Turk Gogus Kalp Dama 2015;23(2):309-315
doi: 10.5606/tgkdc.dergisi.2015.10036

Original Article / Özgün Makale

Using cine magnetic resonance imaging to evaluate the degree of invasion in mediastinal masses

Mediastinal kitlelerde invazyon derecesinin değerlendirilmesinde sine manyetik rezonans görüntüleme kullanımı

Mesut Özgökçe,[1] Fatih Alper,[1] Yener Aydın,[2] Hayri Oğul,[1] Metin Akgün[3]

Departments of [1]Radiology, [2]Thoracic Surgery and [3]Chest Diseases,
Medical Faculty of Atatürk University, Erzurum, Turkey

ABSTRACT

Background: This study aims to evaluate motion and contiguity of lesions detected in computed tomography and conventional magnetic resonance imaging (MRI) with cine MRI.

Methods: This prospective study included 32 patients (15 males, 17 females; mean age 51 years; range 24 to 86 years) with solid or cystic mediastinal mass lesion and suspected of invasion. Firstly, patients were performed posteroanterior chest radiography and chest computed tomography scan. Then, lesions' static morphological characteristics were investigated with conventional MRI (T_1, T_2, short T_1 inversion recovery). Dynamic characteristics of lesions were shown with cine MRI in three planes. Lesions were evaluated in terms of shape, size, motion, and relationships with adjacent tissues.

Results: Of 32 patients, 17 were operated with 13 patients having benign cysts (four mediastinal goiters, two teratomas, two pericardial cysts, one bronchogenic cyst, one hydatid cyst, one neurenteric cyst, one schwannoma, and one aorta aneurysm), and four patients having malignant cysts (two esophagus cancer, one lung cancer, and one synovial sarcoma). Preoperative cine MRI showed no invasion in 16 of these patients, and presence of invasion in one patient. Our findings were consistent with the operation results. It was thought that seven of the 15 patients who were diagnosed histopathologically had invasion. Of these 15 patients, 13 had malignant cysts (seven lung cancer, three lymphomas, one esophagus cancer, one mesothelioma, and one thymoma) and were accepted clinicoradiologically inoperable. Treatment was started in two patients who were detected to have osseous inflammatory pathology and tuberculosis lymphadenitis. Cine MRI was statistically significantly superior than conventional MRI in showing invasion to mediastinal structures ($p<0.001$).

Conclusion: Cine MRI may provide significant assistance in diagnosis of mediastinal lesions and evaluation of their relationships with adjacent tissues.

Keywords: Cine magnetic resonance imaging; cyst; invasion; mass; mediastinum.

ÖZ

Amaç: Bu çalışmada bilgisayarlı tomografi ve konvansiyonel manyetik rezonans görüntülemede (MRG) tespit edilen lezyonların hareket ve komşulukları sine MRG ile değerlendirildi.

Çalışma planı: Bu prospektif çalışmaya mediastende solid veya kistik kitlesel lezyonu olan ve invazyondan şüphelenilen 32 hasta (15 erkek, 17 kadın; ort. yaş 51 yıl; dağılım 24-86 yıl) dahil edildi. Hastalara öncelikle arka-ön göğüs radyografisi ve göğüs bilgisayarlı tomografi taraması uygulandı. Ardından, lezyonların statik morfolojik özellikleri konvansiyonel MRG (T_1, T_2, kısa T_1 inversiyon iyileşme) ile araştırıldı. Lezyonların dinamik özellikleri üç planda sine MRG ile gösterildi. Lezyonlar şekil, boyut, hareket ve komşu dokularla ilişkileri açısından değerlendirildi.

Bulgular: Otuz iki hastanın 17'si ameliyat edildi; bunlardan 13 hastada benign kistler (dört mediastinal guatr, iki teratom, iki perikardiyal kist, bir bronkojenik kist, bir kist hidatik, bir nöroenterik kist, bir schwannoma ve bir aort anevrizması) ve dört hastada malign kistler (iki özofagus kanseri, bir akciğer kanseri ve bir sinoviyal sarkom) vardı. Ameliyat öncesi sine MRG bu hastaların 16'sında invazyon olmadığını, birinde invazyon olduğunu gösterdi. Bulgularımız ameliyat sonuçları ile uyumlu idi. Histopatolojik tanı konulan 15 hastanın yedisinde invazyon olduğu düşünüldü. Bu 15 hastanın 13'ünde malign kistler (yedi akciğer kanseri, üç lenfoma, bir özofagus kanseri, bir mezotelyoma ve bir timoma) var idi ve bu hastalar klinikoradyolojik olarak ameliyat edilemez kabul edildi. Osseöz enflamatuvar patoloji ve tüberküloz lenfadenit tespit edilen iki hastada tedavi başlandı. Mediastinal yapılara invazyonu göstermede sine MRG konvansiyonel MRG'den istatistiksel olarak anlamlı şekilde üstün idi ($p<0.001$).

Sonuç: Mediastinal lezyonların tanısında ve komşu dokularla ilişkilerinin değerlendirilmesinde sine MRG anlamlı yardım sağlayabilir.

Anahtar sözcükler: Sine manyetik rezonans görüntüleme; kist; invazyon; kitle; mediasten.

Available online at
www.tgkdc.dergisi.org
doi: 10.5606/tgkdc.dergisi.2015.10036
QR (Quick Response) Code

Received: February 19, 2014 *Accepted:* May 18, 2014

Correspondence: Yener Aydın, M.D. Atatürk Üniversitesi Tıp Fakültesi Göğüs Cerrahisi Anabilim Dalı, 25240 Erzurum, Turkey.
Tel: +90 535 - 784 89 70 e-mail: dryeneraydin@hotmail.com

The mediastinum, which is comprised of many different organs and tissues, is a highly complex area because of its anatomical structure and wide range of pathologies.[1] Although computed tomography (CT), multi-detector CT, and magnetic resonance imaging (MRI) have been used in the preoperative staging of mediastinal masses, the role of MRI in the morphological evaluation of mediastinal masses as well as the relationship between the masses and the adjacent structures has increased as the technology has become more advanced. Magnetic resonance imaging is not a limitation-free technique, and its sensibility to motion artefacts is a disadvantage. This is especially true in thoracic examinations because of the movement of the main vascular structures along with the heartbeat and respiration. However, these limitations can be overcome by the use of electrocardiography (ECG) triggering in which radio frequency (RF) pulses are sent and data is collected via synchronization with the cardiac phase[2] and the breath-holding sequences. In addition, the individual and relative motion between the tumor and the surrounding mediastinal structures can be evaluated with cine MRI.[3-5]

In this study, we aimed to determine whether or not mediastinal lesions invade the surrounding cardiovascular and mediastinal structures and also evaluate the breath-holding results using the ECG-gated cine MRI.

PATIENTS AND METHODS

This prospective study was composed of 32 patients (15 males, 17 females; mean age 51 years; range 24 to 86 years) with mediastinal lesions who underwent a routine chest X-ray and thoracic CT imaging between January 2010 and November 2011. The thoracic CT allowed us to examine the location of the lesions and the presence of calcification and fat as well as the amount of invasion and involvement of the lung. Furthermore, we looked at their composition (i.e., cystic or solid) and size together with their relationship with the adjacent mediastinal structures and the distribution of the mediastinal compartments. When invasion was suspected, MRIs were obtained via the Siemens 1.5-Tesla Magnetom Vision system (Siemens Medical Systems, Erlangen, Germany) which utilized a body coil ECG-gated. For ECG-gated imaging, four probes were inserted according to the device instructions, and the lesions were localized by performing axial planar T_2 true fast imaging (TRUFI) of the entire chest (TR: 10.2 ms, TE: 4.7 ms) prior to the MRI.

Axial T_1 and T_2-weighted images and short inversion time inversion-recovery (STIR) turbo split echo (SE) sequences were taken using conventional MRI. Then the cine MRI was performed on the sagittal, coronal, and axial plane sequential dynamic sections using steady-state free precession (SSFP) on the localized mass lesion, especially on the obliterated adjacent fat planes by taking into account the direct invasion of the lesion as seen on the earlier MRI sequences.

Next, the axial T_1 (repetition time (TR)/echo time (TE)= 700/7.1 msec, number of excitations (NEX)= 1, slice thickness= 6 mm, slice gap= 15 mm, matrix= 125x56, field of view (FOV)= 360 mm) and T_2-weighted images (TR/TE= 700/71 msec, NEX= 1, slice thickness= 6 mm, slice gap= 15 mm, matrix= 119x256, FOV= 360 mm) along with the axial STIR turbo SE images (TR =800 msec, TE= 66 msec, inversion time (TI)= 150 msec, NEX= 1, slice thickness= 5 mm, slice gap= 15 mm, matrix= 119x256, FOV= 340 mm) and cine MRI images (TR= 43.26 msec, TE= 1.3 msec, fractional anisotropy (FA)= 80, slice thickness= 6 mm, matrix= 156x192, FOV= 320 mm) were obtained using the image parameters. The lesion's shape, signal characteristics, edge structure, relationship with adjacent tissues, and mediastinal distribution were then investigated via these same images.

For the cine MRI, which is a routine sequence of cardiac MRI, we obtained 20-30 images at approximate intervals of between five and six seconds without the need of a contrast medium. Afterwards, dynamic evaluation was performed at a workstation by stimulating the images sequentially in an animated movie format. Lesion movements were then evaluated to determine whether they were individual/independent or collective motion when adjacent to the relative organs. The lesion's free wall movements were also investigated along with whether fat planes were present between the lesion and the adjacent organs. Furthermore, we investigated the invasion of the masses into the adjacent mediastinal tissues utilizing mass extensions. Two radiologists obtained these images. Moreover, the lesions were evaluated for the presence of invasion, and in the patient follow-ups, their clinical findings and operative results were compared.

RESULTS

The demographic data of the patients, lesion characteristics, including T_1, T_2, STIR, and cine MRI features, and operative data are shown in Table 1. The conventional MRI indicated 11 invasions, and the cine MRI results agreed with the conventional MRI in seven cases, but they also indicated another invasion

Table 1. Characteristics of the patients

Case	Age/sex	Localization	Pathological diagnosis	Operation	Conventional MRI	Cine MRI
1	40/F	Anterior-superior med.	Mature thyroid tissue	Resection	–	–
2	51/M	Anterior-superior med.	Thyroid adenomatous hyperplasia	Resection	–	–
3	39/F	Anterior-superior med.	Thyroid adenomatous hyperplasia	Resection	–	–
4	49/F	Anterior-superior med.	Thyroid adenomatous hyperplasia	Resection	–	–
5	71/F	Anterior mediastinum	Thymoma	Follow-up	Invasive	Invasive
6	62/F	Anterior mediastinum	Pericardial cysts	Resection	–	–
7	39/F	Anterior mediastinum	Mature cystic teratoma	Resection	–	–
8	48/F	Anterior mediastinum	Mature cystic teratoma	Resection	Invasive	–
9	59/F	Anterior mediastinum	Synovial sarcoma	Resection	Invasive	–
10	63/F	Posterior mediastinum	Oesophageal cancer	Resection	Invasive	–
11	49/F	Posterior mediastinum	Oesophageal cancer	Resection	Invasive	–
12	67/M	Posterior mediastinum	Oesophageal cancer	Inoperable	Invasive	Invasive
13	61/F	Posterior mediastinum	Schwannoma	Resection	–	–
14	40/F	Posterior mediastinum	Neuroenteric cyst	Resection	–	–
15	78/M	Middle mediastinum	Bronchogenic cyst	Resection	–	–
16	61/M	Middle mediastinum	Hydatid cyst	Resection	–	–
17	67/M	Middle mediastinum	Hodgkin lymphoma	–	–	–
18	33/F	Middle mediastinum	Non-Hodgkin lymphoma	–	Invasive	Invasive
19	33/M	Middle mediastinum	Aneurysm	Resection	–	–
20	71/M	Middle mediastinum	Tuberculosis	–	–	–
21	24/F	Middle mediastinum	Non-Hodgkin lymphoma	–	–	–
22	41/M	Middle mediastinum	Pericardial cyst	Resection	–	–
23	48/M	Right lung parenchyma	Small cell lung carcinoma	–	Invasive	Invasive
24	78/M	Left hilar area	Non-small cell lung carcinoma	Resection	Invasive	Invasive
25	86/M	Left lung apex	Non-small cell lung carcinoma	–	–	–
26	48/F	Left hilar area	Small cell lung carcinoma	–	Invasive	Invasive
27	58/M	Right lung parenchyma	Non-small cell lung carcinoma	–	–	–
28	69/M	Right lung paracardiac	Non-small cell lung carcinoma	–	–	Invasive
29	67/F	Left lung apex	Non-small cell lung carcinoma	–	Invasive	Invasive
30	58/F	Right lung pleura	Mesothelioma	–	–	–
31	52/M	Right hilar area	Non-small cell lung carcinoma	–	–	–
32	75/F	Right apex	Osseous inflammation	–	–	–

MRI: Magnetic resonance imaging; med.: Mediastinum

that had been considered normal on the conventional MRI (Figure 1-5). Using a chi-square test, we then determined that this difference between the imaging techniques was statistically significant in favor of the cine MRI ($p<0.001$).

According to the imaging findings, the tumor locations were as follows: for nine patients, (28%), it was in the anterior-superior mediastinum, for eight (25%), it was in the middle mediastinum, for five (16%), it was in the posterior mediastinum, for three (9%), it was in the hilar area, and for seven others (22%), it involved paramediastinal lung parenchyma.

Seventeen of the 32 patients underwent surgery. Of these, 13 had benign tumors (four mediastinal goiters, two teratomas, two pericardial cysts, one bronchogenic cyst, one hydatid cyst, one neuroenteric cyst, one schwannoma, and one aortic aneurysm), whereas four were malignant (two had esophageal cancer, one lung cancer, and one synovial sarcoma). Only in the lung cancer patient cine MRI indicated a suspicion of pulmonary artery invasion, and this was later confirmed during the surgery. The preoperative cine MRI findings and the intraoperative outcomes were the same for these 17 patients.

Minimal volumetric changes were found via the dynamic images in the cystic patients (n=5). In addition, loss of compression and the opening of the intermediary fat planes were also seen. Compression even occurred in the adjacent structures. Invasion was not considered in these cases preoperatively, and this was verified by the surgical results.

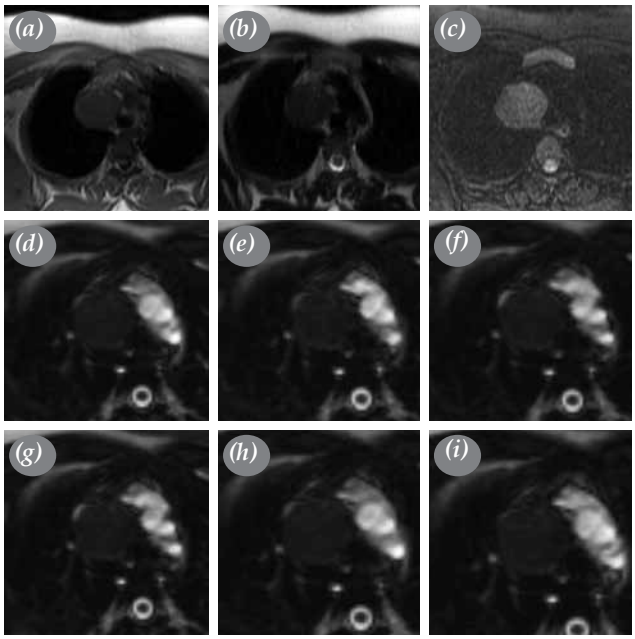

Figure 1. (a) T_1 isointense; **(b)** T_2 hypointense; and **(c)** intrathoracic goiter case that was hyperintense on short time inversion recovery **(d-i)** and the disappearing of superior vena cava compression on moving images.

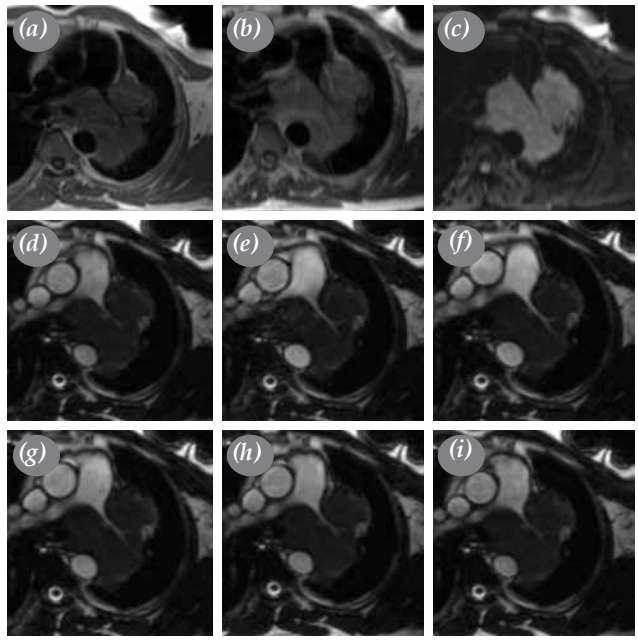

Figure 2. (a) T_1 hypointense; **(b)** T_2 hypointense; and **(c)** central lung mass that was hyperintense on short time inversion recovery **(d-i)** along with right pulmonary artery decompression and left pulmonary artery dilatation on cine magnetic resonance imaging.

Thirteen of the other 15 histopathologically diagnosed cases were malignant, with seven having lung cancer and three having lymphoma. There was also one case each of esophageal cancer, mesothelioma, and thymoma. These were considered to be inoperable in both the clinical and radiological follow-ups. In seven patients (five with lung cancer, one with thymoma, and one with lymphoma), invasion was seen. Two others

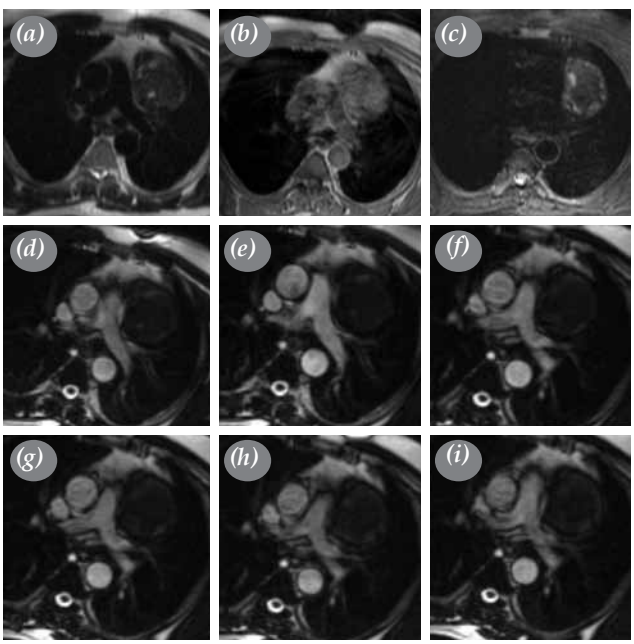

Figure 3. (a) T_1 heterogeneous hypointense; **(b)** T_2 hyperintense; and **(c)** hypointense cystic components on short time inversion recovery **(d-i)** hydatid cyst case which the lesion is separated from pulmonary vascular structures on moving images.

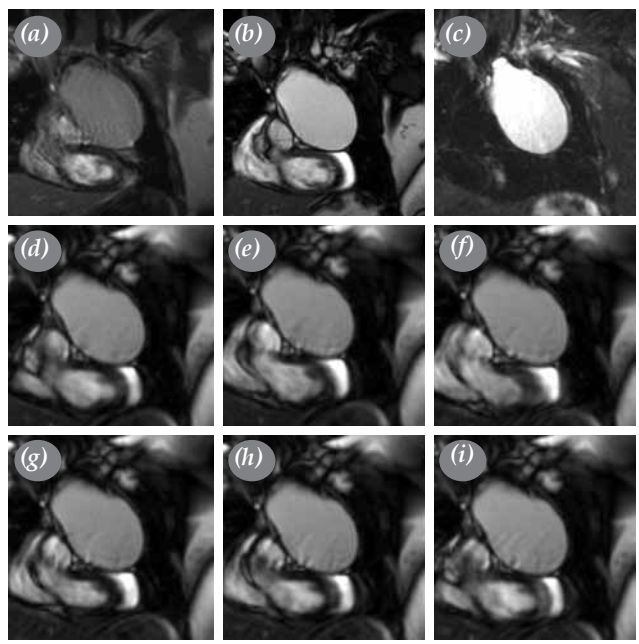

Figure 4. (a) T_1 hypointense; **(b)** T_2 isointense; **(c)** short time inversion recovery hyperintense **(d-i)** mature cystic teratoma which is seen separate from pericard on cine magnetic resonance imaging.

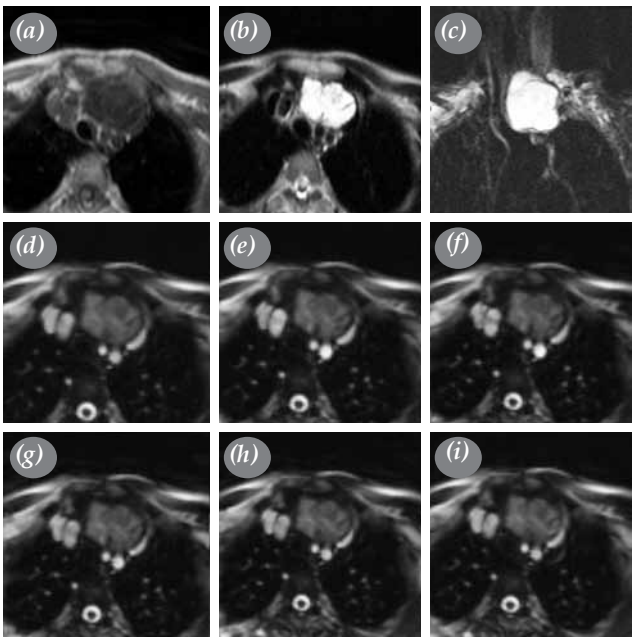

Figure 5. (a) T_1 hypointense; **(b)** T_2 hyperintense; **(c)** short time inversion recovery hyperintense **(d-i)** synovial sarcoma which the invasion is not seen but also reduced compression with adjacent left subclavian vein.

had no invasion. They were diagnosed with osteitis and tuberculosis lymphadenitis, and prescribed medical treatment.

In the cine MRI assessment, invasion was suspected in eight patients (five with lung cancer, one with esophageal cancer, one with thymoma, and one with lymphoma). In three patients there were pericardium invasions, while in others there were also thoracic aorta, arcus aorta, superior vena cava-right main bronchus, thoracic aorta-pericardium and left pulmonary artery invasions. In one patient, the invasion to the left pulmonary artery was confirmed after the surgery, which was performed as pneumonectomy.

DISCUSSION

We found that cine MRI was better at detecting mediastinal invasion and that its results were more compatible with the intraoperative findings than those of conventional MRI, which missed the invasion in one case and gave false positive results in four others.

The mediastinum has a very complex, dynamic structure because it has moving structures like the superior vena cava, trachea, vessels, pericardium, and esophagus. Since it contains major vascular structures, such as the trachea and heart tissues, it is vitally important. Continuous movement in the mediastinum necessitates more accurate imaging modalities for the invasion of mediastinal lesions.

Computed tomography is the most commonly used method for evaluating mediastinal lesions. Chest CT provides important information about the localization of the tumor, the invasion and infiltration, the tumor's relationship with vascular structures, the degree of involvement, calcification, mass density, possible pleural abnormalities, and the mediastinal lymph nodes. However, it is not sufficiently reliable for the preoperative assessment of thoracic masses, including lung cancer.[6-10] Furthermore, MRI is superior for examining $T_{3/4}$ separation and for identifying the presence of local invasions.[4,8]

The most reliable evidence of mediastinal spread is the demonstration of mediastinal tissues being held by the tumor tissue in the bronchi, great vessels, and esophagus. Computed tomographic scans of mediastinal invasion have a sensitivity of between 40 and 77%, and a specificity of between 67 and 99%.[11,12] A thoracic CT examination takes between seven and 10 seconds and consists of static axial planar images. Evaluations of shape changes in the lesion stemming from the neighboring mobile organs, time evaluations regarding the compressed fat planes, and movement evaluations are not possible. Cine MRI is indicated for patients for whom a decision about mediastinal and vascular invasion cannot be reached via CT.

The role of MRI in the evaluation and staging of intrathoracic masses is rapidly increasing because of developments in MRI technology, and it is currently the highest soft-tissue contrast imaging method. The advantages of CT are that it can be used for patients who are allergic to the contrast media, it is not affected by radiation, and it can be multiplanar. In some studies, it has been shown that MRI is superior to CT for determining the relationship between masses and the chest wall as well as the adjacent vascular and mediastinal structures,[13,14] and Seo et al.[14] found that MRI was superior for examining chest wall invasion, especially when Pancoast tumors were present.

The significant disadvantage of MRI is its sensitivity to the moving tissues, and for that reason, it often has artifacts that can cause diagnostic difficulties because they may impair the image. Hence, cardiac triggering methods and fast imaging techniques are often used to minimize cardiac motion artifacts. Moreover, lesions may display different motion characteristics due to their density as well as the continuous movement of the mediastinal structures. In our study, there were no changes in shape or size in the rigid solid lesions.

However, compression-decompression was seen in the sizes and shapes of the benign lesions, such as mediastinal cysts, on cine MRI along with minimal volumetric changes, especially in the cystic lesions. The disappearance of the intervening fat planes during compression along with the opening of these planes were seen via dynamic imaging in the lesions that were compressing against adjacent structures, but invasion was not considered in these cases. As stated in some studies, separate movements between two neighboring areas proves the absence of invasion with 100% specificity.[15,16]

Seo et al.[14] conducted a study that detected the direct invasion of the thoracic mass into adjacent cardiovascular structures with 94.4% accuracy, 100% sensitivity, and 92.9% specificity by showing separate movements between the thoracic mass and adjacent structures on cine MRI. This method reveals once again the importance of dynamic evaluation for mediastinal masses. In this study, by chance we even obtained an image similar to that found in a preoperative virtual mediastinoscopy or mediastinal ultrasound and evaluation via the use of dynamic imaging with cine MRI.

The effacing of the fat planes between the lesion and adjacent structures and volumetric changes in those that are cystic in nature can provide valuable information about invasion. Thus, while images obtained with CT and conventional MRI provide information related to the edge and adjacent structure in a single plane at a certain period of time, dynamic cine MRI can show almost all of the lesion's movements as well as those of the adjacent mobile structures. In our study, mediastinal invasion was found in 11 of the 32 patients when conventional MRI was performed. However, invasion was shown in only seven of these cases via cine MRI. Therefore, our findings indicate that cine imaging can reduce false positivity associated with routine MRI. In addition, cine MRI detected that there was no invasion in one instance in which conventional MRI showed the opposite. Thus, cine MRI appears to decrease the number of false negative results. Furthermore, the cine imaging revealed that there was no invasion in 16 of the 17 surgical patients and that one had invasion, and these results were verified during the operations.

Conclusion

Our study results suggest that cine MRI is preferable to conventional MRI when evaluating the relationship between mediastinal lesions and the adjacent structures. Additionally, it is better for assessing the degree of compression and invasion. Therefore, we believe that cine MRI is currently the most definitive and reliable method for the evaluation of mediastinal lesions.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

The authors received no financial support for the research and/or authorship of this article.

REFERENCES

1. Lalwani P, Chawla R, Kumar M, Tomar AS, Raman P. Posterior mediastinal mass: do we need to worry much? Ann Card Anaesth 2013;16:289-92.
2. Alper F, Turkyilmaz A, Kurtcan S, Aydin Y, Onbas O, Acemoglu H, et al. Effectiveness of the STIR turbo spin-echo sequence MR imaging in evaluation of lymphadenopathy in esophageal cancer. Eur J Radiol 2011;80:625-8.
3. Cai N, Wang S, Zhu S, Liang D. Accelerating Dynamic Cardiac MR imaging using structured sparse representation. Comput Math Methods Med 2013;2013:160139.
4. Sakai S, Murayama S, Murakami J, Hashiguchi N, Masuda K. Bronchogenic carcinoma invasion of the chest wall: evaluation with dynamic cine MRI during breathing. J Comput Assist Tomogr 1997;21:595-600.
5. Giovagnoni A, Ercolani P, Misericordia M, Terilli F, De Nigris E. Cine-MR in the assessment of the cardiovascular structures in extensive mediastinal pathology. [Abstract] Radiol Med 1992;83:24-30.
6. Kajiwara N, Akata S, Uchida O, Usuda J, Ohira T, Kawate N, et al. Cine MRI enables better therapeutic planning than CT in cases of possible lung cancer chest wall invasion. Lung Cancer 2010;69:203-8.
7. Imai K, Minamiya Y, Ishiyama K, Hashimoto M, Saito H, Motoyama S, et al. Use of CT to evaluate pleural invasion in non-small cell lung cancer: measurement of the ratio of the interface between tumor and neighboring structures to maximum tumor diameter. Radiology 2013;267:619-26.
8. Nakatsu M, Hatabu H, Itoh H, Morikawa K, Miki Y, Kasagi K, et al. Comparison of short inversion time inversion recovery (STIR) and fat-saturated (chemsat) techniques for background fat intensity suppression in cervical and thoracic MR imaging. J Magn Reson Imaging 2000;11:56-60.
9. Ohno Y, Koyama H, Yoshikawa T, Nishio M, Aoyama N, Onishi Y, et al. N stage disease in patients with non-small cell lung cancer: efficacy of quantitative and qualitative assessment with STIR turbo spin-echo imaging, diffusion-weighted MR imaging, and fluorodeoxyglucose PET/CT. Radiology 2011;261:605-15.
10. Sommer G, Wiese M, Winter L, Lenz C, Klarhöfer M, Forrer F, et al. Preoperative staging of non-small-cell lung cancer: comparison of whole-body diffusion-weighted magnetic resonance imaging and 18F-fluorodeoxyglucose-positron emission tomography/computed tomography. Eur Radiol

2012;22:2859-67.

11. Takahashi K, Furuse M, Hanaoka H, Yamada T, Mineta M, Ono H, et al. Pulmonary vein and left atrial invasion by lung cancer: assessment by breath-hold gadolinium-enhanced three-dimensional MR angiography. J Comput Assist Tomogr 2000;24:557-61.
12. Ohno Y, Adachi S, Motoyama A, Kusumoto M, Hatabu H, Sugimura K, et al. Multiphase ECG-triggered 3D contrast-enhanced MR angiography: utility for evaluation of hilar and mediastinal invasion of bronchogenic carcinoma. J Magn Reson Imaging 2001;13:215-24.
13. Webb WR, Gatsonis C, Zerhouni EA, Heelan RT, Glazer GM, Francis IR, et al. CT and MR imaging in staging non-small cell bronchogenic carcinoma: report of the Radiologic Diagnostic Oncology Group. Radiology 1991;178:705-13.
14. Seo JS, Kim YJ, Choi BW, Choe KO. Usefulness of magnetic resonance imaging for evaluation of cardiovascular invasion: evaluation of sliding motion between thoracic mass and adjacent structures on cine MR images. J Magn Reson Imaging 2005;22:234-41.
15. Sakai S, Murayama S, Murakami J, Hashiguchi N, Masuda K. Bronchogenic carcinoma invasion of the chest wall: evaluation with dynamic cine MRI during breathing. J Comput Assist Tomogr 1997;21:595-600.
16. Giovagnoni A, Ercolani P, Misericordia M, Terilli F, De Nigris E. Cine-MR in the assessment of the cardiovascular structures in extensive mediastinal pathology. Radiol Med 1992;83:24-30. [Abstract]