Signature: © Pol J Radiol, 2016; 81: 566-571
DOI: 10.12659/PJR.898242

Polish Journal of Radiology
www.PolRadiol.com
ORIGINAL ARTICLE

Received: 2016.02.27
Accepted: 2016.04.25
Published: 2016.11.25

Utility of Electrocardiography (ECG)-Gated Computed Tomography (CT) for Preoperative Evaluations of Thymic Epithelial Tumors

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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Summary

Background: Preoperative evaluation of invasion to the adjacent organs is important for the thymic epithelial tumors on CT. The purpose of our study was to evaluate the utility of electrocardiography (ECG)-gated CT for assessing thymic epithelial tumors with regard to the motion artifacts produced and the preoperative diagnostic accuracy of the technique.

Material/Methods: Forty thymic epithelial tumors (36 thymomas and 4 thymic carcinomas) were examined with ECG-gated contrast-enhanced CT using a dual source scanner. The scan delay after the contrast media injection was 30 s for the non-ECG-gated CT and 100 s for the ECG-gated CT. Two radiologists blindly evaluated both the non-ECG-gated and ECG-gated CT images for motion artifacts and determined whether the tumors had invaded adjacent structures (mediastinal fat, superior vena cava, brachiocephalic veins, aorta, pulmonary artery, pericardium, or lungs) on each image. Motion artifacts were evaluated using a 3-grade scale. Surgical and pathological findings were used as a reference standard for tumor invasion.

Results: Motion artifacts were significantly reduced for all structures by ECG gating (p=0.0089 for the lungs and p<0.0001 for the other structures). Non-ECG-gated CT and ECG-gated CT demonstrated 79% and 95% accuracy, respectively, during assessments of pericardial invasion (p=0.03).

Conclusions: ECG-gated CT reduced the severity of motion artifacts and might be useful for preoperative assessment whether thymic epithelial tumors have invaded adjacent structures.

MeSH Keywords: Artifacts • Mediastinum • Thymoma

PDF file: http://www.polradiol.com/abstract/index/idArt/898242

Background

Thymic epithelial tumors represent a wide spectrum of lesions; some are indolent and non-invasive, whereas others are aggressive and invade the surrounding organs. Surgical resection with or without postoperative radiation therapy is the standard treatment [1–4] for these tumors, and CT is the modality that is most commonly used to evaluate whether they have invaded adjacent organs prior to surgery. However, since thymic epithelial tumors develop in the anterior mediastinum, they often exhibit blurred contours on CT due to cardiac movement and motion artifacts. Such motion artifacts can adversely affect image quality and make it difficult to assess whether a tumor has invaded the adjacent organs.

On CT, thymic tumor invasion is basically diagnosed by evaluating the irregularity of the tumor contour and/or irregular interface with absence of the mediastinal fat layer or space between the tumor and surrounding structures. Vascular involvement is determined from the findings of the irregular vessel lumen contour or endoluminal soft tissue density [5,6]. To more accurately evaluate these features and improve the accuracy of preoperative evaluations of thymic epithelial tumors, we hypothesized that electrocardiography (ECG)-gated CT would be useful. So far,

ECG-gated CT has mainly been used to evaluate the coronary artery status. Although some studies have suggested that images of the thoracic aorta, pulmonary vessels, and pulmonary parenchyma obtained with ECG-gated CT exhibit less severe motion artifacts than images obtained with standard CT [7–11], no reports about the application of the ECG-gated technique to evaluations of mediastinal tumors have been published.

In our institution, ECG-gated CT has been used to reduce motion artifacts and make it easier to assess the degree of tumor invasion. The purpose of this study was to investigate the utility of ECG-gated multi-detector row (MD) CT for preoperative evaluations of thymic epithelial tumors.

Material and Methods

Subjects

Between 2008 and 2012, consecutive 60 pathologically proven thymic epithelial tumors were listed for this study, and 40 of the 60 cases who underwent ECG-gated CT for preoperative evaluation of the thymic epithelial tumors (15 males and 25 females; aged 25–87 years, median: 64 years) were included in this study. The institutional review board approved this retrospective study, and no individual patient consent was required. All patients underwent surgical resection. The 40 tumors consisted of 36 thymomas and 4 thymic cancers, and all of them were located in the anterior mediastinum. The major and minor axis lengths of the tumors ranged from 17 to 131 mm (mean: 52 mm) and from 12 to 92 mm (34 mm), respectively. The Masaoka stage [12] was as follows: stage I in 13 cases, stage II in 13 cases, stage III in 7 cases, stage IVa in 3 cases, and stage IVb in 4 cases. The 27 tumors (69%) staged as II, III or IV showed invasion into the capsule or surrounding structures. Furthermore, 14 (36%) stage III, IVa, or IVb tumors showed more aggressive invasiveness into neighboring organs and/or pleural/pericardial dissemination. The following invasion to surrounding structures was observed: the mediastinal fat in 25 of 40 cases, pericardium in 7 of 39 evaluable cases, superior vena cava (SVC) and brachiocephalic vein in 6 of 23, aorta and pulmonary artery in 0 of 38, and lung in 9 of 39. All cases underwent ECG-gated CT examinations as preoperative evaluations. The interval between the CT examination and surgery ranged from 1 to 59 days, with the median interval being 11 days. Three patients received chemotherapy, and three received steroid therapy before surgery. Two of them were evaluated after the treatment.

CT scanning parameters

All CT studies were performed with a 64-detector row dual source scanner (Somatom Definition, Siemens Medical System, Erlangen, Germany). Chest CT scanning with or without the administration of contrast medium was performed in the craniocaudal direction during inspiratory breath-holding. In all cases, a scan without any contrast medium was performed first and then 100 mL of contrast medium (300 mgI/mL in 38 cases and 320 mgI/mL in 2 cases) were injected at a rate of 2 mL/s into the antecubital vein. In the latter 18 of the 40 cases, 50 mL of saline were simultaneously injected into the antecubital vein at a rate of 1 mL/sec using a dual injector. The CT data were acquired after a scan delay of 30 s without ECG gating and after a scan delay of 100 s with ECG gating. In our institution, the scan delay of 30 s was used mainly for evaluating the enhancement pattern and vascularity of mediastinal tumors and for detecting lymphadenopathy. The scan parameters for the non-ECG-gated and ECG-gated CT scans were as follows: non-ECG-gated CT: single source mode, reference mAs: 215, tube voltage: 120 kVp, collimation: 64×0.6 mm, rotation speed: 0.33 s/rotation, and pitch: 1; ECG-gated CT: dual source mode, reference mAs: 320/rotation, tube voltage: 120 kVp, collimation: 64×0.6 mm, rotation speed: 0.33 s/rotation, and pitch: variable depending on the patient's heart rate. Axial images were reconstructed using 3-mm-thick gapless slices and B35f, a smooth kernel for the mediastinum. A retrospective ECG-gating method was used for the ECG-gated CT, and the cardiac phase that showed the fewest motion artifacts was selected for the mediastinal tumor evaluations. In the retrospective ECG-gating method, continuous CT images and ECG data are simultaneously obtained, and then, the images for a particular cardiac phase are retrospectively reconstructed from the obtained data.

Image analysis

CT images with or without ECG gating were randomly displayed on the diagnostic-grade liquid crystal display monitor of a PACS viewer (Centricity PACS RA1000 Workstation, GE Healthcare, Barrington, IL, USA). The window width and level were adjusted as appropriate for each case.

Two radiologists independently interpreted the images without being conscious of whether they were ECG-gated. The images were used to assess whether each tumor had invaded the mediastinal fat, pericardium, superior vena cava (SVC), brachiocephalic veins, aorta, or lungs. The radiologists were blinded with regard to the tumors' pathological and surgical findings during the image interpretation. If a tumor was not located adjacent to a particular structure, we did not evaluate its invasion into that structure. We assessed the invasiveness of the tumors using the following criteria. 1) Invasion into the surrounding mediastinal fat: the contours of the mediastinal tumor were irregular and protruded into the mediastinal fat tissue; 2) pericardial invasion: the border between the tumor and pericardium was irregular. Pericardial effusion *per se* was not regarded as a finding of pericardial invasion or dissemination, but it was used as a reference finding; 3) invasion into the SVC and/or brachiocephalic veins: the border between the tumor and those veins was irregular or protruded into those veins; 4) invasion into the aorta and/or pulmonary artery: the border between the tumor and the aorta/pulmonary artery was irregular or the tumor had altered the shape of the vessel; 5) invasion into the lungs: the border between the tumor and the lungs was irregular, although contours exhibiting fine coarse lobulation were not considered to represent invasion.

The two radiologists also graded the degree of motion artifacts at each structure (mediastinal fat, pericardium, SVC, brachiocephalic veins, aorta, and lungs) using the following

3-grade scale: none, no motion artifacts were detected: slight, motion artifacts that slightly influenced the diagnostic process were detected; and marked, motion artifacts that markedly influenced the diagnostic process were detected.

The final assessments of tumor invasiveness and motion artifact grades were reached by consensus. We then compared the results with the surgical and pathological findings as a reference standard and calculated the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of the two techniques. Accuracy was defined as follows: (true positive + true negative cases)/(true positive + false positive + true negative + false negative cases). We also evaluated whether ECG-gated CT changed Masaoka stage or not.

Radiation dose

The dose-length product (DLP) of the non-ECG gated and ECG-gated CT was recorded. Radiation from the preliminary localization CT radiographs and CT scan without contrast media administration was not included.

Statistical analysis

Interclass correlation coefficients (ICC) were used for the inter-rater reliability of two radiologists. Fisher's exact test was used to compare the PPV and NPV of the two techniques, and the McNemar test was used for comparing the sensitivity, specificity, and accuracy of the two techniques. The Wilcoxon signed rank test was used to compare the degree of motion artifacts between the two types of CT images. Evaluation of ICC was as follows: slight, 0.0–0.20; fair, 0.21–0.40; moderate, 0.41–0.60; substantial, 0.61–0.80; and almost perfect, 0.81–1.00. *P* values of less than 0.05 were considered to indicate significant differences. The paired t-test was used to compare radiation doses between the two types of CT examinations.

Results

ICC and 95% confidence intervals (CI) for invasiveness were 0.62 (0.52–0.71) and 0.80 (0.74–0.85) in non-ECG-gated and ECG-gated CT, respectively. ICC and 95% CI for motion artifact were 0.54 (0.43–0.63) and 0.35 (0.23–0.47) in non-ECG-gated and ECG-gated CT, respectively.

Invasion into the mediastinal fat, pericardium, SVC and brachiocephalic veins, aorta and pulmonary artery, and lungs were evaluated for 40, 39, 23, 38, and 39 tumors, respectively.

The sensitivity, specificity, PPV, NPV, and overall accuracy of non-ECG-gated and ECG-gated CT for assessing the invasion of mediastinal tumors into the surrounding structures are shown in Table 1. The differences between the sensitivity, specificity, PPV, and NPV of non-ECG gated and ECG-gated CT were not significant. ECG-gated CT was significantly more accurate at assessing pericardial invasion than non-ECG-gated CT ($p=0.03$, Figure 1), but the accuracy values of the two techniques for assessing invasion did not differ significantly at any other site.

ECG-gated CT changed Masaoka stage in 12 of the 40 cases. Eight of those 12 cases were correctly staged, and the other 4 cases were understaged by ECG-gated CT.

The extent of the motion artifacts observed at the examined structures (mediastinal fat, pericardium, SVC and brachiocephalic veins, aorta, and lung) is shown in Table 2. The motion artifacts seen on ECG-gated CT were significantly less severe compared with those observed on non-ECG-gated CT for all structures ($p<0.0001$ for the mediastinal fat, pericardium, SVC, brachiocephalic veins, and aorta, and $p=0.0089$ for the lungs; Figure 2). Generally, the degree of motion artifacts on ECG-gated CT was significantly lower than that on non-ECG-gated CT when the results of the two observers were independently evaluated (for both radiologists, $p<0.0001$).

The mean ± standard deviation of DLP was 367.6±75.9 mGy cm in the non-ECG-gated CT, and 1797.3±558.5 mGy cm in the ECG-gated CT. The DLP of the ECG-gated CT was higher than that of the non-ECG-gated CT (paired t-test, $p<0.001$).

Discussion

Our results showed that the ability of ECG-gated CT to determine whether a thymic epithelial tumor had invaded the surrounding structures tended to be higher than that of non-ECG-gated CT, and the abilities of the two techniques to detect pericardial invasion differed significantly. ECG-gated CT significantly reduced the pulsating motion artifacts caused by cardiac movement, which affected their ability to assess the invasiveness of thymic epithelial tumors. Thus, ECG-gated CT makes it easier for radiologists to determine whether thymic epithelial tumors have invaded the surrounding organs.

To the best of our knowledge, the usefulness of ECG-gated CT for evaluating mediastinal tumors has not been assessed in previous studies, although there are some reports about the application of the ECG-gating technique to the chest region [7–11]. Cardiac motion artifacts can cause blurring or doubling of the aorta, pulmonary parenchyma, bronchi, and/or blood vessels, particularly in the vicinity of the heart. Such artifacts sometimes mimic aortic dissection, bronchiectasis, and pulmonary emboli [7]. ECG gating is useful for solving these problems because it improves image quality by reducing the severity of cardiac motion artifacts. Nevertheless, previous studies examining the utility of ECG-gated CT for assessing thoracic diseases did not detect significant differences in its diagnostic ability to assess lung diseases [7,9,10]. However, our objective was the accurate assessment of the invasiveness of thymic epithelial tumors. Ideally, the borders between tumors and the surrounding structures should be clear, as this facilitates accurate preoperative diagnosis. Developments in CT have led to high temporal resolutions and reductions in the severity of cardiac motion artifacts, even without ECG-gated scanning. A previous study showed that the cardiac motion artifacts produced by a 64-row MDCT scanner with a 400-ms gantry rotation time were significantly less severe than those produced by an 8-row MDCT scanner, and motion artifacts did not hinder the diagnosis of diffuse

Table 1. Accuracy of the techniques for assessing tumor invasion into adjacent structures.

	n	Sensitivity	Specificity	PPV	NPV	Accuracy
Mediastinal fat	40					
Non-ECG-gated		96	67	83	91	85
ECG-gated		96	87	92	93	93
Pericardium	39					
Non-ECG-gated		43	88	43	88	79
ECG-gated		86	97	86	97	95
SVC and BV	23					
Non-ECG-gated		67	88	67	88	83
ECG-gated		67	100	100	89	91
Aorta and PA	38					
Non-ECG-gated		–	100	–	100	100
ECG-gated		–	100	–	100	100
Lungs	39					
Non-ECG-gated		78	80	54	92	79
ECG-gated		78	97	88	94	92

Figures are shown as percentages. BV – brachiocephalic vein; SVC – superior vena cava; PA – pulmonary artery; PPV – positive predictive value; NPV – negative predictive value.

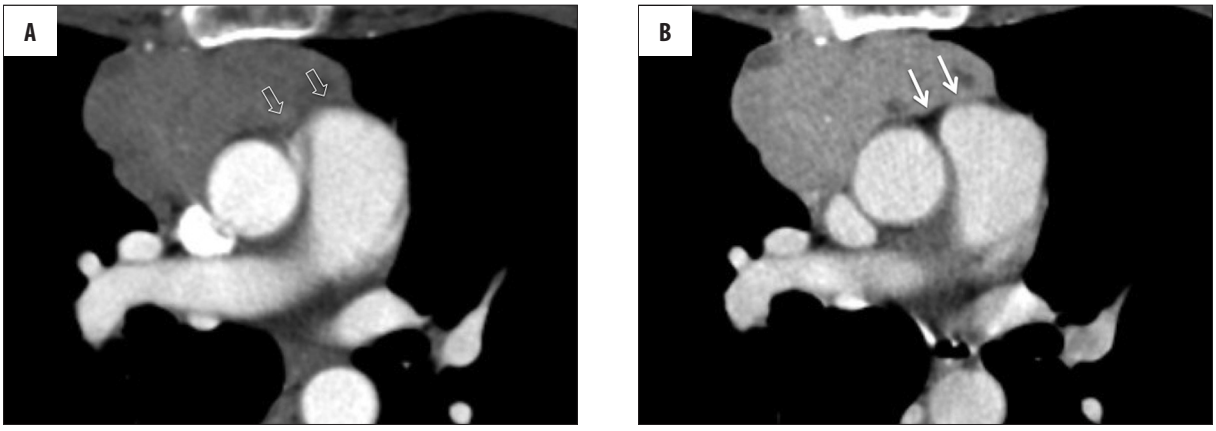

Figure 1. Non-ECG-gated (**A**) CT and ECG-gated (**B**) CT of a 53-year-old woman with thymoma. Her Masaoka stage was I. On non-ECG-gated and ECG-gated CT, the degree of motion artifacts was judged as fair and good, respectively. The border between the tumor and pericardium on non-ECG-gated CT was not clear (open arrow) because of motion artifacts, while that on ECG-gated CT was clear (arrow). Blurring border at the pericardium mimicked irregular tumor contour on non-ECG-gated CT. Pericardial invasion was considered to be present on non-ECG-gated CT and absent on ECG-gated CT. Surgical and pathological assessments did not detect any pericardial invasion; i.e., ECG-gated CT allowed a correct assessment to be made.

lung disease using non-ECG-gated 64-row MDCT [13]. Performing CT with a temporal resolution of about 250 ms can produce motion-free images in patients with heart rates of up to 70 beats/minute (bpm) during diastole, whereas a temporal resolution of 150 ms is required to achieve motion-free images in patients with heart rates of up to 100 bpm [7,14]. For imaging of a systolic cardiac phase, 50 ms is required [14]. However, performing non-ECG-gated CT with a rotation time of 330 ms is not necessarily adequate for assessing mediastinal tumor invasion.

Even though recent developments in CT technology have improved its temporal resolution, cardiac motion artifacts can still affect assessments of the invasiveness of thymic epithelial tumors. Accurate preoperative evaluations help surgeons to devise appropriate surgical strategies, e.g., to decide whether to perform extended thymothymectomy via video-assisted thoracic surgery or a median sternotomy, or whether preoperative chemotherapy should be employed [15]. Precise evaluations of invasiveness also aid prognosis prediction because organ invasion leads to a poor prognosis [16–19]. According to the Masaoka staging system, which is based on

Table 2. Degree of motion artifacts.

	Degree of motion artifacts			*p*
	None	Slight	Marked	
Mediastinal fat				
Non-ECG-gated	11	23	6	
ECG-gated	35	5	0	<0.0001
Pericardium				
Non-ECG-gated	2	25	13	
ECG-gated	27	13	0	<0.0001
SVC and BV				
Non-ECG-gated	19	21	0	
ECG-gated	37	3	0	<0.0001
Aorta				
Non-ECG-gated	1	16	23	
ECG-gated	21	19	0	<0.0001
Lungs				
Non-ECG-gated	20	15	5	
ECG-gated	30	10	0	0.0089

BV – brachiocephalic vein; SVC – superior vena cava.

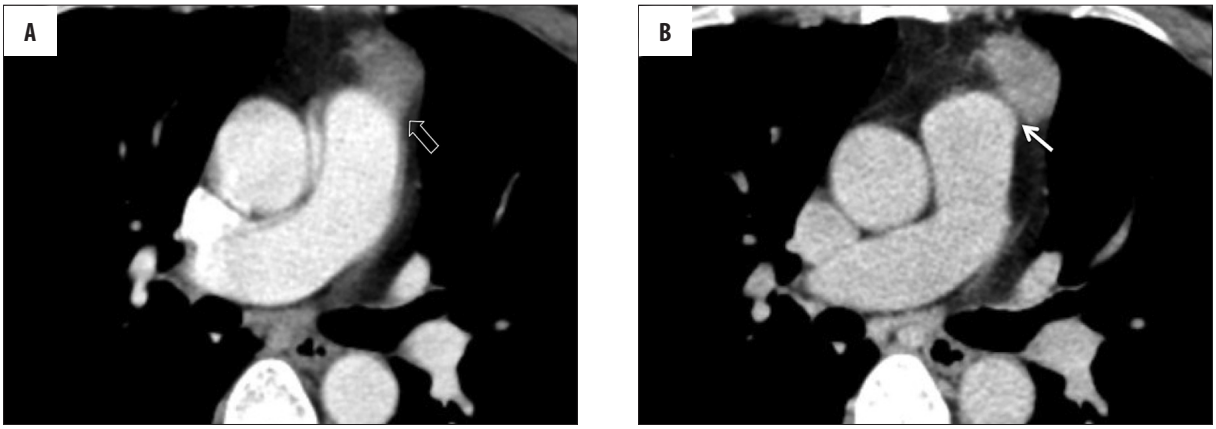

Figure 2. Non-ECG-gated (**A**) CT and ECG-gated (**B**) CT of a 78-year-old woman with thymoma, which had invaded the mediastinal fat and lungs and exhibited pleural dissemination. Her Masaoka stage was IVa. On non-ECG-gated and ECG-gated CT, the degree of motion artifacts was poor and good, respectively. The border between the tumor and pulmonary artery on non-ECG-gated CT was not clear (open arrow) because of motion artifacts, while that on ECG-gated CT was clear (arrow) and ECG-gated CT depicted the linear fat tissue between the tumor and pulmonary artery. Pulmonary artery invasion was judged to be absent on both types of CT. Surgical and pathological assessments did not reveal any invasion into the pulmonary artery; i.e., both techniques allowed correct assessments to be made. However, it was easier to diagnose invasion on ECG-gated CT than non-ECG-gated CT.

invasion into the surrounding organs, invasive thymomas are associated with low survival rates. In Masaoka stage III thymomas, lung invasion can cause pleural recurrence, and vascular invasion can cause distant metastasis [19].

Our study had the following limitations. First, the study was retrospective, and the patients' heart rates were not recorded during the CT scans. So, the relationship between motion artifact severity and patient heart rate was not evaluated. However, a dual-source CT scanner with a high temporal resolution of 83 ms was used for this study so our results should not be affected by variations in the patients' heart rates. Second, the scan delay differed between the non-ECG-gated CT and ECG-gated CT protocols (30 and 100 s, respectively) so the contrast enhancement of the tumors would also have varied. However, it is difficult to compare non-ECG-gated

and gated CT using a similar scan delay in the same patient, unless the contrast material is injected twice. We adjusted the window level and width for each case for the most accurate diagnosis of invasion and this method also reduced the influence of different scan delay times.

Conclusions

ECG-gated CT exhibited less severe motion artifacts and improved diagnostic accuracy compared with non-ECG-gated CT. ECG-gated CT might be useful for preoperative assessments of the invasiveness of thymic epithelial tumors.

Conflict of interest

The authors declare that they have no conflict of interest.

References:

1. Falkson CB, Bezjak A, Darling G et al., Lung Cancer Disease Site Group of Cancer Care Ontario's Program in Evidence-Based Care: The management of thymoma: A systematic review and practice guideline. J Thorac Oncol, 2009; 4: 911–19
2. Venuta F, Anile M, Diso D et al: Thymoma and thymic carcinoma. Eur J Cardiothoracic Surg, 2010; 37: 13–25
3. Detterbeck FC, Parsons AM: Thymic tumors. Ann Thorac Surg, 2004; 77: 1860–69
4. Sugie C, Shibamoto Y, Ikeya-Hashizume C et al: Invasive thymoma: Postoperative mediastinal irradiation, and low-dose entire hemithorax irradiation in patients with pleuraldissemination. J Thorac Oncol, 2008; 3: 75–81
5. Qu YJ, Liu GB, Shi HS et al: Preoperative CT findings of thymoma are correlated with postoperative Masaoka clinical stage. Acad Radiol, 2013; 20: 66–72
6. Marom EM: Advances in thymoma imaging. J Thorac Imaging, 2013; 28: 69–83
7. Marten K, Funke M, Rummeny EJ, Engelke C: Electrocardiographic assistance in multidetector CT of thoracic disorders. Clin Radiol, 2005; 60: 8–21
8. Roos JE, Willmann JK, Weishaupt D et al: Thoracic aorta: motion artifact reduction with retrospective and prospective electrocardiography-assisted multi-detector row CT. Radiology, 2002; 222: 271–77
9. Schoepf UJ, Becker CR, Bruening RD et al: Electrocardiographically gated thin-section CT of the lung. Radiology, 1999; 212: 649–54
10. Boehm T, Willmann JK, Hilfiker PR et al: Thin-section CT of the lung: Does electrocardiographic triggering influence diagnosis? Radiology, 2003; 229: 483–91
11. Shuman WP, Leipsic JA, Busey JM et al: Prospectively ECG gated CT pulmonary angiography versus helical ungated CT pulmonary angiography: Impact on cardiac related motion artifacts and patient radiation dose. Eur J Radiol, 2012; 81: 2444–49
12. Masaoka A, Monden Y, Nakahara K, Tanioka T: Follow-up study of thymomas with special reference to their clinical stages. Cancer, 1981; 48: 2485–22
13. Yanagawa M, Tomiyama N, Sumikawa H et al: Thin-section CT of lung without ECG gating: 64-detector row CT can markedly reduce cardiac motion artifact which can simulate lung lesions. Eur J Radiol, 2009; 69: 102–7
14. Desjardins B, Kazerooni EA: ECG-gated cardiac CT. Am J Roentgenol, 2004; 182: 993–1010
15. Lindenmann J, Fink-Neuboeck N, Pichler M et al: Stage-based treatment for thymoma in due consideration of thymectomy: A single-center experience and comparison with the literature. World J Surg Oncol, 2015; 13; 303
16. Utsumi T, Shiono H, Kadota Y et al: Postoperative radiation therapy after complete resection of thymoma has little impact on survival. Cancer, 2009; 115: 5413–20
17. Okumura M, Miyoshi S, Takeuchi Y et al: Results of surgical treatment of thymomas with special reference to the involved organs. J Thorac Cardiovasc Surg, 1999; 117: 605–13
18. Okumura M, Ohta M, Tateyama H et al: The World Health Organization histologic classification system reflects the oncologic behavior of thymoma: A clinical study of 273 patients. Caner, 2002; 94: 624–32
19. Utsumi T, Shiono H, Matsumura A et al: Stage III thymoma: Relationship of local invasion to recurrence. J Thorac Cardiovasc Surg, 2008; 136: 1481–85