The Diagnostic Utility of Cardiac-Gated Magnetic Resonance Imaging for Assessing Surgical Resectability of Mediastinal Tumors

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Objective: To evaluate the diagnostic utility of cardiac-gated magnetic resonance imaging (MRI) for assessing surgical resectability of mediastinal tumours.

Materials and Methods: We searched our database for cardiac-gated MRI scans [cine steady-state free precession (SSFP), T1-weighted spin-echo sequences] performed for mediastinal tumor staging. Nine patients underwent both cardiac-gated MRI and non-cardiac-gated computed tomography (CT) scans with subsequent surgical confirmation. Pathological diagnoses were germ cell tumors (n=4) and thymic tumors (n=5). The criteria for mediastinal invasion on CT included tumor abutment of mediastinal structures (>90 degrees) with loss of the intervening fat plane or direct vascular invasion, while those for MRI included absence of sliding motion between tumor and mediastinal structure or direct vascular invasion. Imaging findings were compared and correlated to surgical/histopathological findings.

Results: CT showed 48 mediastinal structures with tumor abutment (>90 degrees), with 19 structures confirmed to be involved intraoperatively. MRI showed 38 structures with tumor abutment (>90 degrees), with 18 structures confirmed to be involved intraoperatively. The accuracy, sensitivity, and specificity in determining mediastinal invasion using the presence of tumor abutment of mediastinal structures (>90 degrees) on CT were 50.8 (31/61), 95 (19/20), and 29.3% (12/41), respectively, and those for MRI were 63.9 (39/61), 90 (18/20), and 51.2% (21/41). Cardiac-gated cine SSFP images showed loss of sliding motion in 15 structures, with 14 confirmed to be involved intraoperatively. The accuracy, sensitivity, and specificity in determining mediastinal invasion using absence of sliding motion were 88.5 (54/61), 70 (14/20), and 97.6% (40/41), respectively.

Conclusion: This study shows that cardiac-gated MRI is more accurate than non-cardiac-gated CT in mediastinal tumor staging. However, because of higher cost, cardiac-gated MRI may be used to detect mediastinal invasion when findings are equivocal on CT.

Key words Mediastinal neoplasms · Neoplasm staging · Cardiac-gated imaging techniques · Magnetic resonance imaging · Neoplasm invasiveness.

Received: October 17, 2016

Revised: December 28, 2016

Accepted: February 2, 2017

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INTRODUCTION

Accurate staging of mediastinal tumors is a diagnostic quandary for surgical resectability. Gross et al. [1] found that preoperative radiological evidence of invasion of intrathoracic structures other than the lung is associated with incomplete surgical resection of primary malignant mediastinal tumors because

invaded lung can be easily resected en bloc with the mediastinal mass. Scenarios in which incomplete surgical resection can occur include invasion of myocardium, great vessels, or long tracheal segment [2]. Depending on the available surgical expertise, local practice, and patient's clinical status, the extent of surgical resection in locally advanced mediastinal tumors varies.

In a study by Bacha et al. [2], 70 of 89 patients underwent radical resection. The structures resected included pulmonary structures (phrenic nerve, lung, and pleura), vessels [superior vena cava (SVC), innominate vein, part of the pulmonary ar-

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tery], pericardium, chest wall, and diaphragm. The overall 5-year survival rate for 97% of patients was 63%. However, Park et al. [3] (10 patients) took a more radical approach, anticipating that a highly select group of patients (no extrathoracic metastasis or those with metastasis and impending cardiovascular collapse) with cardiac chamber or great vessel invasion may have better palliation and potential for cure with aggressive surgical resection. Four patients had left atrial resection and 2 had right atrial resection. The median survival for these 10 patients was 21.7 months (range, 3.2 to 69 months).

Ultimately, the decision to radically resect involved neighboring structures must be weighed against the morbidity of the procedure and the potential long-term survival benefit [2]. Complete resection is the mainstay treatment for many mediastinal tumors, and the ability to accomplish complete resection appears to be the most important prognostic factor [2,4]. Surgeons should determine the extent of tumor invasion of adjacent cardiovascular structures in locally advanced disease for preoperative planning.

Currently, most clinicians rely on non-cardiac-gated computed tomography (CT) of the thorax for preoperative planning as it is cheaper and more readily available, as compared to cardiac-gated CT or magnetic resonance imaging (MRI). Criteria for diagnosing local mediastinal invasion on CT include the extent or angle of the contact area between the thoracic mass and adjacent mediastinal structures and obliteration of intervening fat [5-8]. However, the sensitivity and specificity for assessing mediastinal invasion by non-cardiac-gated CT thorax imaging vary in the literature and largely depend on the study design and patient population [5]. The sensitivity for assessing mediastinal invasion by CT ranges from 20% to 84%, while the specificity ranges from 57% to 97% [7-19].

MRI, albeit a more expensive modality, has superior soft-tissue resolution [20-22] with fat-sensitive T1-weighted (T1W) sequences and does not require the use of ionizing radiation. For patients with contraindications for contrast-enhanced CT (such as renal failure or contrast allergy), non-contrast MRI may be performed to characterize mediastinal tumors and evaluate involvement of vascular structures [23-26]. More importantly, cardiac-gated MRI, which is the gold standard for evaluating the pericardium [27] and heart, can provide dynamic imaging and assess the sliding motion of the tumor throughout the cardiac cycle. Preservation of the sliding motion during cine imaging has been reported to improve the accuracy of preoperative staging for predicting cardiovascular invasion of a thoracic mass [5,6,28] with an accuracy of 94.4%, as reported by Seo et al. [5]. When sliding motion between the mediastinal mass, cardiac chambers, and proximal great vessels [ascending aorta and main pulmonary artery (MPA)] is preserved, it can imply the absence of invasion [5].

Although cardiac-gated MRI has been available since the 1980s, literature on its utility for staging mediastinal tumors is still limited, indicating that it is not widely used. The objective of this study was to evaluate the utility of cardiac-gated MRI for staging of mediastinal tumors, especially in assessing mediastinal tumor involvement of cardiovascular structures. This is important for determining tumor resectability, which in turn affects treatment choice and prognosis.

MATERIALS AND METHODS

We performed a search of our MRI database from 2008 to 2011 for patients with cardiac-gated [cine steady-state free precession (SSFP), T1W spin-echo (SE)] MRI mediastinum scans performed for staging of mediastinal tumors.

Thirty patients underwent MRI mediastinum scans to evaluate mediastinal tumours. Sixteen of these scans were not performed with cardiac-gated sequences and were excluded. The other 14 patients had cardiac-gated MRI scans, with T1W SE and cine SSFP sequences, performed for mediastinal tumour staging. All 14 patients had concomitant CT scans (performed within 18.3 ± 14.3 days of the MRI scan). The imaging findings were confirmed surgically in 9 of the 14 patients. These 9 patients (7 males, 2 females) were included in the study. Their ages ranged from 21 to 64 years (mean age=38 years). The surgeries were performed within 16.3 ± 8.9 days of the MRI scans and 34.7 ± 21.3 days of the CT scans. Of the 9 patients who underwent surgery, 4 had germ cell tumors [mature teratoma (n=1), malignant germ cell tumor (n=3)] and 5 had thymic tumors [thymoma (n=4), thymic carcinoma (n=1)]. Four patients underwent CT and MRI scans after neoadjuvant chemotherapy. Five patients did not have surgery due to locally advanced disease (n=1), metastatic disease (n=2), diagnosis of lymphoma where surgery was not indicated (n=1), or loss to follow up (n=1).

The MRI and CT images and clinical notes of these 9 patients were reviewed.

The MRI scans were performed on a 1.5T machine (Magnetom Symphony; Siemens Healthcare, Erlangen, Germany). All MRI scans were performed with cardiac gating. The cardiac-gated T1W SE sequences were obtained at repetition time/echo time (TR/TE) of 558–1194 ms/5.3–7.4 ms, with a slice thickness of 6–10 mm, and matrix ranging from 180×256 to 216×256 . The cardiac-gated cine SSFP images were obtained at TR/TE of 41–43 ms/1.3 ms with a slice thickness of 6–8 mm and matrix of 114×192 to 162×192 . Twenty-five phases per slice during one breath hold were obtained during each SSFP sequence.

All CT scans were performed using a routine departmental protocol without cardiac gating. The CT scans were performed on either a 64- or 128-slice CT scanner (Somatom Sensation

Cardiac 64, Somatom Sensation 64, Siemens Healthcare, Forchheim, Germany; Brilliance iCT 128, Philips Healthcare, Cleveland, OH, USA). The scans were performed in helical/spiral mode with either a 64×0.625 mm detector collimation (Philips Healthcare) or 64×0.6 mm detector collimation (Siemens Healthcare). The tube voltage was set at 120 kVp for all scans. Automated tube current modulation was used (DoseRight, Philips Healthcare or CARE Dose4D, Siemens Healthcare). Tube current ranged between 200 and 750 mAs, depending on body habitus. Rotation time was 0.5 s, and the pitch was 1.3 (Siemens Healthcare) or 0.993 (Philips Healthcare). The CT scans were performed in venous phase with bolus tracking technique after intravenous injection of contrast medium (Omnipaque 350; General Electric Healthcare, Oslo, Norway) at a rate of 1–2 mL/s with power injection in all patients. Patients were asked to hold their breath in end-inspiration during scan acquisition. The CT images were reconstructed into standard axial and coronal images using lung and soft tissue kernels with a 5-mm slice thickness and a matrix of 512×512 and were reviewed on the hospital picture archiving and communication system.

The CT and MR images were reviewed by two radiologists, one with 9 years and the other with 16 years of experience, and a final decision on the findings was reached by consensus. Only mediastinal structures in contact with the mediastinal tumor mass were included in this study. The following specific mediastinal structures were assessed: 1) right brachiocephalic vein, 2) left brachiocephalic vein, 3) SVC, 4) aortic arch, 5) ascending thoracic aorta, 6) descending thoracic aorta, 7) arch vessels (innominate artery, left common carotid artery, left subclavian artery), 8) MPA, 9) right pulmonary artery, 10) left pulmonary artery, 11) pulmonary vein(s), 12) pericardium, 13) atria, 14) ventricles.

The following parameters were evaluated in both CT and MRI images:

- 1) Whether there was loss of intervening fat planes between the tumor and mediastinal structures.
- 2) Presence or absence of tumor abutment with mediastinal structures (more than 90 degrees) with loss of fat plane between the tumor and adjacent mediastinal structures.
- 3) Presence or absence of direct intraluminal vascular invasion. Vascular invasion is diagnosed when tumor tissue directly extends into the vessel lumen [29] with irregularity/thickening of the vessel wall.

The following parameter was also evaluated on MRI: presence or absence of sliding motion between the tumor and adjacent mediastinal structure on cine SSFP images.

The diagnostic criteria for local invasion on CT were presence of tumor abutment of mediastinal structures (more than 90 degrees) with loss of intervening fat plane or direct intralu-

minal vascular invasion.

The diagnostic criteria for local invasion on MRI were absence of sliding motion between the tumor and adjacent mediastinal structure on cine SSFP images or direct intraluminal vascular invasion.

Imaging findings were compared to surgical and histopathological findings.

The study was approved by the local institutional review board. Written informed consent was waived as this was a retrospective study with no interventions, and patient confidentiality was guaranteed by the study protocol.

RESULTS

A total of 61 mediastinal structures in these 9 patients showed loss of the intervening fat plane on CT and were included for analysis. The intervening fat plane was preserved in 6 of these 61 structures [innominate artery (n=1), aortic arch (n=1), ascending aorta (n=1), MPA (n=2), left pulmonary artery (n=1)] on cardiac-gated MRI images. These 6 structures also had preserved sliding motion and were confirmed not to be involved intraoperatively. The intervening fat plane was lost in the remaining 55 structures on both CT and MRI. The 55 structures are as follows: brachiocephalic veins (n=9), SVC (n=5), ascending aorta (n=5), aortic arch (n=2), descending aorta (n=2), pulmonary vein (n=6), pericardium (n=8), branch pulmonary artery (n=3), MPA (n=4), arch vessel (n=2), left ventricle (n=2), and right or left atrium (n=7). Two brachiocephalic veins were thrombosed on both CT and MRI scans and confirmed intraoperatively. Of these 55 structures, 20 were found to be involved/adhered during surgery [brachiocephalic veins (n=4), SVC (n=5), ascending aorta (n=2), aortic arch (n=1), descending aorta (n=1), pericardium (n=5), right or left atrium (n=2)]. The other 35 structures were found to be not involved intraoperatively [brachiocephalic vein (n=5), ascending aorta (n=3), aortic arch (n=1), descending aorta (n=1), pulmonary vein (n=6), pericardium (n=3), branch pulmonary artery (n=3), MPA (n=4), arch vessel (n=2), left ventricle (n=2), right or left atrium (n=5)].

A total of 48 mediastinal structures showed tumor abutment of more than 90 degrees with loss of the intervening fat plane on CT (Table 1). The 48 mediastinal structures are as follows: brachiocephalic veins (n=7), SVC (n=5), ascending aorta (n=6), aortic arch (n=2), descending aorta (n=2), arch vessel (n=1), pulmonary vein (n=4), pericardium (n=8), branch pulmonary artery (n=2), MPA (n=3), left ventricle (n=2), and right or left atrium (n=6). Of these 48 mediastinal structures, 19 [brachiocephalic veins (n=3), SVC (n=5), ascending aorta (n=2), aortic arch (n=1), descending aorta (n=1), pericardium (n=5), right or left atrium (n=2)] were confirmed to be involved/adhered intraoperatively.

The accuracy, sensitivity, and specificity in determining mediastinal invasion using tumor abutment of mediastinal structures (of more than 90 degrees) and loss of intervening fat plane on CT were 50.8 (31/61), 95 (19/20), and 29.3% (12/41), respectively. Twenty-nine cases were false-positives [brachiocephalic vein (n=4), aortic arch (n=1), ascending aorta (n=4), descending aorta (n=1), arch vessel (n=1), MPA (n=3), branch pulmonary artery (n=2), pulmonary vein (n=4), pericardium (n=3), right or left atrium (n=4), left ventricle (n=2)], and 1 case was a false-negative (brachiocephalic vein).

A total of 38 mediastinal structures showed tumor abutment of more than 90 degrees with loss of the intervening fat planes on MRI (Table 2): brachiocephalic vein (n=6), SVC (n=5), ascending aorta (n=5), aortic arch (n=2), descending aorta (n=1), pulmonary vein (n=4), pericardium (n=8), branch pulmonary artery (n=1), MPA (n=1), left ventricle (n=1), and right or left atrium (n=4). Of these 38 structures, 18 [brachiocephalic vein (n=3), SVC (n=5), ascending aorta (n=2), aortic arch (n=1), pericardium (n=5), right or left atrium (n=2)] were confirmed to be involved/adhered intraoperatively.

Table 1. Mediastinal structures with more than 90 degrees of tumor abutment assessed on CT, correlated with surgical findings

Mediastinal/ cardiac structures (n=61)	Presence of tumour abutment of more than 90 degrees on CT (n=48)	Absence of tumour abutment of more than 90 degrees on CT (n=13)	Structure adhered/invaded during surgery (n=20)	True positive (n=19)	False positive (n=29)	True negative (n=12)	False negative (n=1)
BCV (n=9)	7	2	4	3	4	1	1
SVC (n=5)	5	0	5	5	0	0	0
Aortic arch (n=3)	2	1	1	1	1	1	0
Ascending aorta (n=6)	6	0	2	2	4	0	0
Descending aorta (n=2)	2	0	1	1	1	0	0
Arch vessels (n=3)	1	2	0	0	1	2	0
MPA (n=6)	3	3	0	0	3	3	0
RPA/LPA (n=4)	2	2	0	0	2	2	0
PV (n=6)	4	2	0	0	4	2	0
Pericardium (n=8)	8	0	5	5	3	0	0
RA/LA (n=7)	6	1	2	2	4	1	0
LV (n=2)	2	0	0	0	2	0	0

BCV: brachiocephalic vein, SVC: superior vena cava, MPA: main pulmonary artery, RPA: right pulmonary artery, LPA: left pulmonary artery, PV: pulmonary vein, RA: right atrium, LA: left atrium, LV: left ventricle

Table 2. Mediastinal structures with more than 90 degrees of tumor abutment assessed on MRI, correlated with surgical findings

Mediastinal/ cardiac structures (n=61)	Presence of tumour abutment of more than 90 degrees on MRI (n=38)	Absence of tumour abutment of more than 90 degrees on MRI (n=23)	Structure adhered/invaded during surgery (n=20)	True positive (n=18)	False positive (n=20)	True negative (n=21)	False negative (n=2)
BCV (n=9)	6	3	4	3	3	2	1
SVC (n=5)	5	0	5	5	0	0	0
Aortic arch (n=3)	2	1	1	1	1	1	0
Ascending aorta (n=6)	5	1	2	2	3	1	0
Descending aorta (n=2)	1	1	1	0	1	0	1
Arch vessels (n=3)	0	3	0	0	0	3	0
MPA (n=6)	1	5	0	0	1	5	0
RPA/LPA (n=4)	1	3	0	0	1	3	0
PV (n=6)	4	2	0	0	4	2	0
Pericardium (n=8)	8	0	5	5	3	0	0
RA/LA (n=7)	4	3	2	2	2	3	0
LV (n=2)	1	1	0	0	1	1	0

BCV: brachiocephalic vein, SVC: superior vena cava, MPA: main pulmonary artery, RPA: right pulmonary artery, LPA: left pulmonary artery, PV: pulmonary vein, RA: right atrium, LA: left atrium, LV: left ventricle

The accuracy, sensitivity, and specificity of determining mediastinal invasion using the presence of tumor abutment of mediastinal structures (of more than 90 degrees) and loss of intervening fat plane on MRI were 63.9 (39/61), 90 (18/20), and 51.2% (21/41), respectively. Twenty cases were false-positive [brachiocephalic vein (n=3), aortic arch (n=1), ascending aorta (n=3), descending aorta (n=1), MPA (n=1), branch pulmonary artery (n=1), pulmonary vein (n=4), pericardium (n=3), right or left atrium (n=2), left ventricle (n=1)], and 2 cases were false-negative [brachiocephalic vein (n=1) and descending aorta (n=1)].

The cardiac-gated cine SSFP images showed loss of sliding motion in 15 mediastinal structures [brachiocephalic vein (n=3),

SVC (n=3), ascending aorta (n=2), pericardium (n=5), atrium (n=2)] (Table 3). Fourteen of these 15 mediastinal structures were confirmed to be involved/adhered during surgery [brachiocephalic vein (n=3), SVC (n=3), ascending aorta (n=1), pericardium (n=5), atrium (n=2)]. One of these structures (ascending aorta) showed loss of normal sliding motion but was not involved intraoperatively. In addition, 6 other mediastinal structures [brachiocephalic vein (n=1), SVC (n=2), aortic arch (n=1), ascending aorta (n=1), descending aorta (n=1)] were found to be involved/adhered intraoperatively, but MRI failed to demonstrate loss of normal sliding motion.

The accuracy, sensitivity, and specificity in determining me-

Table 3. Mediastinal structures assessed on cine SSFP MRI, correlated with surgical findings

Mediastinal/ cardiac structures (n=61)	Presence of sliding motion on MRI (n=46)	Absence of sliding motion on MRI (n=15)	Structure adhered/ invaded during surgery (n=20)	True positive (n=14)	False positive (n=1)	True negative (n=40)	False negative (n=6)
BCV (n=9)	6	3	4	3	0	5	1
SVC (n=5)	2	3	5	3	0	0	2
Aortic arch (n=3)	3	0	1	0	0	2	1
Ascending aorta (n=6)	4	2	2	1	1	3	1
Descending aorta (n=2)	2	0	1	0	0	1	1
Arch vessels (n=3)	3	0	0	0	0	3	0
MPA (n=6)	6	0	0	0	0	6	0
RPA/LPA (n=4)	4	0	0	0	0	4	0
PV (n=6)	6	0	0	0	0	6	0
Pericardium (n=8)	3	5	5	5	0	3	0
RA/LA (n=7)	5	2	2	2	0	5	0
LV (n=2)	2	0	0	0	0	2	0

BCV: brachiocephalic vein, SVC: superior vena cava, MPA: main pulmonary artery, RPA: right pulmonary artery, LPA: left pulmonary artery, PV: pulmonary vein, RA: right atrium, LA: left atrium, LV: left ventricle, SSFP: cine steady-state free precession

Fig. 1. A 24-year-old male with a malignant germ cell tumor in the anterior mediastinum. (A) Coronal contrast-enhanced CT image shows a lobulated hypoattenuating mass (asterisk) in the anterior mediastinum, abutting the pericardium/main pulmonary artery (white arrow) with loss of intervening fat. (B) Coronal oblique T1W MRI shows the mass (asterisk) abutting the pericardium, with clear preservation of the fat plane (white arrow) between the pericardium and main pulmonary artery. CT: computed tomography, T1W: T1-weighted, MRI: magnetic resonance imaging.

diastinal invasion using the presence or absence of sliding motion were 88.5 (54/61), 70 (14/20), and 97.6% (40/41), respectively. One case was false-positive (ascending aorta), and 6 were false-negatives [brachiocephalic vein (n=1), SVC (n=2), aortic arch (n=1), ascending aorta (n=1), descending aorta (n=1)].

DISCUSSION

CT has long been the modality of choice in imaging mediastinal tumors. With the advent of improved and faster MRI techniques, MRI may be an alternative or complementary modality in imaging of mediastinal tumors [5,30-33]. However, due to its higher cost, increased scan time, and reduced availability

compared to CT, MRI is not routinely used [5]. Also, the lack of protons in lung tissue results in poor signal return and poor evaluation of lung invasion on MRI [22]. Nonetheless, cardiac-gated MRI may help accurately assess surgical resectability of mediastinal tumors, given its multiplanar capability and superior soft tissue resolution [20]. This assessment in turn affects treatment planning. Although some centers have reported promising results with extensive radical surgery for locally invasive mediastinal tumors [2,3], most centers still consider invasion of the myocardium, great vessels, or long tracheal segment as contraindications for surgical resection [2]. Therefore, accurate preoperative radiological staging is important in helping clinicians to better select patients who will benefit from poten-

Fig. 2. A 23-year-old male with a non-seminomatous germ cell tumor. (A) Coronal contrast-enhanced CT image shows a large hypoattenuating anterior mediastinal mass (asterisk) abutting the right atrium (white arrow) with loss of intervening fat plane. (B) Sagittal-oblique T1W SE image shows similar findings. Coronal oblique cine SSFP image in atrial (C) systole and (D) diastole shows loss of normal sliding motion between the mass (asterisk) and right atrium (white arrow). CT: computed tomography, T1W: T1-weighted, SE: spin-echo, SSFP: cine steady-state free precession.

Fig. 3. A 21-year-old female with a large mature teratoma occupying almost the entire left hemithorax. (A) Axial contrast-enhanced CT image shows a large heterogeneous mass (asterisk) in the left hemithorax, abutting the left heart border with loss of intervening fat plane (white arrow). (B) Axial T1W SE image shows similar findings of a large mass (asterisk) in the left hemithorax, abutting the left heart border with loss of intervening fat plane (white arrow). Axial cine SSFP image in ventricular (C) diastole and (D) systole shows normal contraction of the left ventricle, indicating no invasion into the left ventricle. There is however loss of the normal sliding motion between the mass (asterisk) and pericardium (white arrow). CT: computed tomography, T1W: T1-weighted, SE: spin-echo, SSFP: cine steady-state free precession.

tially high-risk surgery.

Our study shows that MRI was slightly better in delineating intervening fat planes than CT (Fig. 1). This result is not unexpected given the superior soft-tissue resolution of MRI [20-22]. The intervening fat planes are best visualized on T1W SE images [5,34]. When assessing fat planes on cine SSFP images, it is crucial to be mindful of an important artefact resulting from the chemical shift, sometimes referred to as the Indian ink artefact, which can occur with gradient echo sequences [35]. This artefact is due to pixel cancellation at boundaries between fat and water-based tissues. It depends on TE, and the maximum cancellation occurs when fat-water signals are completely out of phase, which first occurs at a TE of approximately 2.4 ms for 1.5 T scans [35]. Therefore, T1W SE images have to be correlated to determine the presence of intervening fat planes.

Our study also shows that the absence of sliding motion has the highest specificity in determining mediastinal invasion compared with tumor abutment of more than 90 degrees with the loss of intervening fat planes assessed by both CT and MRI. Therefore, adding cardiac-gated MRI, particularly cine SSFP sequences, may help increase the diagnostic accuracy of imaging studies by excluding mediastinal structure invasion when sliding motion is preserved. This result is especially helpful for assessing cardiac chamber invasion, as sliding motion is prominent in normal cardiac chambers (Fig. 2) [5].

Mediastinal vessels, however, normally only show minimal sliding motion, which may result in false-positive diagnoses of tumor invasion when relying solely on the absence of sliding motion [5]. Given the normal minimal sliding motion of mediastinal vessels, loss of sliding motion may be difficult to demonstrate when a tumor is involved, resulting in false-negative findings [28]. Also, the mass effect of large tumors reduces sliding motion and may lead to subsequent false-positive diagnoses of tumor involvement [5,36]. In addition, the absence of sliding motion between structures does not always imply invasion as it could also be a result of fibrous adhesion (Fig. 3) [28,36,37].

The limitations of our study include the small number of patients (9). Given that this is a retrospective study, the surgical notes may not be detailed enough. Due to the lack of reimbursement and higher cost of MRI, not all patients with mediastinal tumors at our institution undergo cardiac-gated MRI mediastinum scans.

Our preliminary study shows that cardiac-gated MRI using cine SSFP sequences is more accurate than routine, non-cardiac-gated CT and can improve diagnostic accuracy of local mediastinal tumor invasion, especially when CT findings are equivocal. With the increasing availability of MRI and rapid improvement in technology, MRI has the potential to be a complementary and problem-solving modality for select cases with equivocal tumor involvement of mediastinal structures on CT, in partic-

ular the cardiac chambers.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Acknowledgments

We thank Dr Pei Ing NGAM for her statistical advice.

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