Ultrasonography (USG) is a non-invasive, cost-effective, and widely accessible imaging modality that enables real-time visualization of soft tissue structures[8–10]. Unlike CT, USG does not expose patients to radiation, making it particularly suitable for repeated evaluations and use in pediatric or elderly populations. Additionally, USG provides dynamic imaging, allowing assessment of neural structures in different head and neck positions, which may help reveal positional changes not apparent on static imaging modalities.

While cadaveric studies have contributed significantly to our understanding of CVN anatomy, they do not capture the temporal variations observed in living individuals. Consequently, there is growing emphasis on in vivo imaging studies to bridge this gap in anatomical knowledge. This study aims to evaluate CVN anatomy using ultrasonography in a large population and to correlate findings with patient demographics, thereby providing clinically relevant anatomical insights.

Materials and methods

Study design and duration

A cross-sectional observational study was conducted at the Department of Radiodiagnosis and Clinical Imaging, Sri Guru Ram Das Institute of Medical Sciences and Research, India, over a period of 18 months. Ethical clearance was obtained from the institutional ethics committee, and informed consent was secured from all participants.

Participants

The study included 347 patients referred for neck ultrasonography for various indications, including thyroid evaluation, metastatic workup, and systemic disease screening.

Although a formal power analysis was not performed, the sample size of 347 patients exceeds that of previous similar studies, ensuring sufficient power to detect clinically relevant differences in variation prevalence.

Inclusion criteria:

- Patients who gave their informed consent.
- Participants undergoing neck ultrasonography.

Exclusion criteria:

- Patients with a cervical mass which infiltrates the carotid space, causing disruption of the normal anatomy of the carotid space.
- Patients with a cervical mass involving the VN, such as vagal schwannoma or metastatic carcinoma invading the VN.
- Patients with a prior history of neck irradiation or surgery.

Ultrasound equipment and technique

Ultrasonography was performed using high-resolution linear transducers with frequencies ranging from 4–18 MHz (GE Voluson E8, GE Venue Go, Samsung V8 and Philips Affinity 50). Patients were examined in the supine position with neck extension and rotation opposite to the side of interest. The cervical carotid sheath was scanned bilaterally from the level of the digastric muscle to the clavicle. The VN was identified as a round, hypoechoic, fascicular structure with a hyperechoic rim, devoid of vascular flow on color Doppler.

Anatomical classification

The position of the CVN was evaluated with reference to the C-I axis, which connects the centers of the CA and the IJV. Variations were classified into the following categories (Fig. 1):

- **Typical:** Posterolateral to the CCA and posteromedial to the IJV (Fig. 1)
- **Anterolateral:** Anterior to the lateral one-third of the CCA diameter
- **Anteromiddle:** Anterior to the middle one-third of the CCA diameter (Fig. 2)
- **Anteromedial:** Anterior to the medial one-third of the CCA diameter (Fig. 3)
- **Medial:** Medial to the medial border of the CCA

In potentially vulnerable positions (anteromedial, anteromiddle, and medial), the shortest distance between the CVN and the ipsilateral thyroid lobe was measured.

Limitations: observer variability and image review

To minimize operator bias, all ultrasound examinations were independently reviewed by an experienced musculoskeletal radiologist with over 10 years of expertise in neck ultrasonography.

Statistical analysis

Data were compiled using SPSS software. Chi-square and t-tests were used for evaluating associations between CVN variations and

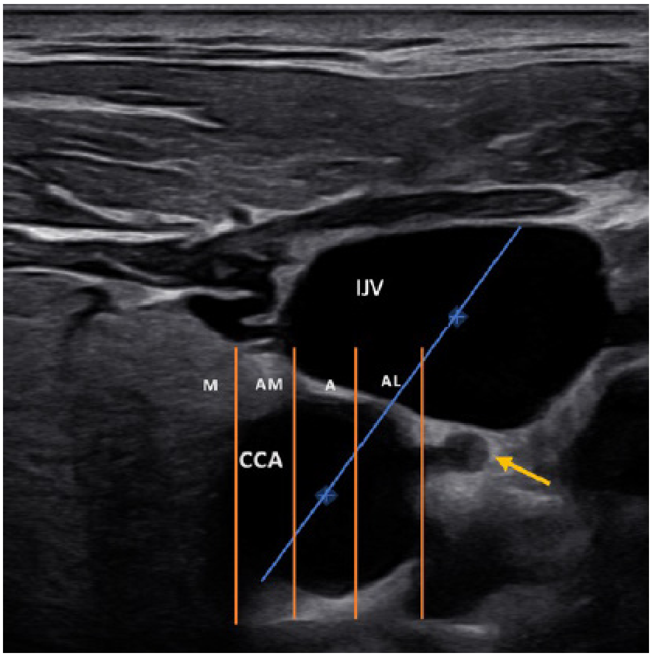

Fig. 1. *Ultrasound of the neck showing the usual position of the VN (yellow arrow). The VN is located posterior or lateral to the reference axis that joins the centers of the CA and IJV (blue line). A variation in position is defined as the VN being located anterior or medial to the C-I axis. Variations are classified into four types: anterolateral (AL), anteromiddle (A), anteromedial (AM), and medial(M) – based on the relative location of the VN to the carotid artery*

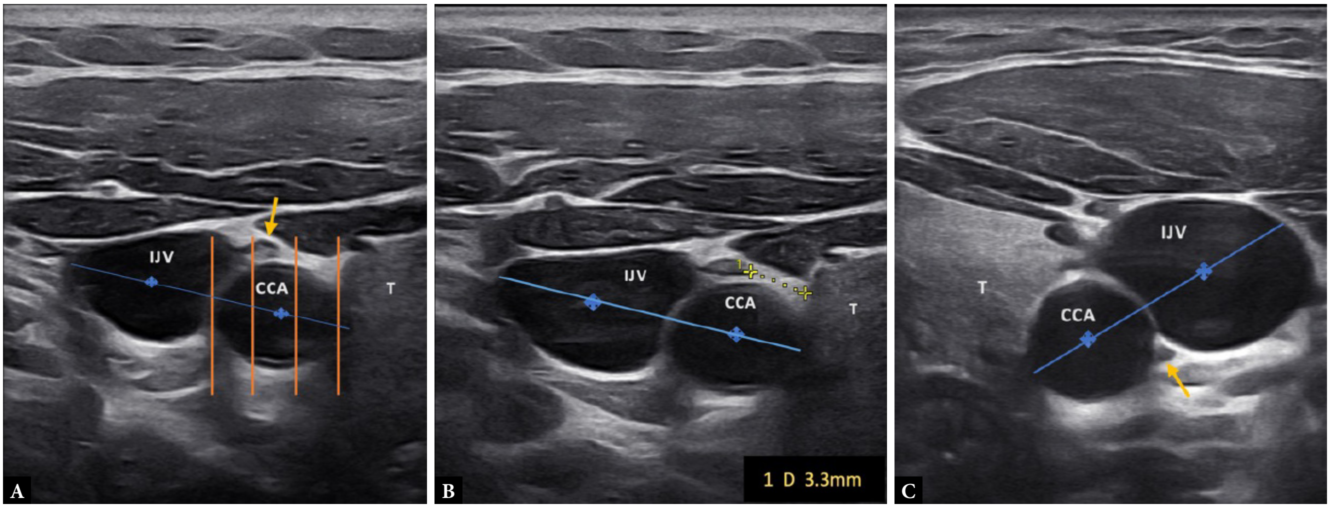

Fig. 2. *Transverse gray-scale ultrasonographic images of the right (***A***) and left (***C***) carotid sheaths in a 24-year-old female, showing the CVN relative to the reference axis (C-I axis). The right VN (yellow arrow) shows an anteromiddle variation (***A***). Image* **B** *shows the shortest distance of 3.3 mm between the right VN and the ipsilateral thyroid lobe (represented by "T"). The left VN is in the typical textbook anatomical location i.e. posterolateral to the CCA and posteromedial to the IJV on the right side, as demonstrated in image* **C**

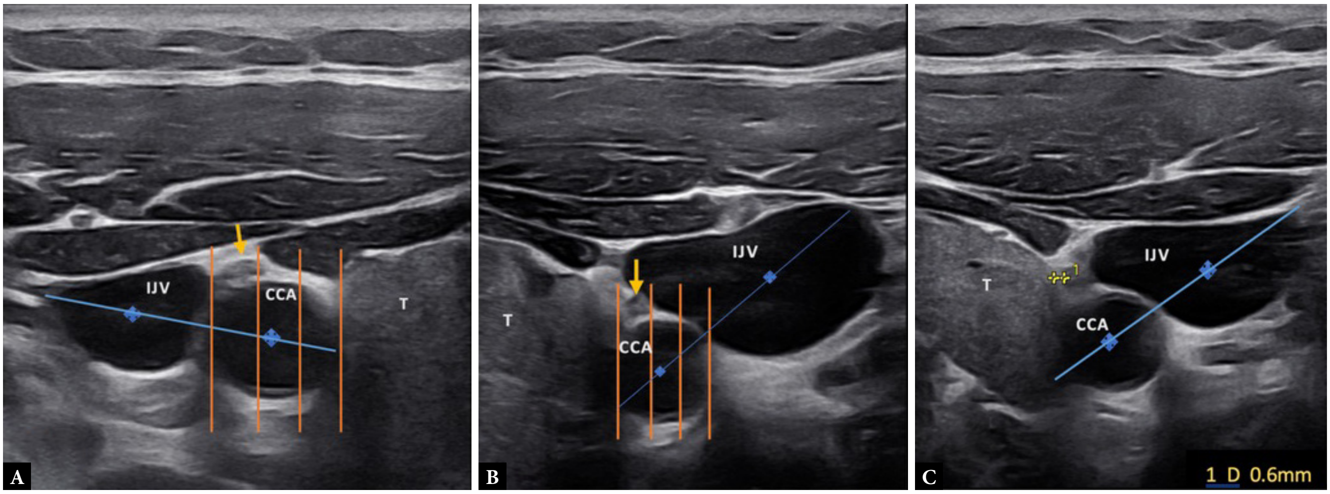

Fig. 3. *Transverse gray-scale ultrasonographic images of the right (***A***) and left (***B***) carotid sheaths in a 40-year-old female, showing the CVN relative to the reference axis (C-I axis). The right VN (yellow arrow) shows anterolateral variation, as demonstrated in image* **A.** *The left VN (yellow arrow) shows anteromedial variation, as demonstrated in image* **B.** *Image* **C** *shows the shortest distance of 0.6 mm of the left VN from the ipsilateral thyroid lobe (represented by "T")*

demographic variables. A *p*-value of <0.05 was considered statistically significant.

Results

Demographic data

Among the 347 patients, the male-to-female ratio was approximately 1:2.4 (103 males, 244 females), with a mean age of 40.04 ± 17.51 years. Participants were divided into age groups: <20 years (11%), 20–39 years (37.8%), 40–59 years (37.8%), and ≥60 years (13.5%).

The indications for neck ultrasonography (USG) included routine metastatic workup (8.3%), which was the most common; routine health examination (7.8%); difficulty in swallowing with dry mouth (4.3%); diagnostic evaluation of Hashimoto's thyroiditis in patients receiving treatment (4.3%); and bone pain with kidney stones and hypercalcemia suggestive of hyperparathyroidism (3.4%). The remaining 249 cases (71.8%) were classified as "others," representing a broad spectrum of clinical indications.

Prevalence and laterality of variations

Of the 347 patients evaluated, variations were observed in 132 (38%). Left-sided variations were significantly more frequent (67.1%) than right-sided variations (6.0%) (*p* <0.001). Eight participants (2.3%) exhibited bilateral variations (Tab. 1).

Distribution of variation types

On the left side, the anteromiddle configuration was the most common variation (32.9%), followed by anterolateral (18.1%), anteromedial (12.1%), and medial (4.0%). On the right side, the anteromiddle

Tab. 1. Prevalence of vagus nerve variations by side and variation characteristics

Variable, *n* (%)	Right (*n* = 347)	Left (*n* = 347)	*P*-value
Position of the vagus nerve			
Normal	326 (94.0)	114 (32.9)	**<0.001**
Variation	21 (6.0)	233 (67.1)	
Types			
Anterolateral	5 (1.4)	63 (18.1)	
Anteromiddle	9 (2.6)	114 (32.9)	**0.040**
Anteromedial	3 (0.9)	42 (12.1)	
Medial	4 (1.1)	14 (4.0)	
Level of variation			
Variation at **Level III**	8 (2.3)	112 (32.3)	**<0.001**
Variation at **Level IV**	13 (3.7)	121 (34.9)	
Proximity to the thyroid gland			
Significant proximity (<2 mm, including abutting)	8 (2.3)	61 (17.6)	
• Abutting thyroid gland (0 mm)	**3 (0.9)**	**10 (2.9)**	0.071
• Within <2 mm but not abutting	**5 (1.4)**	**51 (14.7)**	
>2 mm (safe distance)	8 (2.3)	109 (31.4)	

Tab. 2. Vagus nerve variations according to patient demographics

Variable, *n* (%)	No.	Variation (+) (*n* = 132)	Variation (-) (*n* = 215)	*P*-value
Sex				
Male	103	48 (36.4)	55 (25.6)	0.033
Female	244	84 (63.6)	160 (74.4)	
Age				
<20	38	5 (3.8)	33 (15.3)	
20–39	131	27 (20.5)	104 (48.4)	**<0.001**
40–59	131	70 (53.0)	61 (28.4)	
>60	47	30 (22.7)	17 (7.9)	

configuration was also the most common variation (2.6%), followed by anterolateral (1.4%), medial (1.1%), and anteromedial (0.9%). The typical posterior configuration was preserved in 94% of right-sided nerves compared with 32.9% of left-sided nerves (Tab. 1).

Level of variation

The majority of variations were located at Level IV (lower cervical region), suggesting a progressive anterior shift of the IJV in the lower neck[11,12] (Tab. 1).

Proximity to the thyroid gland

In 69 cases (20.0%), the CVN was situated less than 2 mm from the thyroid capsule. Of these, 13 nerves were directly abutting the gland, posing an increased risk during thyroid-related interventions[13] (Tab. 1).

Relationship with demographics

The frequency of variations showed a statistically significant increase with advancing age (p <0.001). Variations were more prevalent in males (46.6%) than in females (34.4%) (p = 0.033). No significant sex-related difference was noted in bilateral variations (Tab. 2).

Discussion

Our findings align with previously published studies showing that the CVN demonstrates significant anatomical variability, especially on the left side[2,6,12]. This asymmetry is likely rooted in embryological development, as the left vagus nerve follows a longer and more complex thoracic course, predisposing it to positional deviations.

The high prevalence of anteromiddle and anterolateral variants has direct clinical relevance. These configurations are more susceptible to accidental injury during anterior cervical surgical approaches, VNS electrode implantation, and percutaneous interventions, such as radiofrequency ablation[7,13]. The closer the nerve is to the thyroid capsule, the greater the risk of thermal or mechanical injury.

Ultrasonography proved to be a sensitive modality for detecting even subtle positional changes of the CVN. Compared to cadaveric studies or CT imaging, USG allows for dynamic and functional evaluation[8,9]. Our results are consistent with those of Ahn *et al.*[6], who observed anterior variations in nearly 35% of left-sided nerves.

The findings also support the integration of preoperative sonographic mapping into clinical workflows. For instance, intraoperative neuromonitoring (IONM) during thyroidectomy could benefit from prior knowledge of nerve position, especially in patients with altered anatomy due to pathology or aging[5,14]. Tailoring surgical approaches based on preoperative imaging could significantly minimize the incidence of nerve-related complications.

Interestingly, age-related changes may reflect soft tissue laxity and vascular tortuosity, displacing the VN from its classical location[10,15]. Additionally, degenerative changes associated with aging could impact the fascicular structure of the nerve, further complicating its identification and preservation during interventions. This emphasizes the need for individualized imaging rather than reliance on textbook anatomy[16].

Another important observation is the higher frequency of variations in males compared to females. Although the underlying reasons remain speculative, differences in neck anatomy, vascular dimensions, or hormonal influences may play a role and warrant further investigation in future studies. The sample was skewed toward female participants (M:F = 1:2.4), which may have influenced this result. Future studies with balanced cohorts and multivariate analyses, such as logistic regression, are warranted to control for these variables and to determine whether sex independently predicts anatomical variation in CVN.

While the current study provides comprehensive data, limitations include its single-center design and operator dependence of ultrasonography. Furthermore, longitudinal follow-up studies could enhance the understanding of how positional changes evolve with age, disease states, or post-surgical alterations.

Our results, in conjunction with intraoperative findings reported by Gürsoy *et al.* in 2025, suggest that the use of ultrasonography to determine VN position preoperatively can optimize surgical exposure during VN stimulation procedures. In their series, head rotation significantly altered sternocleidomastoid muscle positioning, obstructing access to the carotid sheath and potentially increasing operative time and the risk of complications. Thus, similar ultrasonographic mapping in the preoperative phase may be advantageous for patient-specific planning[17].

Additionally, recent interventional applications of VN sonography extend beyond diagnostic imaging. Lam *et al.* in 2024, described a novel therapeutic hydrodissection technique using 5% dextrose under ultrasound guidance to treat chronic pain and autonomic dysfunction. Their findings reinforce the importance of precise VN localization within the carotid sheath, further underscoring the value of anatomical mapping in both surgical and interventional contexts[18].

Future research integrating 3D ultrasonography, elastography, or fusion imaging techniques may offer even more detailed and reproducible evaluation of CVN anatomy. Multicenter studies with larger sample sizes and more diverse populations are also recommended to validate these findings and establish standardized imaging protocols.

Conclusions

Ultrasonographic assessment of the CVN reveals considerable anatomical variability, particularly on the left side and in older individuals. The anteromiddle configuration is the most common variant and often places the nerve in close proximity to the thyroid gland[13].

Understanding these anatomical nuances is imperative for clinicians performing neck surgeries, VNS electrode implantation, and ablative procedures. Routine preoperative mapping of the CVN using high-resolution ultrasound can significantly reduce the risk of iatrogenic injury and improve patient safety.

Future studies should focus on multicenter validation, integration of 3D ultrasound techniques, development of standardized protocols for CVN assessment, and also inclusion of patients with a history of thyroidectomy, as ultrasonography could serve as a useful tool for VN localization in this higher-risk group undergoing re-intervention.

Conflict of interest

The authors do not report any financial or personal connections with other persons or organizations which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

Author contributions

Original concept of study: KPS. Writing of manuscript: SR. Analysis and interpretation of data: KPS, AS, SK. Final acceptation of manuscript: KPS. Collection, recording and/or compilation of data: SR. Critical review of manuscript: KPS, AS, PP.

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