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Laryngeal imaging

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The purpose of this article is to describe key anatomical feature of the larynx and to review contemporary imaging protocols for the evaluation of nonmalignant lesions and pathologies of the larynx. The role of computed tomography (CT), magnetic resonance imaging, and positron emission tomography CT in the evaluation of laryngeal pathologies will be addressed. Imaging feature in CT and magnetic resonance imaging is discussed in particular conditions, such as cysts and laryngoceles, nonsquamous laryngeal lesions including laryngeal vascular lesions and vocal cord paralysis.
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Anatomy

The larynx is comprised of skeleton including the hyoid bone and cartilages that articulates with muscles and ligaments to allow for voice production, airway passage and protection. The cartilaginous skeleton includes the epiglottis, thyroid, and cricoid cartilage, and 4 paired cartilages (arytenoid, corniculate, cuneiform, and triticeous). The arytenoid cartilages articulate with the cricoid cartilage by true synovial joints and have an anterior vocal process that attaches to the vocal ligament, and lateral muscular process that provides attachment to the lateral and posterior cricoarytenoid muscles. Asymmetric mineralization occurs in the arytenoid cartilage with age.

The vocal cords are located in a subsite of the larynx, called the glottis that includes the true vocal cords, the anterior commissure, and the posterior commissure. The true vocal cords extend from the anterior commissure (located at the posterior aspect of the angle of the thyroid cartilage) to the space between the 2 arytenoid cartilages known as the posterior commissure. The vestibular folds (false vocal cords) are located superiorly, parallel to the plane of the true cords, and extend from the angle of the thyroid cartilage to the anterolateral surface of the arytenoid cartilage. The vocal cords are lined by mucosa, while deeper components from medial to lateral include the vocal ligaments, the vocalis and thyroarytenoid (TAM) muscles). The most prominent muscle visualized on imaging is the TAM, extending from the anterior commissure anteriorly to the vocal process of the arytenoid cartilage posteriorly and makes up the main bulk of the true vocal cord.

During quiet respiration, the cords are in a relaxed, abducted state. Breath-holding and Valsalva maneuver brings the cords together in an adducted midline position. The movement of the vocal cords is controlled by the intrinsic laryngeal muscles which are all innervated by the recurrent laryngeal nerves (RLN), a branch of the vagus nerve.[1]

The aryepiglottic folds extend from both lateral edges of the epiglottis to the arytenoids on both sides. They are comprised by a fibrous fascial sheet called the quadrangular membrane covered by mucosal membrane, and their lower free edge forms the false vocal fold, also called the ventricular ligament. The paraglottic space is the space

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bounded medially by the aryepiglottic folds and laterally by the thyroid cartilage.

The laryngeal ventricle is a slit-like opening directly cranial to the true vocal cords and separates the true vocal cords inferiorly from the false vocal cords superiorly. The saccule/laryngeal appendix is a diverticular outpouching emerging from the anterior aspect of the laryngeal ventricle extending superiorly into the paraglottic space and is lined by mucus glands.

Cross-sectional imaging

Diagnostic evaluation of the larynx is primarily based on endoscopic evaluation, with cross-sectional imaging including either computed tomography (CT) or magnetic resonance imaging (MRI) playing a complementary role. It enables evaluation of the deep submucosal structures and spaces[2] and often used for evaluation of a neoplasm.

CT is usually the preferred imaging modality for laryngeal evaluation, whereas MRI is used when additional information is needed. The laryngeal area can be very well evaluated by routine standard neck CT examination due to rapid image acquisition of the newer generation of multidetector CT (MDCT) scans (Figure 1). Dedicated laryngeal imaging is done in a MDCT with collimation varying from 4 mm × 1 mm to 64 mm × 0.6 mm[3] depending on the specific CT machine used, with a slice thickness of 1.5 mm and overlapping reconstructions every 0.75 mm. Imaging acquisition is best obtained parallel to the true vocal cords. Unless there is a clear contraindication, all routine laryngeal scans should be performed with intravenous iodinated contrast. Image acquisition is obtained during quiet breathing, rather than breath holding, results in abducted position of the true vocal cords and facilitates evaluation of the anterior and posterior commissures.[4] For specific indications, Valsalva maneuver will be used during imaging to improve visualization of specific anatomical location such as the laryngeal ventricle.

MRI has 2 clinical advantages over CT for laryngeal imaging that include the absence of ionizing radiation and superior soft tissue contrast. The second feature is usually very useful for evaluation of malignancies.[5] Nonetheless, MRI scans are usually compromised by motion artifacts of the larynx caused by breathing and swallowing. In addition, prolonged scan time and multiple non-MRI compatible implanted devices, limit the usage of MRI for laryngeal evaluation, which is mostly used as a second-line imaging modality.

MRI of the larynx is done using dedicated surface neck coils. The protocol is based on axial T1-weighted fast spin echo (FSE) and T2-weighted FSE images obtained from the skull base to the thoracic inlet with a scan orientation parallel to the true vocal cords. T1-weighted images following intravenous administration of a gadolinium-containing contrast agent should be obtained in all 3 planes, preferably with fat suppression. The slice thickness is usually of 3-4 mm with 0-1 mm gap with a field of view of 18 cm × 18 cm or less and an acquisition matrix of at least 256 × 512 or 512 × 512. Coronal and sagittal planes allow for further evaluation of the ventricles with the corresponding paraglottic spaces and the pre epiglottic space, respectively.

Positron emission tomography CT combines simultaneous acquisition of anatomical data by CT imaging with co-registration of metabolic activity by glucose analogue fluorodeoxyglucose. This modality is usually used for initial staging of advanced laryngeal cancer and for the detection of tumor recurrences.[6] It can often demonstrate asymmetric metabolic activity in cases of VCP on the side opposite the paralyzed cord due to compensatory vocal cord hyperactivity and hypertrophy of the nonparalyzed muscles.[7]

CT imaging of the vocal cords

Breathing cycle and phonation affect the position of the vocal cords and should be taken into consideration during CT acquisition along with the clinical indication for the study. The common instructions given to patients during CT acquisition include performing inspiratory breath holding, quiet breathing, "e"-phonating, or performing a Valsalva maneuver (an attempt to exhale against a closed airway). Each maneuver will result in a different position of the vocal cords. The "e" phonation distends the airway with air which provides a natural contrast to better delineate mucosal lesions.[8] Phonation also allows for a more precise anatomical localization of tumor borders by better displaying the laryngeal ventricles and the pyriform sinuses. Nowadays, quiet respiration is usually preferred for CT assessment of the larynx, since it brings the vocal cords to an intermediate position[9] and improves demonstration of small superficial lesion of the vocal cords. Inspiratory breath hold and Valsalva maneuver will result in adduction of the vocal cords and will better demonstrate the paraglottic spaces,[10] but may obscure small mucosal lesion.

The radiographic laryngeal evaluation includes axial, sagittal, and coronal images with angled planes that would be parallel to the true vocal cords to better demonstrate lesions that could be obscured in oblique section planes. On the axial images, the level of the true vocal cords is determined by identifying the cricoarytenoid joints, and the angled planes with the appropriate reformatted images can be obtained on the sagittal and coronal planes as well.

Cysts and laryngoceles

The laryngeal saccule is a blind pouch extending superiorly from the anterior portion of the laryngeal ventricle between the false vocal cord and the thyroid cartilage to as high as the superior border of the thyroid cartilage.[11] Laryngocele is defined as saccular dilatation that extends above the upper border of the thyroid cartilage. Laryn-

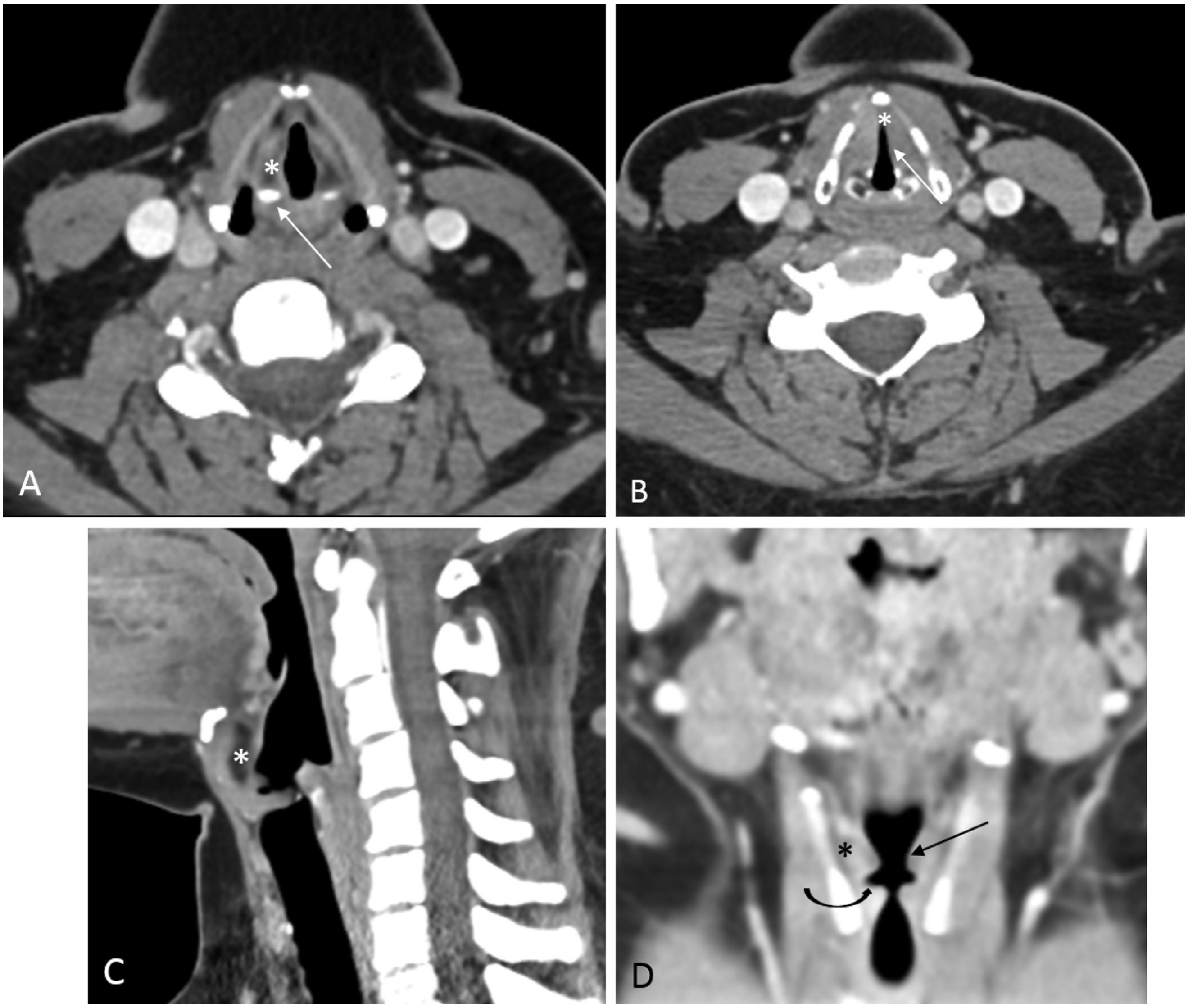

Figure 1 CT imaging of the larynx. (A) Axial contrast-enhanced CT scan at the level of the supraglottis. The right arytenoid cartilage (arrow) is demonstrated posterior to the false vocal cord, which creates the roof of the laryngeal ventricle. The right paraglottic space (asterix) is demonstrated lateral to the false vocal cord. (B) Axial contrast-enhanced CT scan at the level of the glottis. The cricoarytenoid joints are visible, with the posterior commissure in between. The thyroarytenoid muscle (arrow) forms the bulk of the vocal cord. The asterix marks the anterior commissure. (C) Sagittal contrast-enhanced CT scan of the larynx. The epiglottis is visible with the fat containing pre-epiglottic space anterior to it (asterix). (D) Coronal contrast-enhanced CT image of the larynx demonstrates the false cords (arrow points to left false cord), laryngeal ventricles (curved arrow points to right ventricle), and paraglottic spaces (asterix points to right paraglottic space).

gocele can be further classified as internal, external, or mixed, depending on the absence or presence of extension through the thyrohyoid membrane (Figure 2). Retention mucous secretions within a laryngocele results in a mucocele (or saccular cyst) and superinfection would result in a laryngopyocele.

Laryngoceles can be diagnosed with endoscopy as well as with cross-sectional imaging studies and are often diagnosed incidentally on CT scans. On endoscopy, the internal component of a laryngocele is evident as a submucosal bulging of the false vocal fold.[12] CT and MRI are particularly well suited for demonstrating their relationship to the thyrohyoid membrane in order to further classify into internal, external, or mixed laryngocele. On cross-sectional imaging, laryngoceles are well-circumscribed lesions arising beneath the false vocal cords at the level of the laryngeal ventricle and extending superiorly within the paraglottic fat. Air-filled laryngoceles are easily identified due to their low CT density surrounded by adjacent paraglottic fat. With thin slices CT scan, it is sometime possible to detect the mucosal orifice at the level of the laryngeal ventricle. The paraglottic component of a laryngocele can be either dilated or demonstrated as a collapsed mucosal tract.

On MRI, air-filled laryngoceles show very low signal on all pulse sequences.[11] Mucoceles/saccular cysts can

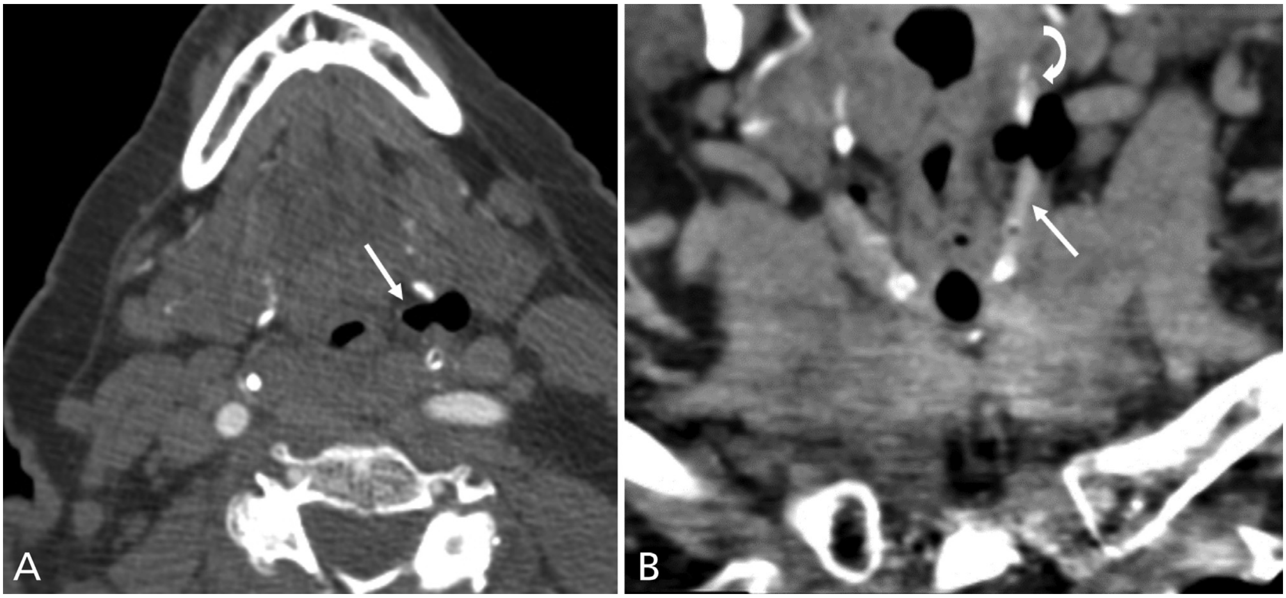

Figure 2 Left combined laryngocele. (A) Axial contrast-enhanced CT scan at the level of the thyrohyoid membrane demonstrates an air containing structure in the left paraglottic space (arrow) herniating through the thyrohyoid membrane. (B) Coronal imaging of the combined laryngocele clearly demonstrates its herniation between the thyroid cartilage (arrow) and the hyoid bone (curved arrow).

demonstrate densities ranging between those of water and soft tissue, depending on the content. A relatively clear fluid content will demonstrate high signal intensity on T2-weighted and low signal intensity on T1-weighted images, while high signal intensity on T1-weighted images correlates with high protein content. Apart from slight mucosal enhancement, laryngoceles usually do not enhance after contrast administration, unless there is superinfection and progression into laryngopyoceles, which can occur in up to 8% of cases.[13]

Non squamous laryngeal lesions

A variety of benign and malignant tumors of nonsquamous cell origin may rarely (less than 5%) affect the larynx,[4,14] and unlike squamous cell carcinoma that are mucosal tumors and are usually obvious on endoscopy, many of the less common neoplasms of the larynx are submucosal and may not be so clearly visualized on endoscopy. For these tumors, there will often be discrepancy between cross-sectional imaging and endoscopy, which should raise suspicious for an unusual nonsquamous tumor.[14] The role of imaging is to detect and characterize the submucosal mass, and to guide the surgeon where to obtain deep biopsies. Mesenchymal lesion that can potentially involve the larynx include hemangiomas, lymphatic malformations, nerve sheath tumors, paragangliomas, lipomas, chondroid lesions, and leiomyomas. Infantile hemangiomas have a tendency to involve the subglottic larynx and may progress to produce airway obstruction, while paragangliomas have a tendency to involve the supraglottic larynx.

Some submucosal masses have specific imaging features and can be further characterized. For example, on CT, vascularized laryngeal tumors such as hemangiomas and paragangliomas appear as well-circumscribed soft tissue masses that display intense contrast enhancement, with phleboliths being a pathognomonic sign for hemangiomas. On MRI, laryngeal hemangiomas are usually hyperintense on T2-weighted sequences and display heterogeneous enhancement on T1-weighted images following gadolinium administration. Paragangliomas typically display "salt and pepper" appearance with multiple curvilinear signal voids on both T1- and T2-weighted images.

Vocal cord paralysis

VCP indicates RLN dysfunction and may herald the presence of severe pathology involving the neck and/or mediastinum,[15,16] and can be reliably demonstrated by routine neck CT.[17] The RLN could be compromised anywhere along its course, from the brainstem to the mediastinum. The RLN exits with the vagus nerve through the jugular foramen and descends through the neck posterolateral to the internal carotid arteries within the carotid sheath, and posteromedial to the internal jugular veins. On the right side, the RLN branches out from the vagus nerve anterior to the subclavian artery and courses a short distance posteriorly under the artery at the level of the brachiocephalic bifurcation. On the left side, the RLN branches out from the vagus nerve at the level of the aortic arch, and then courses posteromedially, passes through the aorticopulmonary window posterior to the ligamentum arteriosum, and ascends vertically through the superior mediastinum to reach the tracheoesophageal groove.[18]

Radiological signs on axial CT scans of VCP include: (1) ipsilateral piriform sinus dilatation, (2) medial rotation

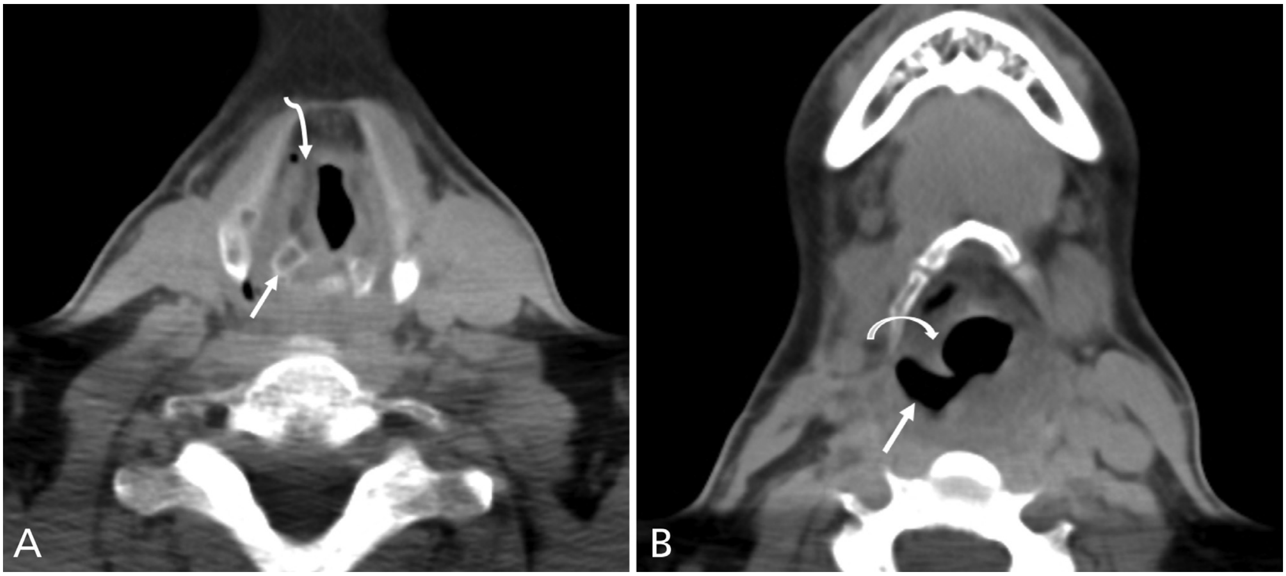

Figure 3 Right vocal cord paralysis. (A) Axial noncontrast CT at the level of the arytenoid cartilages demonstrates anteromedial deviation of the right arytenoid cartilage (arrow) and relative atrophy of the thyroarytenoid muscle (curved arrow). (B) Axial noncontrast CT at the level of the hyoid bone demonstrates enlarged right pyriform sinus (arrow) with medialization and thickening of the right aryepiglottic fold (curved arrow).

and thickening of the aryepiglottic fold (both are a result of paralysis of the posterior cricoarytenoid [PCA] muscle), and (3) ipsilateral laryngeal ventricle dilatation resulting from atrophy of the ipsilateral cord. PCA is the only muscle responsible for vocal cord abduction, and therefor paralysis results in medialization of the vocal cord and the arytenoid cartilage as well. Medialization of the arytenoid cartilage due to atrophy of PCA muscle results in medial deviation of the aryepiglottic fold attached to it, and (passive) dilatation of the piriform sinus (Figure 3).

Anteromedial displacement of the ipsilateral arytenoid cartilage with medial displacement of the posterior vocal cord margin is another helpful sign of VCP on axial CT scan known as the 'sail sign'.[9] This results from the combination of medialization of the posterior vocal cord and ipsilateral enlarged laryngeal ventricle due to TAM atrophy.[19]

In addition to these sensitive imaging findings, several other less specific supportive signs have been described in the literature.[20] The paralyzed cord often rests in a paramedian position due to its inability to abduct. The subglottic area on the affected side can appear full due to sagging of the paralyzed cord.

Laryngeal imaging during breath holding will result in incomplete adduction of the paralyzed vocal cord with excessive contralateral vocal cord adduction and bowing in a compensatory manner.[9] On positron emission tomography CT, unilateral VCP appears as unilateral increased uptake in the nonparalyzed cord due to compensation, and should not be misdiagnosed as a malignant process.[7]

Conclusion

In addition to the role of cross-sectional imaging in the workup of malignant laryngeal lesions, it has a paramount significance for the evaluation of benign and nonsquamous laryngeal lesions. CT and MRI usually play a key role in the diagnosis and workup of benign laryngeal lesions, especially when located submucosally. Laryngeal imaging is also beneficial for the evaluation of pathologic laryngeal conditions which do not involve space occupying lesions, such as vocal cord palsy. Due to constant movement of the vocal cords and the larynx during the respiratory cycle and phonation, CT imaging protocols should be specifically tailored to the clinical question.

Declaration of Competing Interest

The authors have no conflicts of interest.

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