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A modified method for locating parapharyngeal space neoplasms on magnetic resonance images: implications for differential diagnosis

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Abstract

The parapharyngeal space (PPS) is an inverted pyramid-shaped deep space in the head and neck region, and a variety of tumors, such as salivary gland tumors, neurogenic tumors, nasopharyngeal carcinomas with parapharyngeal invasion, and lymphomas, can be found in this space. The differential diagnosis of PPS tumors remains challenging for radiologists. This study aimed to develop and test a modified method for locating PPS tumors on magnetic resonance (MR) images to improve preoperative differential diagnosis. The new protocol divided the PPS into three compartments: a prestyloid compartment, the carotid sheath, and the areas outside the carotid sheath. PPS tumors were located in these compartments according to the displacements of the tensor veli palatini muscle and the styloid process, with or without blood vessel separations and medial pterygoid invasion. This protocol, as well as a more conventional protocol that is based on displacements of the internal carotid artery (ICA), was used to assess MR images captured from a series of 58 PPS tumors. The consequent distributions of PPS tumor locations determined by both methods were compared. Of all 58 tumors, our new method determined that 57 could be assigned to precise PPS compartments. Nearly all (13/14; 93%) tumors that were located in the pre-styloid compartment were salivary gland tumors. All 15 tumors within the carotid sheath were neurogenic tumors. The vast majority (18/20; 90%) of trans-spatial lesions were malignancies. However, according to the ICA-based method, 28 tumors were located in the pre-styloid compartment, and 24 were located in the post-styloid compartment, leaving 6 tumors that were difficult to locate. Lesions located in both the pre-styloid and the post-styloid compartments comprised various types of tumors. Compared with the conventional ICA-based method, our new method can help radiologists to narrow the differential diagnosis of PPS tumors to specific compartments.

Key words Parapharyngeal space, neoplasm, magnetic resonance imaging (MRI), differential diagnosis, location

The parapharyngeal space (PPS) is an inverted pyramid-shaped deep space in the head and neck region. The bottom and apex of the inverted pyramid are the skull base and the hyoid bone pyramid, respectively. The PPS is medially bounded by the pharyngobasilar fascia and the buccopharyngeal fascia and laterally bounded by the superficial layer of the deep cervical fascia curving around the medial surface of the pterygoid muscles. The tensor-vascular-styloid (TVS) fascia, a layer that extends from the inferior border of the tensor veli palatini (TVP) muscle and posterolaterally and inferiorly to the styloid process and muscles, separates the PPS into a pre-styloid compartment and a post-styloid compartment [1].

Primary lesions of the PPS are rare, accounting for only 0.5% of all head and neck tumors[2], and approximately 70%–80% of the tumors originating from the PPS itself are benign[3-5]. However, due to the variety of structures in the PPS and the fact that tumors arising from the nasopharynx and the masticator space may intrude into or invade the PPS, a variety of tumors [e.g., nasopharyngeal

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carcinomas (NPC) with parapharyngeal invasion, salivary gland tumors, neurogenic tumors, and lymphomas] can be found in this space. Most reports regarding PPS tumors have been based on the division of the PPS into two compartments (pre- and post-styloid) and have used the positioning of the internal carotid artery (ICA) as a diagnostic landmark[4,6-9]. Using this approach, "pre-styloid tumors" are defined as those that displace the ICA in the posterior direction, and "post-styloid tumors" are defined as those that displace the ICA in the anterior direction. Previous reports concluded that tumors within the pre-styloid compartment were predominantly deep lobe parotid tumors and ectopic salivary gland tumors; conversely, tumors within the post-styloid compartment were predominantly neurogenic tumors[4,6-9]. Miller *et al*.[9] found that information pertaining to displacements of the ICA could not only help radiologists to separate PPS tumors based on location (i.e., pre-styloid vs. post-styloid) but also allow surgeons to select the surgical approach with the least morbidity. However, instead of simple division into two compartments, Shirakura *et al*.[8] argued that displacements of the ICA were more varied and included posterolateral, anterolateral, lateral, and anterior orientations.

The identification of PPS tumors according to how they dislocate the ICA has certain limitations. First, because the ICA is a structure within the post-styloid compartment, tumors arising from the tissues outside the carotid sheath in the post-styloid compartment and tumors of the nasopharynx that invade the post-styloid compartment may posteriorly displace the ICA and distort tumor localization. Second, certain tumors arising from or invading the PPS, particularly malignancies arising from the mucosal or submucosal areas of the nasopharynx (such as NPC and lymphomas), may surround the ICA and do not displace it at all.

Due to the increasing resolution of modern magnetic resonance imaging (MRI) systems, small anatomic structures in the PPS, particularly the TVP muscle and the styloid process, are clearly displayed by MRI. Therefore, although the TVS fascia, which is the true anatomic boundary of the pre-styloid and post-styloid compartments, is not visible on imaging, the TVP and the styloid process, serving as the starting and terminal attachment points, have the potential to be used as surrogates for the TVS and as a diagnostic landmark for locating PPS tumors. In the present study, we developed a new protocol that uses displacements of the TVP muscle, the styloid process, and the blood vessels in the carotid sheath to identify the precise location of PPS tumors. We applied this new method to a series of PPS tumors to determine whether it would be more helpful for preoperative differential diagnosis than the more conventional method, which is based on visualizing displacements of the ICA.

Materials and Methods

Patients

This retrospective study was approved by the institutional review board, and the requirement to obtain informed consent was waived. Between October 2004 and August 2012, images collected from patients with PPS tumors who underwent MRI at our hospital were selected from our picture archiving and communication system (PACS) workstation (Centricity RA1000 Workstation V. 3.0, GE Healthcare, Barrington, IL, USA). The exclusion criteria were as follows: (1) patients without a definite pathologic diagnosis; (2) patients with recurrent disease or any treatments before the magnetic resonance (MR) scan; (3) patients lacking clinical materials, which included a medical history, physical examination, and treatment process; (4) patients who had a tumor that was primarily located in the nasopharynx, the masticator space, and/or the superficial lobe of the parotid gland; and (5) patients who had MR images of poor quality. The selection of patients was performed by Dr. L. W., who has 3 years of experience in head and neck radiology. Information regarding preoperative signs and symptoms, histological diagnoses, radiographic evaluations, and treatments was tabulated for all patients.

Imaging protocols

All MRI examinations were performed using a 1.5-Tesla unit (Signa Horizon LX High Speed, General Electric Medical Systems, Milwaukee, WI, USA) with a head and neck combined coil. For all patients, the following seven sequences were obtained: non-contrast-enhanced T1-weighted images (T1WI) in the axial, coronal, and sagittal planes; non-contrast-enhanced T2-weighted images (T2WI) in the axial plane; contrast-enhanced T1WI in the axial and sagittal planes; and contrast-enhanced, fat-suppressed T1WI in the coronal plane. The parameters of these sequences are listed in **Table 1**. For contrast enhancement, a 0.2 mmol/kg body weight bolus injection of gadopentate dimeglumine was administered.

Image assessment

All MR images were viewed on a PACS workstation monitor (Coronis Fusion 6MP DL, Barco Inc., Kortrijk, Belgium). Two experienced head and neck radiologists (Drs. X. L. and H. L., both with 8 years of experience in head and neck radiology), who were blinded to the final pathologic diagnosis and did not participate in the selection, separately evaluated the MR images. Any disagreements were resolved by consensus.

The new protocol included the following steps for analyzing MR images. First, the lateral margins of the levator veli palatini and the constrictor muscles were used to separate the PPS from the pharyngeal cavity (**Figure 1A**). The medial margin of the lateral pterygoid plate, the medial pterygoid muscle, and the extension line to the styloid process were then used to separate the PPS from the masticator space (**Figure 1**). The PPS was further subdivided into three compartments: the pre-styloid compartment, the carotid sheath, and the areas outside the carotid sheath. The pre-styloid compartment was then separated from the post-styloid compartment (including the carotid sheath and the areas outside the carotid sheath) using the boundary formed by the TVS, which was represented by a line between the TVP and the styloid (**Figure 1B**). The post-styloid compartment was then further subdivided into two areas: the carotid

Table 1. Parameters for the magnetic resonance sequences that were collected

Sequence(s) obtained	Scanning method	TR (ms)	TE (ms)	Ex.	FOV (cm)	Matrix
Non-contrast T1WI in axial, coronal, and sagittal planes	FSE	420–450	Minimal full	2	22	320 × 224
Non-contrast T2WI in axial plane	FSE	3,200–3,500	85	2	22	320 × 224
Contrast-enhanced T1WI in axial and sagittal planes	SE	320–350	Minimal full	1	22	512 × 224
Contrast-enhanced T1WI in coronal plane	SE + FS	320–350	Minimal full	1	22	512 × 224

T1WI, T1-weighted image; T2WI, T2-weighted image; TR, repetition time; TE, echo time; Ex., excitations; FOV, field-of-view; FSE, fast spin-echo; SE, spin-echo; FS, fat suppression.

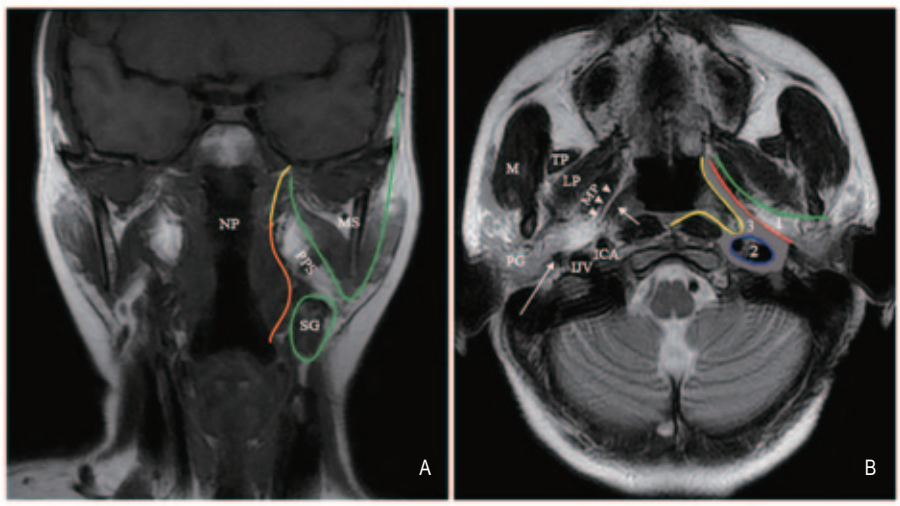

Figure 1. **Anatomy of the parapharyngeal space (PPS), as depicted by magnetic resonance imaging (MRI). A, coronary T1-weighted image (T1WI); B, axial T2-weighted image (T2WI). The PPS is laterally separated from the masticator space by the medial margin of the lateral pterygoid plate and the medial pterygoid muscle (green line) and is inferiorly separated from the submaxillary gland by the superficial layer of the deep cervical fascia that curves around it. Additionally, the PPS is medially separated from the nasopharynx by the lateral margins of the levator veli palatini (yellow line) and the constrictor muscles (orange line). Moreover, the PPS is subdivided into the pre-styloid compartment and the post-styloid compartment by the tensor-vascular-styloid fascia (red line). The post-styloid compartment comprises the carotid sheath (blue ellipse) and the areas outside the carotid sheath (the gray area). NP, nasopharynx; PPS, parapharyngeal space; MS, masticator space; SG, submaxillary gland; M, masseter muscle; PG, parotid gland; TP, temporalis muscle; LP, lateral pterygoid muscle; MP, medial pterygoid muscle; ICA, internal carotid artery; IJV, internal jugular vein. The short white arrow indicates the levator veli palatini muscle; white arrowheads indicate the tensor veli palatini (TVP) muscle; the long white arrow indicates the styloid process and its muscles. Area 1 refers to the pre-styloid compartment; Area 2 refers to the carotid sheath, Area 3 refers to the areas outside the carotid sheath in the post-styloid compartment.**

sheath and the areas outside the carotid sheath (**Figure 1B**). The carotid sheath was defined as the ICA, the internal jugular vein, the external carotid artery, and the areas between them, and the areas outside the carotid sheath was defined as the entire post-styloid compartment, except for the space between the carotid vessels.

After locating the aforementioned anatomic areas on MR images, changes in the TVP and the styloid process, invasion of the medial pterygoid muscle, and displacements of the carotid blood vessels (including the ICA, the internal jugular vein, and the external carotid artery) were observed and recorded. The possible changes in the TVP included anterior or posterior displacement, encroachment or encasement by tumors, and uncertain/no changes. The changes in the styloid process included anterior and posterior displacements. The possible changes in the carotid blood vessels also included anterior or posterior displacement and no changes. If any two of the three blood vessels had opposite displacements, this phenomenon was assessed as blood vessel separation. Any disagreements were resolved by consensus. All these changes were then entered into a computer, forming a computerized database.

Ultimately, all the tumors were located using the information in the computerized database. For instance, posterior displacements (including posteromedial displacements) of the TVP and/or the styloid process indicated the presence of a tumor within the pre-styloid compartment (**Figure 2**), whereas anterior displacements (including

anterolateral displacements) of these structures indicated that a tumor was located within the post-styloid compartment (**Figures 3** and **4**). Moreover, blood vessel separation (including separation of the ICA and the internal jugular vein, the ICA and the external carotid artery, and the internal jugular vein and the external carotid artery) helped to identify tumors that arose within the carotid sheath (**Figure 3**). Any tumors located in the post-styloid compartment, based on posterior displacements of the TVP or styloid process, without blood vessel separation, were then categorized as tumors within the areas outside the carotid sheath (**Figure 4**). Tumors encroaching on and/or encasing the TVP (meaning that they spanned both the pre-styloid and the post-styloid compartments) and those with medial pterygoid invasion (meaning that they spanned both the pre-styloid compartment and the masticator space) were categorized as trans-spatial lesions (**Figure 5**).

The conventional method, based solely on displacements of the ICA, was also used to locate all PPS tumors according to the changes of the ICA recorded in the computerized database. Posterior displacement of the ICA indicated the presence of a tumor within the pre-styloid compartment, whereas anterior displacement indicated that a tumor was located within the post-styloid compartment. In the case of no ICA changes, tumors' locations were defined as uncertain. The differences between the determinations of the PPS tumor locations were then compared.

Results

Clinical findings

In total, 57 patients were enrolled in the present study. Of these 57 patients, 31 were males, and 26 were females, with a median age of 49 years (range, 3–68 years). Fifty-eight PPS tumors were found: 1 patient had bilateral vagal glomus tumors; 56 patients had a single lesion. The pathologic types of all tumors are listed in **Table 2**. The most frequently diagnosed tumors were neurogenic tumors (19/58), salivary gland tumors (18/58), and NPC (12/58). Other tumors included non-Hodgkin's lymphomas (4/58), inflammatory myofibroblastic tumors (2/58), embryonal rhabdomyosarcomas (2/58), and a meningioma (1/58). Thirty patients (53%) had benign PPS tumors, whereas 27 patients (47%) had malignancies. In terms of treatment, most patients with benign tumors were surgically treated (28/30; 93%), whereas the treatment plans of patients with malignancies varied widely, including chemoradiotherapy (9/27; 33%), radiotherapy (7/27; 26%), surgery (4/27; 15%), and chemotherapy (4/27; 15%). Two patients with benign tumors and 3 with malignancies declined any radical treatments.

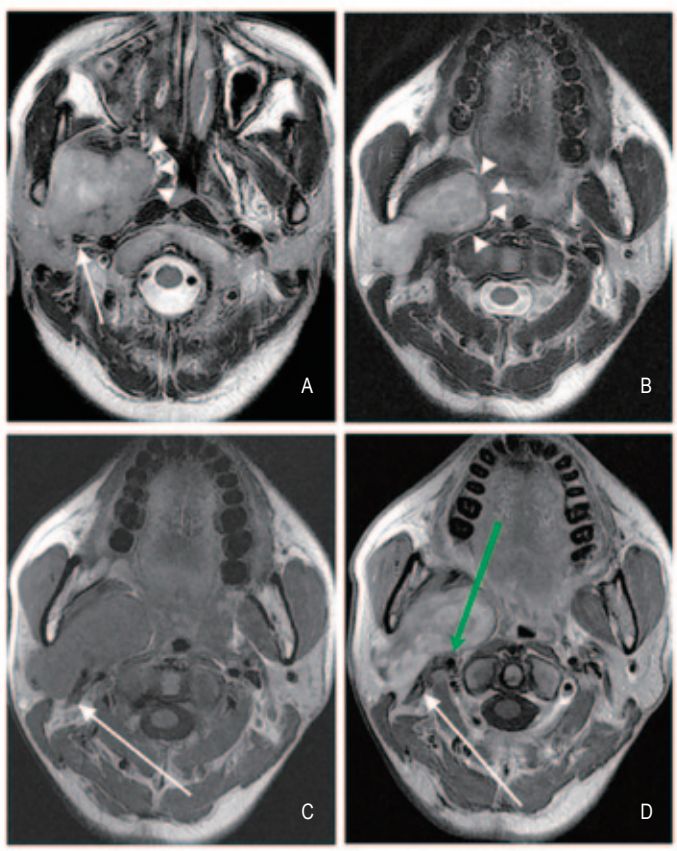

Figure 2. **Magnetic resonance (MR) images of a 42-year-old woman with a pleomorphic adenoma in the right pre-styloid compartment. A and B, axial T2WI; C, axial T1WI; D, post-contrast axial T1WI. The TVP muscle and its fascia (white arrowheads) and the styloid process (white arrow) are pushed posteromedially by the tumor. Posterior displacement of the digastric muscle (long white arrow) and the ICA (long green arrow) can also be observed on the MR images. The absence of a fat layer between the tumor and the deep lobe of the parotid gland may indicate that the tumor originates from the parotid.**

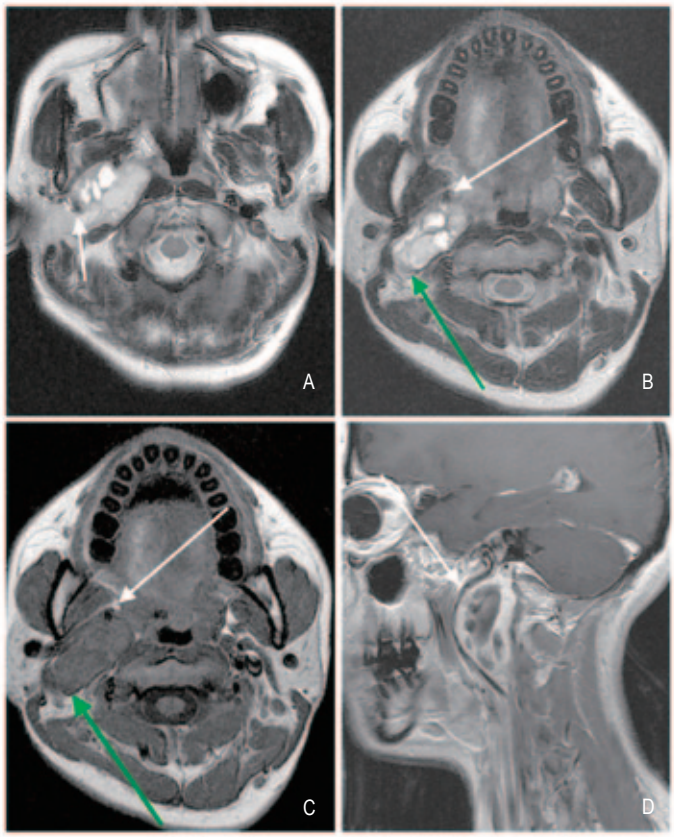

Figure 3. **MR images of a 39-year-old woman with a schwannoma in her right carotid sheath.** A and B, axial T2WI; C, axial T1WI; D, sagittal post-contrast T1WI. The anterior displacement of the styloid process and its muscles (white arrows) and the separation of the blood vessels within the carotid sheath indicate that the tumor is in the carotid sheath. The pattern of the separation of the blood vessels conveys that the ICA is pushed anteriorly (long white arrows), whereas the IJV is pushed posteriorly (long green arrows).

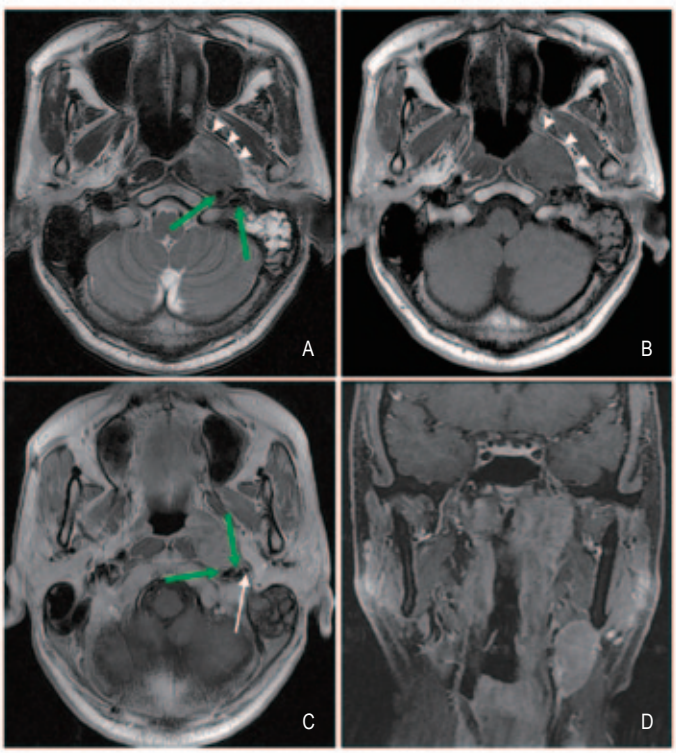

Figure 4. **MR images of a 51-year-old man with nasopharyngeal carcinoma invading his left parapharyngeal space and appearing as a lesion within the areas outside the carotid sheath.** A, axial T2WI; B, axial T1WI; C, post-contrast-enhanced T1WI; D, coronal contrast-enhanced and fat-suppressed T1WI. The TVP muscle and its fascia (white arrowheads) and the styloid process and its muscles (white arrow) are pushed anteriorly by the tumor. The carotid sheath is clear, without tumor invasion, and the ICA and the IJV are pushed together posteriorly, without separation (green arrows). Notably, if we use the displacement patterns of the ICA to locate this tumor, an incorrect diagnosis of a pre-styloid tumor will be made.

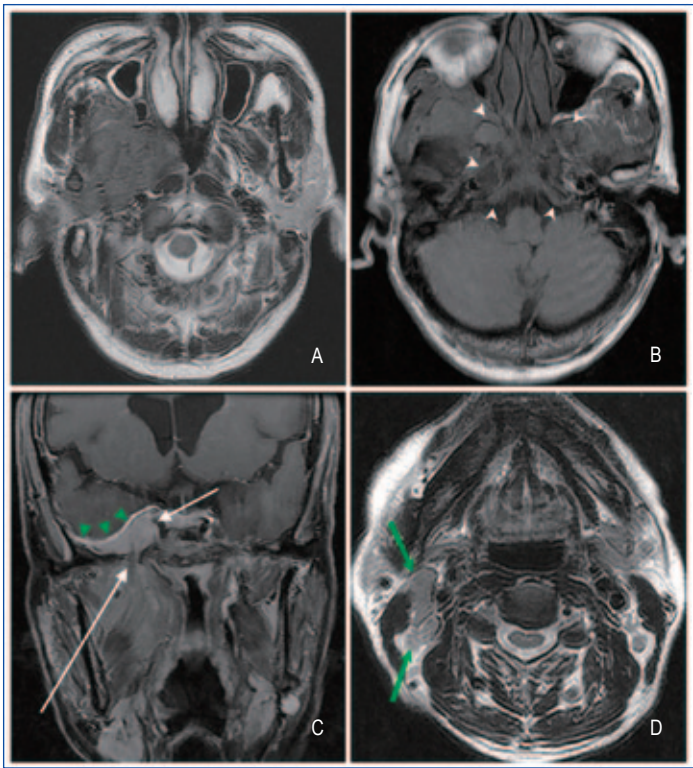

Figure 5. **MR images of a 65-year-old man with extranodal, marginal-zone B-cell lymphoma of mucosa-associated lymphoid tissue appearing as a trans-spatial lesion in his right parapharyngeal space.** A and D, axial T2WI; B, axial T1WI; C, coronal contrast-enhanced and fat-suppressed T1WI. The tumor occupies both the right pre-styloid compartment and the right post-styloid compartment and is invading the right masticatory muscles. The right cavernous sinus (white arrow) and temporal meninges (green arrowheads) are also involved through the enlarged foramen ovale (long white arrow). The skull base bone is also extensively involved (white arrowheads). Extensive tumescent lymph nodes (green arrows) can also be observed in the right neck.

Table 2. Pathologic types of the 58 parapharyngeal space tumors

Pathologic type	Cases	Percentage (%)
Nasopharyngeal carcinoma	12	21
Benign salivary gland tumor	11	19
Pleomorphic adenoma	10	
Adenolymphoma	1	
Malignant salivary gland tumor	7	12
Adenoid cystic carcinoma	4	
Poorly differentiated squamous carcinoma	1	
Myoepithelial carcinoma	1	
Mucoepidermoid carcinoma	1	
Schwannoma	9	16
Paraganglioma	9	16
Vagal glomus tumors	6	
Carotid body tumor	2	
Glomus jugulare tumor	1	
Neurofibroma	1	2
Non-Hodgkin's lymphoma	4	7
Inflammatory myofibroblastic tumor	2	3
Embryonal rhabdomyosarcoma	2	3
Meningioma	1	2

Location of PPS tumors on MR images according to two different methods

All 58 tumors in this study were assessed using two MRI-based methods of localization. The more standard method is based on the displacement of the ICA, whereas our new method is based on displacements of the TVP muscle, the styloid process, and the blood vessels in the carotid sheath (**Figure 6**). Initially, all 58 tumors were located in the pre-styloid or post-styloid compartment according to the standard method. Twenty-eight tumors with posterior displacement of the ICA were diagnosed as tumors within the pre-styloid compartment, whereas 24 tumors with anterior displacement of the ICA were diagnosed as tumors within the post-styloid compartment. There were, however, 6 tumors that were detected but did not disrupt the ICA; thus, the locations of these tumors were uncertain.

We then used our new protocol to localize PPS tumors on MR images. Of 58 tumors, 14 caused displacements of the TVP: 6 tumors caused posterior dislocation of the TVP (5 within the pre-styloid compartment and 1 was trans-spatial); 8 tumors caused anterior displacement of the TVP (2 within the carotid sheath and 6 in the areas outside the carotid sheath). In addition, 16 tumors that encroached on or encased the TVP were categorized as trans-spatial lesions.

The remaining 28 tumors were associated with no or uncertain changes in the TVP and were judged according to their dislocation of the styloid process. Twelve tumors with posterior dislocation of the styloid process were subdivided into tumors within the pre-styloid compartment (n = 9) and tumors deemed to be trans-spatial lesions (n = 3). Of the remaining 15 tumors with anterior dislocation of the styloid process, 13 were categorized as tumors within the carotid sheath, whereas 2 were deemed to be tumors in the areas outside the carotid sheath. Only 1 tumor was associated with no changes

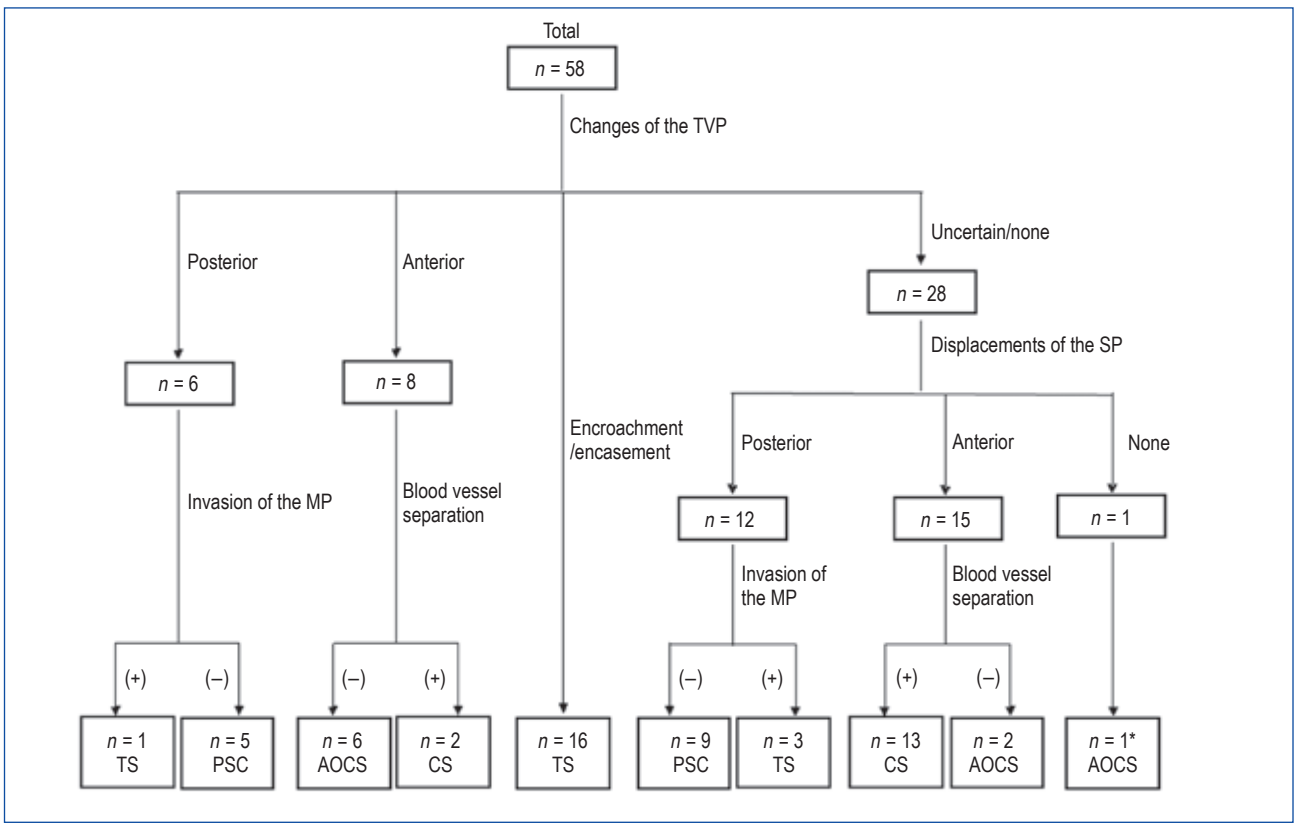

Figure 6. **Schematic of the new protocol for locating PPS tumors on MR images. The new protocol introduced in this study uses MR images to detect changes in the tensor veli palatini muscle and displacements of the styloid process with (+) or without (–) blood vessel separation and with (+) or without (–) invasion of the medial pterygoid muscle. All tumors are located in three PPS compartments: the pre-styloid compartment, the carotid sheath, and the area outside the carotid sheath in the post-styloid compartment. Tumors with encroachment on and/or encasement of the tensor veli palatini muscle and tumors with invasion of the medial pterygoid muscle are categorized as trans-spatial lesions. Of the 58 tumors analyzed in this study, 14 were located in the pre-styloid compartment, 15 were located in the carotid sheath, 9 were located in the areas outside the carotid sheath, and 20 were diagnosed as trans-spatial tumors. One tumor without any changes in these structures was deemed to be located in the areas outside the carotid sheath because it was associated with anterior dislocation of the posterior belly of the digastric muscle. TVP, the tensor veli palatini muscle; SP, the styloid process; MP, the medial pterygoid muscle; TS, trans-spatial; PSC, the pre-styloid compartment; AOCS, the areas outside the carotid sheath; CS, the carotid sheath.**

in either the TVP or the styloid process and was determined to be a tumor within the areas outside the carotid sheath, based on anterior dislocation of the digastric muscle.

Distributions of the PPS tumors according to two different localization methods

The PPS tumor compartmentalization determined by the two different methods is summarized in **Table 3**.

According to the conventional ICA-based method, 28 tumors were located in the pre-styloid compartment, 24 were located in the post-styloid compartment, and the remaining 6 were difficult to locate. Tumors that were located in either the pre-styloid or the post-styloid compartments comprised a variety of tumors and were either benign or malignant. All tumors with uncertain locations were malignancies. Regarding the distribution of each type of tumor, all benign salivary gland tumors were located in the pre-styloid compartment, and nearly all (9/10; 90%) of the schwannomas and neurofibromas were located in the post-styloid compartment. However, all other tumor types [including NPC, paraganglioma, malignant salivary gland tumor, and non-Hodgkin's lymphoma (NHL)] were diffusely distributed in both the pre-styloid and the post-styloid compartments.

According to our new method, 38 tumors were located in a single compartment, and 20 were trans-spatial lesions. Of the 38 single-compartment tumors, 14 were located in the pre-styloid compartment, 15 in the carotid sheath, and 9 in the areas outside the carotid sheath. In contrast to the ICA-based method, nearly all of the tumors within the pre-styloid compartment were salivary gland tumors (13/14; 93%); 11 were benign tumors, and 2 were malignancies. The only non-salivary gland tumor that was found in the pre-styloid compartment was an embryonal rhabdomyosarcoma. Additionally, all 15 tumors within the carotid sheath were neurogenic tumors, including 5 schwannomas, 9 paragangliomas, and 1 neurofibroma. In contrast, the pathologic types of the 9 tumors in the areas outside the carotid sheath varied widely and included 4 NPC, 3 schwannomas, 1 NHL, and 1 inflammatory myofibroblastic tumor. Regarding the trans-spatial lesions, the vast majority (18/20; 90%) of them were malignant tumors, including 8 NPC, 5 malignant salivary gland tumors, 3 NHL, 1 inflammatory myofibroblastic tumor, and 1 embryonal rhabdomyosarcoma. Two benign trans-spatial tumors were also observed: 1 schwannoma and 1 meningioma.

Also of note, using the new localization method, we found that all NPC were located in the areas outside the carotid sheath or were trans-spatial lesions, all benign salivary gland tumors were located in the pre-styloid compartment, and all paragangliomas were located within the carotid sheath. In contrast, schwannomas were diffusely distributed among the carotid sheath, the areas outside the carotid sheath, and the masticator space. Other malignancies, except for NPC, were always located in the pre-styloid compartment or the areas outside the carotid sheath or appeared as trans-spatial lesions.

Discussion

Due to the complex anatomy and the relatively low incidence of PPS tumors, localization and differential diagnosis can be difficult for clinical oncologists, and even occasionally for radiologists. Ironically, the determination of the definite location and origin of PPS tumors is critical for choosing the optimal surgical approach from a variety of options, such as the transoral approach, the transcervical approach, and the transparotid approach[10]. To improve the accuracy of pre-treatment localization and differential diagnosis, we have developed a new protocol for locating PPS tumors on MR images. The method subdivides the PPS into three compartments: the pre-styloid compartment, the carotid sheath, and the areas outside the carotid sheath. In this study, using our new method, we determined that nearly all tumors located in the pre-styloid compartment were salivary gland tumors and that all tumors within the carotid sheath were neurogenic tumors. The vast majority of trans-spatial lesions

Table 3. Distribution of parapharyngeal space tumors in different compartments according to the new method and to the method using displacements of the internal carotid artery (ICA)

Pathologic type	New method				Conventional ICA displacement-based method		
	Pre-styloid compartment	Carotid sheath	Areas outside the carotid sheath	Trans-spatial compartment	Pre-styloid compartment	Post-styloid compartment	Uncertain
Nasopharyngeal carcinoma	0	0	4	8	4	6	2
Benign salivary gland tumor	11	0	0	0	11	0	0
Malignant salivary gland tumor	2	0	0	5	5	0	2
Schwannoma and neurofibroma	0	6	3	1	1	9	0
Paraganglioma	0	9	0	0	2	7	0
Non-Hodgkin's lymphoma	0	0	1	3	1	2	1
Inflammatory myofibroblastic tumor	0	0	1	1	1	0	1
Meningioma	0	0	0	1	1	0	0
Embryonal rhabdomyosarcoma	1	0	0	1	2	0	0
Total	14	15	9	20	28	24	6

were malignancies. Moreover, all NPC and NHL were located in the areas outside the carotid sheath or existed as trans-spatial lesions, all paragangliomas were located in the carotid sheath, and all benign salivary gland tumors were located in the pre-styloid compartment. Compared with the conventional ICA-based method, the new method can narrow the differential diagnosis of tumors in both the pre-styloid and the post-styloid compartments and can achieve a more accurate diagnosis of neurogenic tumors and benign salivary gland tumors.

Separating the carotid sheath from the post-styloid compartment as an independent area can help us to narrow the differential diagnosis of tumors in the post-styloid compartment and to achieve a relatively definitive diagnosis of most neurogenic tumors. The carotid sheath contains the carotid artery, the internal jugular vein, the cranial nerves (IX through XII), and the sympathetic chain. Therefore, angiogenic and neurogenic tumors are common lesions in this space, meaning that schwannomas (usually vagal) and paragangliomas (vagal glomus and carotid body tumors) are frequently found in the carotid sheath, as they were in our study. All tumors that we identified in the carotid sheath were neurogenic tumors, including schwannomas, paragangliomas, and neurofibroma. Notably, because certain cranial nerves (IX and XII) within the carotid sheath are posterior to both the ICA and the internal jugular vein at certain points and because the sympathetic chain is posteriorly oriented relative to the ICA and the internal jugular vein[6,11], certain neurogenic tumors arising from these areas would be characterized as tumors in the areas outside the carotid sheath using our method. This situation may have been the case for the 3 schwannomas that were determined to be located in the areas outside the carotid sheath. Conversely, because the vagus nerve runs nearly directly inside the carotid sheath, at an angle formed by the ICA and the internal jugular vein[7,11], all vagal glomus tumors in our study were located in the carotid sheath.

Similarly, the new method can also help us to narrow the differential diagnosis of tumors in the pre-styloid compartment. The finding that nearly all tumors located in the pre-styloid compartment were salivary gland tumors is consistent with previous reports[9,12] and is not surprising. The contents of the pre-styloid compartment include the deep lobe of the parotid gland, the minor or ectopic salivary glands, fat, the ascending pharyngeal artery, and the pharyngeal venous plexus. Because the majority of the tissue in the pre-styloid compartment comprises the salivary glands, most lesions that arise in this compartment are of salivary gland origin. However, localization using the conventional method based on displacements of the ICA might make the differential diagnosis of tumors in the pre-styloid compartment relatively difficult. The reason is that submucous tumors with relatively small parts in the nasopharynx and large parts in the PPS, causing the ICA to be displaced posteriorly, will be categorized as pre-styloid tumors using the conventional method. In fact, although tumors that arise from the nasopharynx, with relatively small parts in the pharyngeal cavity and invasion of the PPS, may appear as PPS tumors, they do not directly involve the pre-styloid compartment. Because the post-styloid compartment lies between the pre-styloid compartment and the nasopharynx, tumors arising from the nasopharyngeal mucosa and submucosal tissues (such as NPC, NHL, and adenoid cystic carcinomas) must first occupy the areas outside the carotid sheath before invading the pre-styloid compartment. Therefore, if a tumor presents with a small lesion in the nasopharynx that also occupies the areas outside the carotid sheath (which is positioned immediately adjacent to the nasopharynx), it should be diagnosed as a tumor in the areas outside the carotid sheath (**Figure 4**), rather than as a tumor in the pre-styloid compartment. Moreover, using our method, if a tumor extends into relatively distant areas, including the pre-styloid compartment and the masticator space, it will be diagnosed as a trans-spatial lesion (**Figure 5**). In our study, the fact that all NPC and NHL were located in the areas outside the carotid sheath or categorized as trans-spatial lesions supports this hypothesis.

Moreover, the information that we used to define trans-spatial lesions, including encroachment on or encasement of the TVP and invasion of the medial pterygoid, may have potential to differentiate benign and malignant PPS tumors. NPC often invades the PPS and can extend from areas adjacent to the nasopharynx to distant anatomic regions[13]. NHL arising from the submucosal area of the nasopharynx also has a propensity to spread laterally through regions of fat tissue [14]. Malignancies arising from the salivary glands in the pre-styloid compartment have the potential to invade the areas outside the carotid sheath and the masticator space and would therefore be diagnosed as trans-spatial lesions. Similarly, tumors arising from tissues in the masticator space that intrude into or invade the pre-styloid compartment may also be categorized as trans-spatial lesions. Obviously, the tumors that spread from one compartment to another need to break through the barrier between them, which is mostly the deep fascia of the cervical part. As the attaching structures of the deep fascia, TVP and medial pterygoid involvement can be used as an early indicator of tumor infiltration. Other parts of the deep cervical fascia, such as the prevertebral fascia and the pharyngobasilar fascia, can also be used as invasion indicators, and trans-spatial lesions should include tumors invading the prevertebral space, the paranasal sinuses, and other areas. However, because our study only focused on locating PPS tumors, our descriptions of tumor invasion and imaging features were limited.

Honestly, using location alone to make a definitive diagnosis of PPS tumors is not feasible. Other information, such as shapes, textures, margins, and special signals, obtained by MRI is also quite useful and important for the pre-treatment diagnosis of PPS tumors. However, as mentioned above, lesions in a specific PPS compartment may predominantly include one or several types of tumor. Therefore, precise and reasonable localization obtained using the new localization method would be helpful to narrow the differential diagnosis. This possibility, together with other imaging features, will make definitive pre-treatment diagnosis using MRI much easier.

This study has several limitations. First, it was not feasible to find structures separating the carotid sheath from the areas outside the carotid sheath in the post-styloid compartment on MR images. In this study, the carotid sheath was defined as the ICA, the internal jugular vein, and the areas between them. Therefore, certain neurogenic tumors arising from the cranial nerves and the sympathetic chain in the carotid sheath were unavoidably diagnosed as being located

in the areas outside the carotid sheath. Second, because some patients, especially patients with malignant tumors, did not undergo radical surgery, a one-to-one verification of tumor location was not feasible. Therefore, statistical analyses were not performed in our study. A prospective research study with one-to-one verification needs to be performed to validate our initial results in the future. Finally, as several patients declined surgery or biopsy, several rare benign PPS lesions (such as lipoma and hemangioma) were not included due to the absence of pathologic confirmation in our study.

Conclusions

PPS tumors can be more precisely located using our new method of analyzing MR images. This new method can help radiologists to narrow the differential diagnosis of PPS tumors to specific compartments. In addition, this protocol has the potential to facilitate more accurate preoperative diagnoses and to predict tumor invasion.

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