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

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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

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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 25–67 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), 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.

EGC-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±588.5 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<0.0001).

**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.
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 devise appropriate surgical strategies, e.g., to decide whether to perform extended thymectomy 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

| Structure          | Sensitivity | Specificity | PPV  | NPV  | Accuracy |
|--------------------|-------------|-------------|------|------|----------|
| Mediastinal fat    | 96          | 67          | 83   | 91   | 85       |
| Non-ECG-gated      | 96          | 87          | 92   | 93   | 93       |
| ECG-gated          | 86          | 97          | 92   | 89   | 91       |
| Pericardium        | 43          | 88          | 43   | 88   | 79       |
| Non-ECG-gated      | 86          | 97          | 86   | 97   | 95       |
| ECG-gated          | 67          | 100         | 100  | 89   | 91       |
| SVC and BV         | 67          | 88          | 67   | 88   | 83       |
| Non-ECG-gated      | 86          | 100         | 100  | 89   | 91       |
| ECG-gated          | 67          | 100         | 89   | 91   | 91       |
| Aorta and PA       | 78          | 80          | 54   | 92   | 79       |
| Non-ECG-gated      | 78          | 97          | 88   | 94   | 92       |
| 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.
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

|                     | 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.
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.

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