Review paper

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Transesophageal echocardiography in the imaging of spinal cord structures – a systematic review of the literature

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Keywords

ultrasonography; spinal cord; epidural space; intraoperative monitoring; image-guided procedures

Abstract

Background: Transesophageal echocardiography enables visualization of structures within the spinal canal, particularly in the upper thoracic and lower cervical regions, but its diagnostic performance and clinical roles remain unclear. **Aim:** To systematically review studies evaluating the ability of transesophageal echocardiography to depict spinal canal anatomy and its potential diagnostic, monitoring, and interventional applications. **Material and methods:** A PRISMA-guided systematic review (PROSPERO CRD420251074380) was conducted to identify human studies evaluating transesophageal echocardiography for imaging spinal canal structures. PubMed/MEDLINE, Embase, and Web of Science were searched from inception to September 2025; screening and de-duplication were supported by Rayyan, and findings were synthesized narratively. **Results:** Thirteen studies met the inclusion criteria. Transesophageal echocardiography consistently identified key landmarks such as the epidural space, dura mater, subarachnoid compartment, and catheter position, with the best visualization reported in the upper thoracic and lower cervical segments. Reported applications included adjunctive diagnosis of selected pathologies, intraoperative assessment of spinal perfusion, and procedural guidance. Image quality and feasibility were influenced mainly by patient habitus and anatomy. Safety signals were favorable, although systematic assessment was lacking. No study provided robust comparative accuracy versus magnetic resonance imaging or computed tomography, and standardized outcome measures were uncommon. **Conclusions:** Transesophageal echocardiography shows promise for real-time visualization of spinal canal structures and select intraoperative and interventional uses. However, current evidence is limited to small, heterogeneous studies. Rigorous prospective research including standardized imaging endpoints and comparative evaluations is needed to define its diagnostic accuracy, safety, and clinical impact.

Introduction

Transesophageal echocardiography (TEE) is a well-established imaging technique that has found widespread application across medical disciplines(1). Alongside transthoracic echocardiography, it serves as a fundamental tool for assessing the morphology and function of the heart and great vessels. In cardiac surgery and interventional cardiology, TEE is utilized for intraoperative monitoring, guiding decisions regarding the procedural scope and enabling the evaluation of interventional outcomes(2). The utility of TEE also extends to emergency medicine, where it is invaluable for rapid point-of-care diagnosis of critical conditions, including cardiac arrest(3,4). Moreover, its ability to provide real-time imaging is essential for guiding numerous life-saving interventions, such as implantation of mechanical circulatory support systems(5). Recently, several studies have suggested a novel application of TEE for imaging spinal canal structures. This capacity for real-time diagnostics opens new avenues for patient care, particularly during surgery or for individuals in whom conventional imaging is not feasible. The objective of this systematic review is to comprehensively analyze the use of TEE for imaging spinal canal structures, focusing on the accessibility of anatomical features, the feasibility of dynamic measurements, the specific techniques utilized, and the overall benefits and limitations of this emerging application.

Material and methods

Reporting and registration

This systematic review was conducted and reported in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The study protocol was registered in the PROSPERO database (CRD420251074380). Since this study was based entirely on previously published data, approval from an ethics committee was not required.

Eligibility criteria

We included all study designs (including observational studies, case reports, and letters to the editor) that presented original data on the use of transesophageal echocardiography to image spinal canal structures in humans. We excluded editorials, animal studies, non-English publications, and papers not directly related to the review question.

Search strategy

The PubMed/MEDLINE, Embase, and Web of Science databases were searched without a time limit up to September 2025. The strategy combined controlled vocabulary (MeSH/Emtree) and free-text keywords across three core concepts: (1) Transesophageal Echocardiography, (2) Spinal and Neuraxial Anatomy, and (3) Imaging/Localization. The full, reproducible search strings for each database are provided in the Supplement. The reference lists of all included articles were also manually screened.

Study selection and data extraction

The web-based application Rayyan.ai was utilized to facilitate the screening of search results[(6)]. The study selection process, which included a review of titles and abstracts followed by full-text analysis, was performed independently by two investigators (MM, KM). Any disagreements were resolved through discussion. Data extraction from eligible studies was performed independently by two investigators (TD, SK) via a standardized form. The data collected included the following: study and study population characteristics; details regarding the purpose and method of TEE; anatomical and physiological descriptions of the images; measurements performed; reported benefits and limitations.

Risk of bias and data synthesis

Given the heterogeneity of study designs (predominantly case reports and observational studies) and the descriptive nature of outcomes, a formal quantitative risk-of-bias assessment was not performed. Data were synthesized narratively.

Results

The search identified 722 records, of which 13 publications were ultimately included in the review. The initial search was conducted up to May 2025, and an updated search was performed in September 2025 prior to manuscript submission. No additional relevant records were identified. The study selection process is illustrated in the PRISMA flowchart (Fig. 1). Table 1 presents the key characteristics of the included studies[(7–19)].

Patient population

A total of 233 pediatric and adult patients were analyzed. The largest patient groups were described in the studies by Hanada *et al.* (94 patients), Mügge *et al.* (56 patients), and Goswami *et al.* (24 patients)[(7,17,18)]. The use of TEE for imaging spinal canal structures has been reported across several medical fields, including cardiac surgery[(9,11–14,16,19)], thoracic surgery[(17)], vascular surgery[(8)], interventional cardiology[(15)], traumatology[(10)], and neurology[(7)]. Studies were performed in both conscious and anesthetized patients.

Effectiveness of spinal canal structure imaging

Spinal canal structures were successfully visualized in all patients in the studies by Godet *et al.* (17/17 patients), Mügge *et al.* (56/56 patients, at least two segments), and Goswami *et al.* (24/24 patients)[(7,8,17)]. Hanada *et al.* imaged 99% of thoracic segments in children (542/550 segments) and 70% in adults (191/275 segments)[(18)]. In the study by Mügge *et al.*, in one of five patients with syringomyelia, imaging of only one segment was obtained, which did not allow for a complete assessment of the pathology[(7)]. In the case series by Hanada *et al.*, in one of 20 patients, the epidural catheter could not be visualized[(18)]. In all case reports, visualization of the spinal canal structures was complete and unrestricted.

The anatomical structures of the spinal canal depicted included the spinal cord (round in the thoracic region, elliptical in the cervical region, and hypoechoic due to high lipid content), its central canal, ventral and dorsal roots, anechoic cerebrospinal fluid, highly echogenic spinal meninges, and accessory structures of the spinal cord, including intervertebral discs (serving as acoustic windows) as well as vertebral bodies and processes that provide acoustic shadowing. An example image of healthy spinal cord is presented in Figure 2. In addition to static structures, pulsation of the spinal cord and nerve roots, synchronous with the heart rate, was also described, which indirectly indicated preserved spinal perfusion. Several studies obtained direct images of spinal cord vascularization, including flow through the anterior spinal artery[(9,15,16)], radicular branches, and intercostal arteries[(9,14)]. However, visualization of flow in the anterior spinal artery via color Doppler was not always possible, and Voci *et al.* reported an inability to visualize it in the T6-T8 segment, indicating that this region represents a watershed area[(9,13,16)]. Moreover, it was not possible to directly image the artery of Adamkiewicz, most likely due to limited access to the lower thoracic segments.

In four studies, epidural catheters were visualized within the spinal canal with possible precise localization and assessment of the spread of saline, local anesthetics, and air administered through them[(14,16–18)]. In two studies, pathological conditions such as intramedullary cavities in syringomyelia, extraspinal masses in neurofibromatosis, and features of posttraumatic subarachnoid hemorrhage (characterized by fibrin-like echogenic images in CSF, thickening of the pia mater, and spinal edema) were observed[(7,10)].

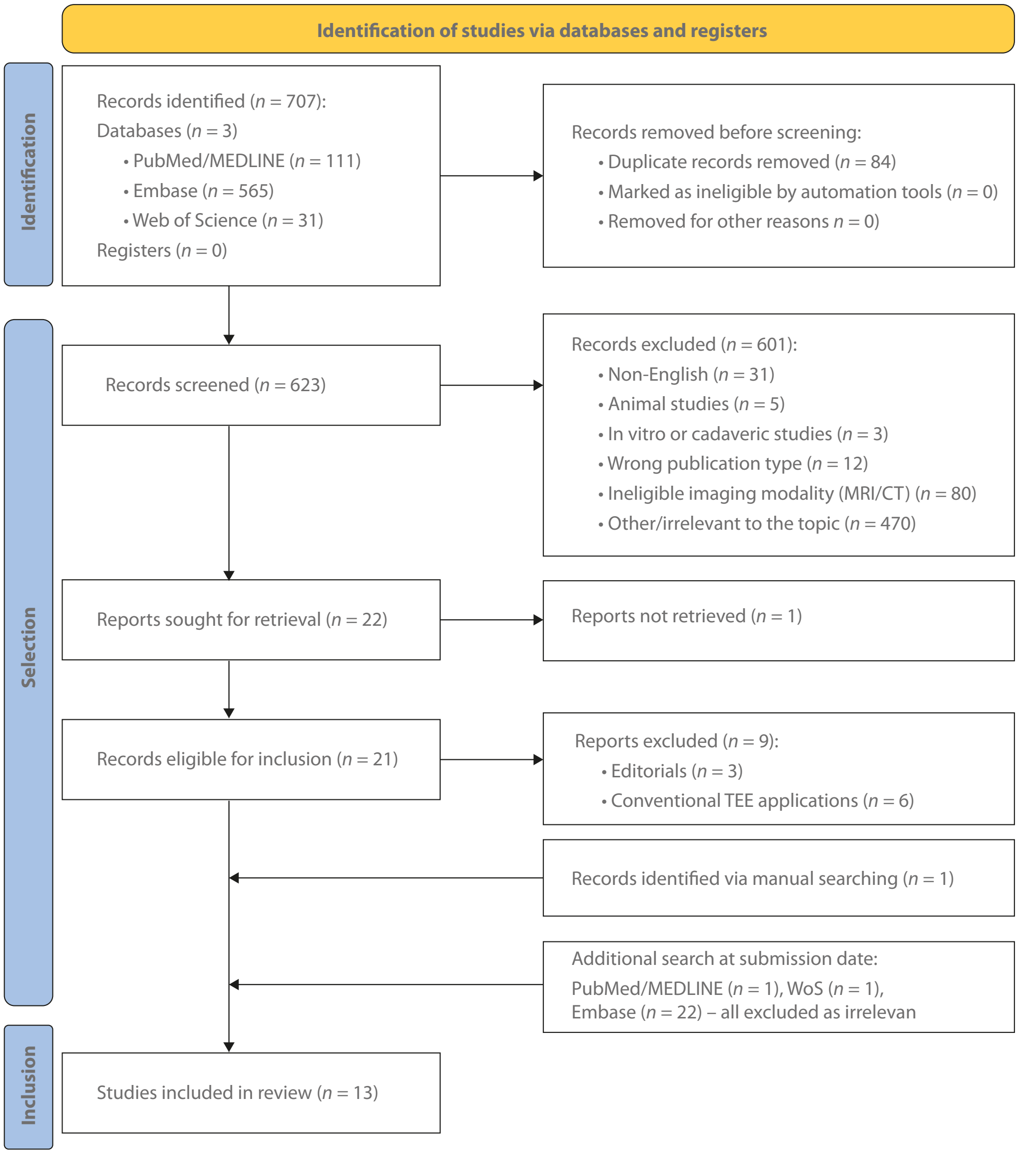

Fig. 1. *PRISMA flowchart of study selection*

Complications

In the analyzed publications, no complications directly related to attempts to image the structures of the spinal cord via TEE were noted.

Discussion

Over the past three decades, there have been only a few published reports indicating the potential benefits of using transesophageal ultrasonography to image spinal canal structures. This seems surprising, given the method's minimal invasiveness, efficacy, and increasing availability. One of the most frequently reported applications of TEE is the localization of thoracic epidural catheters. Hanada *et al.* and Goswami *et al.* emphasized the usefulness of TEE in identifying the position of the catheter tip and the spread of the anesthetic agent[17,18]. Ueda *et al.* also indicated that TEE could serve as an alternative to fluoroscopy for confirming catheter position, which is particularly important in young children[14]. Chitilian *et al.* noted its potential for identifying a herniated intervertebral disc, which may be helpful during catheter placement[11].

The ability of TEE to assess spinal perfusion in real time represents another promising application, particularly during thoracoabdominal aortic surgery involving high-level stent-graft implantation. Some studies demonstrated the feasibility of quantitative assessment of blood flow in the anterior spinal artery, but direct visualization of the artery of Adamkiewicz remains beyond the method's capabilities, largely due to its frequently low origin and significant anatomical variability.

TEE has also been explored for diagnosing rare pathologies of the spinal canal. For instance, Mügge *et al.* described its use for imaging cavities in syringomyelia and specific masses in neurofibromatosis[7]. The technique enables rapid evaluation (under 10 minutes)

Tab. 1. Summary of included studies evaluating transesophageal echocardiography for imaging structures of the spinal canal. Data are presented as reported by the original authors

First author, Year	Publication type	Medical specialty	Number of patients (Age)	Disease	Ultrasound system	Segment visualized	Navigation points	Spinal cord	CSF	Roots	Meninges	Vascular structures	Color Doppler	PW doppler	Measurements	Other observations
Mügge, 1991[7]	Technical note	Cardiology, Neurology	56 (Adults)	Syringomielia (5), Neurofibromatosis (1)	Hewlett Packard, Acuson; 5 Mhz	Upper thoracic and lower cervical (100% 2 segments; 75% 3–5 segments; 25% >5 segments)	30 cm from the incisors (aortic valve/left atrial appendage), descending aorta, 20–30° left rotation	Yes (homogeneous, hypoechoic, central canal/ central echo)	Yes (anechoic)	-	Pia mater (thin, hyperechoic)	-	-	-	-	In syringomyelia, intramedullary cavities with no central echo; in neurofibromatosis, masses abutting the spinal cord
Godet, 1994[8]	Prospective observational study	Vascular surgery	17 (Adults)	None	Hewlett Packard; 5 Mhz	Cervical/Thoracic (min C5–6; max T10–11)	CXR	Yes (pulsation)	-	-	-	-	-	-	Probe distance from incisors: 20 cm = T1–T2; 38 cm = T10–11; 2–3 cm per interspace	Cord not visualized below T10–T11; artery of Adamkiewicz not identified
Voci, 1999[9]	Case report	Cardiac surgery	1 (Adult)	None	Acuson, Sequoia C–256; 5–7 MHz; Nyquist limit 0.039 m/s	Thoracic and Cervical	First supradiaphragmatic vertebral body (T12)	Yes	Yes	-	-	Anterior spinal artery, radicular branches, intercostal arteries	Successful	ASA Vmax = 14 cm/s	Anterior spinal artery (ASA) Vmax = 14 cm/s	Absence of the anterior spinal artery (T6–T8) indicates a watershed area
Orihashi, 2006[10]	Prospective observational study	Cardiac surgery/ Trauma surgery	22 (Adults)	tSAH (3)	Hitachi, EUB–555; Aloka, SSD 5500; 5 Mhz	Upper thoracic	20–30 cm from the incisors	Yes	Yes	-	Pia mater	-	-	-	Cord-to-canal ratio: tSAH 0.59±0.07 vs controls 0.45±0.04; meningeal thickness: 1.41±0.12 mm vs 0.66±0.15 mm	In traumatic subarachnoid hemorrhage (tSAH), fibrin-like echogenic images within the subarachnoid space, meningeal thickening >1 mm, increased cord-to-canal ratio >0.5; changes detectable as early as 3.5 h after injury
Chitilian, 2006[11]	Case report	Cardiac surgery	1 (Adult)	None	-	Thoracic (level not specified)	-	Yes (pulsation)	-	-	Dura mater	-	-	-	-	-
Lohser, 2009[12]	Case report	Cardiac surgery	1 (Adult)	None	General Electric, Vivid 7	Thoracic (level not specified)	Descending aorta, left rotation	Yes (pulsation)	Yes	Yes	-	-	-	-	-	-
Nath, 2011[13]	Case report	Cardiac surgery	1 (Adult)	None	Philips, Agilent SONOS-5500	Thoracic (level not specified)	-	Yes (pulsation)	Yes	Yes	-	-	Unsuccessful	-	-	-
Ueda, 2013[14]	Case report	Cardiac surgery	12 (Pediatric 16 days – 4 years)	None	Philips, T6207	Thoracic (level not specified)	Descending aorta, 10–20° left rotation; tracheal carina (T5/T6); esophagogastric junction (T11)	Yes	-	Yes	Dura mater	Anterior and posterior spinal arteries	-	-	Spread of anesthetic/saline in the epidural space	Epidural catheter
Ahmed, 2014[15]	Case report	Interventional cardiology/ TEER	1 (Adult)	None	Philips, iE 33, X7-2t (3D xMATRIX)	Lower cervical/ Upper thoracic	Ascending aorta; aortic arch	Yes	Yes	-	-	Anterior spinal arteries	-	-	Cord volume 0.64 mL; dimensions 1.49×0.82×0.70 cm; area 1.05 cm²; canal: volume 1.90 mL; dimensions 1.71×1.20×1.12 cm; area 1.76 cm²; anterior spinal arteries (left Ø 0.26 cm, right Ø 0.31 cm)	-
Feinglass, 2015[16]	Retrospective study	Cardiothoracic surgery	2 (Adults)	None	Philips, IE-33, X7-2t (3D xMATRIX)	Thoracic (T4–T12)	Mid-esophageal to transgastric projection	Yes	Yes	Yes	-	Anterior spinal arteries (biphasic flow)	Unsuccessful	V = 9.74 cm/s	-	Epidural catheter
Goswami, 2016[17]	Prospective observational study	Thoracic surgery	24 (Adults)	None	Philips, S7 (pediatric)	Thoracic	Four-chamber view; descending aorta (T4)	Yes	Yes	-	Dura mater; epidural space	-	-		Catheter position: posterior 83%, lateral 17%; poorer anesthetic quality with lateral position	Epidural catheter – tip location: T4 (4%), T5 (79%), T6 (17%)
Hanada, 2023[18]	Prospective observational study and Case series	Surgery/ Pediatrics	94 (Pediatric 2 days –17 years/ Adult)	None	Philips IE33 (iE33); X7-2t (3D xMATRIX); S7-3t (pediatric); S8-3t (TEE)	Thoracic (T1–T12)	Pulmonary artery bifurcation (T5–T6); IVC/esophagus traversing the diaphragm (T11–T12); CXR	Yes	Yes	-	Dura mater; epidural space	-	-		Segments visualized: 99% in children vs 70% in adults; catheter confirmation: TEE 19/19 vs ultrasound 8/19	Epidural catheter; markedly better TEE visualization in children
Kisling, 2023[19]	Case report	Cardiac surgery	1 (Adult)	None	-	Upper thoracic	-	Yes (pulsation)	-	Yes	Dura mater; epidural space	-	-		-	Disc structures (annulus fibrosus, nucleus pulposus); vertebral structures (spinous process, lamina, costovertebral facet)

C – cervical; CSF – cerebrospinal fluid; CXR – chest X-ray; IVC – inferior vena cava; PW Doppler – pulsed-wave Doppler; T – thoracic; TEE – transesophageal echocardiography; TEER – transcatheter edge-to-edge repair; tSAH – traumatic subarachnoid hemorrhage; US – ultrasonography; Vmax – peak velocity; Ø – vessel diameter; "-" indicates not reported

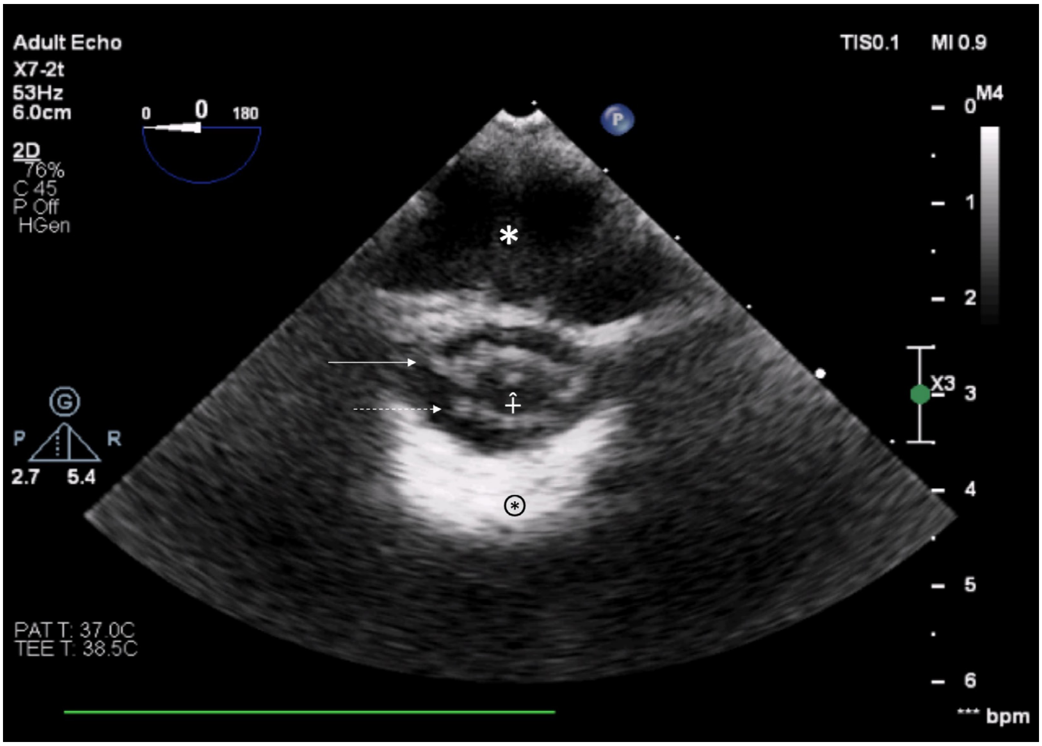

Fig. 2. *Transesophageal echocardiographic short-axis view of the thoracic spinal canal, showing the intervertebral disc (*) with posterior acoustic enhancement (⊛); the spinal cord (+) with central canal (^); anterior nerve roots (solid arrows); posterior nerve roots (dashed arrows); and the surrounding anechoic cerebrospinal fluid*

of lesions such as intra- or extramedullary masses and congenital abnormalities in the upper thoracic and lower cervical spine. Orihashi *et al.* noted characteristic findings in traumatic subarachnoid hemorrhage (tSAH), with fibrin-like echogenic images around the spinal cord showing oscillating movement synchronized with the cardiac cycle, swelling of the spinal cord (cord/canal ratio greater than 0.50), and thickening of the pia mater (larger than 1 mm), which was already visible a few hours after the incident(10). The authors concluded that TEE may have several advantages over CT and lumbar puncture, particularly in patients with multiple injuries who are too unstable to undergo CT, where timely diagnosis of tSAH will dictate further management. Unfortunately, the method was not evaluated further.

Despite these promising results, transesophageal ultrasound imaging of the spinal canal has certain limitations. Images are restricted to segments where the ultrasound beams can penetrate intervertebral discs. Moreover, only the upper thoracic and lower cervical regions of the spine are accessible. The availability of an acoustic window is a fundamental challenge. Degeneration of bone and connective tissue, as well as the presence of air at the esophageal and stomach interface, can significantly impede or even make it impossible to fully image the structures. Importantly, much better access to spinal structures via TEE was obtained in children, most likely because of the lack of degenerative lesions(18). Ultrasound images are also susceptible to various types of artifacts – the lack of standardization may ultimately lead to erroneous diagnostic conclusions. Additionally, although no adverse events, such as esophageal trauma, airway compression, or accidental extubation, were reported during the study, attention was given to these potential risks associated with TEE in young children(14,18).

Advances in ultrasonography may help overcome current limitations and enable new uses, including detailed, real-time imaging of the spinal cord. While contemporary ultrasound often provides sufficient spatial and temporal resolution to delineate larger structures, it remains inferior to MRI for assessing microcirculation and subtle pathologies within the spinal cord or meninges. Ultrafast ultrasound further expands these capabilities, achieving frame rates of several thousand images per second – far beyond conventional systems – and may support more sophisticated dynamic assessments(20). Aguet *et al.* reported that ultrafast power Doppler (UPD) can track small regional changes in cerebral perfusion(21). Similarly, the application of these technologies in the field of imaging of spinal cord structures could revolutionize the assessment of vascularization by visualizing microcirculation and quantitatively assessing perfusion in real time. In addition, shear wave imaging, also known as ultrasonic elastography, allows the assessment of mechanical properties of core tissues, such as their stiffness. In cardiology, this technique is used to assess the mechanical properties of myocardial tissues, and its adaptation to spinal cord studies could provide new diagnostic markers in the context of ischemic changes or degenerative processes(22).

Conclusions

Transesophageal echocardiography is a feasible and safe method for visualizing upper thoracic and lower cervical spinal canal structures. Its potential applications include diagnosing pathologies, assessing spinal perfusion, and guiding procedures such as catheter placement. While advancing technology may further expand its capabilities, further research is needed to validate its clinical accuracy, safety, and overall impact.

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Conflict of interest

The authors declare no conflicts of interest.

Author contributions

Original concept of study: MM, KM. Writing of manuscript: MM, SK, TD, PP, TC, KM. Analysis and interpretation of data: MM, SK, TD, PP, TC, KM. Final acceptation of manuscript: MM, SK, TD, PP, TC, KM. Collection, recording and/or compilation of data: MM, SK, TD, KM. Critical review of manuscript: MM, SK, TD, PP, TC, KM.

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