

# Improving Quality of Chest Computed Tomography for Evaluation of Pediatric Malignancies

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## Abstract

**Introduction:** Atelectasis is a problem in sedated pediatric patients undergoing cross-sectional imaging, impairing the ability to accurately interpret chest computed tomography (CT) imaging for the presence of malignancy, often leading to additional maneuvers and/or repeat imaging with additional radiation exposure. **Methods:** A quality improvement team established a best-practice protocol to improve the quality of thoracic CT imaging in young patients with suspected primary or metastatic pulmonary malignancy. The specific aim was to increase the percentage of chest CT scans obtained for the evaluation of pulmonary nodules with acceptable atelectasis scores (0–1) in patients aged 0–5 years with malignancy, from a baseline of 45% to a goal of 75%. **Results:** A retrospective cohort consisted of 94 patients undergoing chest CT between February 2014 and January 2015 before protocol implementation. The prospective cohort included 195 patients imaged between February 2015 and April 2018. The baseline percentage of CT scans that were scored 0 or 1 on the atelectasis scale was 44.7%, which improved to 75% with protocol implementation. The mean atelectasis score improved from 1.79 ( $\pm 0.14$ ) to 0.7 ( $\pm 0.09$ ). Sedation incidence decreased substantially from 73.2% to 26.5% during the study period. **Conclusions:** Using quality improvement methodology including standardization of care, the percentage of children with atelectasis scores of 0–1 undergoing cross-sectional thoracic imaging improved from 45% to 75%. Also, eliminating the need for sedation in these patients has further improved image quality, potentially allowing for optimal detection of smaller nodules, and minimizing morbidity. (*Pediatr Qual Saf* 2019; 3:e166; doi: 10.1097/pq9.000000000000166; Published online June 13, 2019.)

## INTRODUCTION

Evaluation of pulmonary metastases in pediatric patients with malignancy frequently requires computed tomography (CT)

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To cite: Mansfield SA, Dykes M, Adler B, Uffman JC, Sales S, Ranalli M, Kenney BD, Aldrink JH. Use of Quality Improvement Methodology to Improve the Quality of Chest Computed Tomography for Evaluation of Pediatric Malignancies. *Pediatr Qual Saf* 2019; 3:e166.

Received for publication October 8, 2018; Accepted March 13, 2019.

Published online June 13, 2019.

DOI: 10.1097/pq9.000000000000166



imaging of the chest. In young or uncooperative children, obtaining high-quality imaging to detect very small lesions poses a unique challenge. Although pulmonary atelectasis is a known secondary effect, sedation or general anesthesia is frequently required in these children to facilitate compliance and limit motion artifact.<sup>1–3</sup> Obscured pulmonary parenchyma due to atelectasis reduces the ability to interpret chest imaging for the presence of metastases accurately. Underinflated lung segments may necessitate additional maneuvers such as prone positioning to expand atelectatic lung and/or repeated scanning. Consequently, repositioning of the patient may risk endotracheal tube or laryngeal mask dislodgement, and additional scans increase radiation exposure.

Pulmonary atelectasis in children sedated for thoracic imaging is more frequent and more severe under general anesthesia than in children receiving oral or intravenous (IV) sedation.<sup>1,3–5</sup> Previous studies have evaluated recruitment maneuvers, ventilator settings, and positive pressure masking techniques effect on atelectasis scores on chest CT scans.<sup>2,5–8</sup> The purpose of this study was to develop an institutional evidence-based standard practice protocol to improve the quality of cross-sectional chest imaging obtained for the evaluation of malignancy and metastatic disease in patients who historically required anesthesia for optimal radiological examination. Using quality improvement (QI) methodology, the primary aim

was to increase the percentage of high-quality chest CT scans (atelectasis score 0–1) obtained for the evaluation of pulmonary nodules in patients age 0–5 years with a malignancy, from 45% to 75%, and to sustain this improvement for at least 12 months. The secondary aim was to increase the number of CT scans performed without sedation.

## METHODS

### Context

A QI initiative was developed at the authors' free-standing children's hospital for patients aged 0–5 years with a known or suspected malignancy undergoing initial staging or follow-up chest CT for the evaluation of pulmonary metastases. A QI team was established in 2015 and consisted of members from pediatric surgery, radiology, anesthesiology, pediatric oncology, and QI. We utilized the Institute for Healthcare Improvement model for QI for this study.<sup>9</sup>

### Inclusions and Exclusions

We included all patients between the ages of 0 and 5 years with a known or suspected diagnosis of malignancy which required cross-sectional imaging of the lungs to evaluate for metastatic disease from February 2015 to April 2018 in the prospective cohort. We obtained baseline data retrospectively and consisted of children meeting inclusion criteria who underwent imaging at our institution the year before initiation of the study between February 2014 and January 2015. We considered each cross-sectional scan as an independent event. We excluded patients without a diagnosis of malignancy or older than age 5 years.

### Atelectasis Scoring

The atelectasis scoring system described by Newman et al<sup>2</sup> and similar to other studies<sup>3,10</sup> was used to apply an atelectasis score for each chest CT scan in this study based upon the degree of pulmonary opacification (published Fleiss and Cohen weighted kappa coefficient was 0.92). These scores are illustrated by Figure 1, and include: grade 0 = no atelectasis, grade 1 = minimal atelectasis, grade 2 = small segmental atelectasis, grade 3 = segmental atelectasis, grade 4 = lobar or multisegmental atelectasis, and grade 5 = whole lung collapse. Chest CT scans for the retrospective cohort were assigned scores after review by a single pediatric radiologist (B.A.). In the prospective cohort, imaging was reviewed in real time by 11 pediatric radiologists with specialization in cross-sectional thoracic imaging trained to employ the scoring system.

### Key Driver Interventions

A key driver diagram was developed to identify targets for interventions (Fig. 2). The overall strategic aim was to increase the percentage of chest CT scans obtained for the evaluation of pulmonary metastases with atelectasis

scoring grades of 0–1 in patients age 0–5 years from a baseline of 45%–75% and to sustain this for 12 months. Interventions included: (1) implementation of routine atelectasis scoring by the interpreting radiologist; (2) immediate radiologist review of imaging for quality purposes; (3) preprocedural determination of whether sedation with an airway is required, and if so to perform general anesthetic according to a standardized protocol; (4) involvement of child life services to provide distraction and relaxation techniques to improve patient cooperation; and (5) improving communication between the CT technician performing the scan and the anesthesia team related to the timing of scanning.

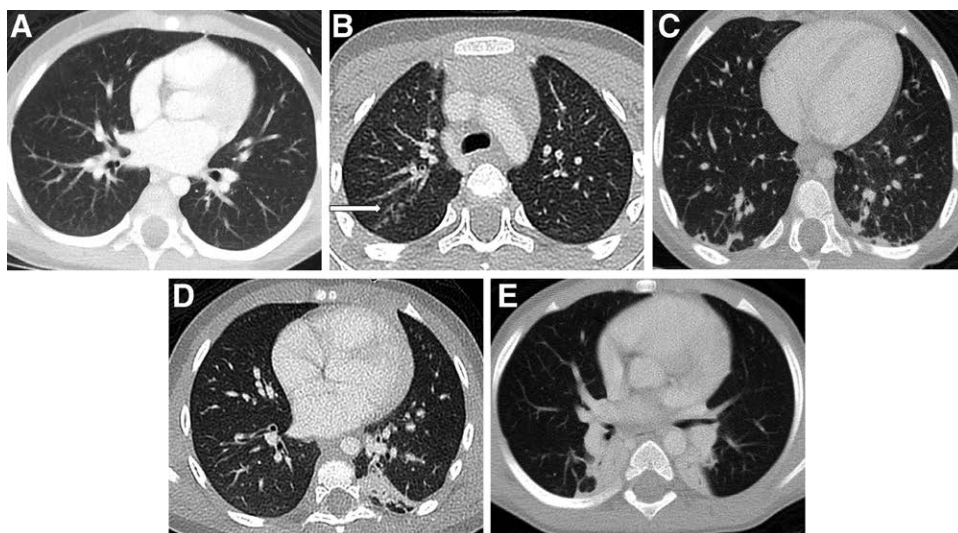
### Standardized Anesthesia Chest CT Protocol

To minimize anesthesia-induced atelectasis, we developed a standardized anesthetic management protocol. All patients that would have met inclusion criteria the 12 months before the protocol underwent imaging review for atelectasis scoring and chart review of the anesthesia technique, specifically including airway management. Based on this retrospective review of data and current evidenced-based practices in the literature and other pediatric hospitals, we established a formal protocol for all sedated cross-sectional CT imaging procedures.<sup>2,6,11</sup>

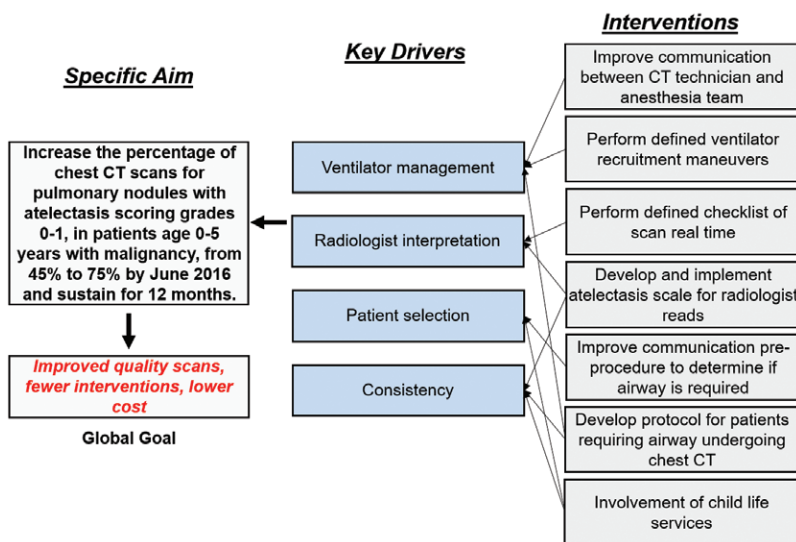
Once the protocol was established, we provided education and installed clinical decision support in the electronic medical record. Specifically, for all cases scheduled as “chest CT,” an electronic medical record alert populates the screen as part of the case initiation sequence. This alert serves 2 purposes: (1) to serve as a reminder for protocol initiation and (2) included protocol elements.

The anesthesia chest CT protocol incorporated the following maneuvers:

1. Determination of appropriate use of IV or inhalational induction.
2. Early bag-valve-mask ventilation is employing peak inspiratory pressures of 24–26 cm H<sub>2</sub>O to generate tidal volumes of 10–12 mL/kg.
3. Expeditious placement of a peripheral IV (if not present) and endotracheal intubation.
4. Immediate controlled ventilation following intubation using inspiratory pressures needed to generate 10–12 mL/kg (up to 30 cm H<sub>2</sub>O), peak end-expiratory pressure of 8 cm H<sub>2</sub>O, and an inspiratory time 1.2 s to minimize atelectasis.
5. The rapid decrease of FiO<sub>2</sub> to 30% as clinically tolerated.
6. Immediately before formal inspiratory scan (CT technician to notify appropriate timing), provide 3 recruitment breaths.
7. Recruitment breath: hold each breath for 15–20 s at 30 cm H<sub>2</sub>O. For the inspiratory scan, provide inspiratory breath hold at 30 cm H<sub>2</sub>O.



**Fig. 1.** Computed tomography of the chest. A, Atelectasis grade 0. No linear or nodular densities that could be confused for lung metastasis. B, Atelectasis grade 1. Small nodular densities that might be confused with metastasis. Please see the right upper lobe posteriorly (arrow). C, Atelectasis grade 2. Subsegmental atelectasis with linear atelectasis present in the posterior aspects of both lungs. D, Atelectasis grade 3. Larger segmental collapse as shown in the left lower lobe medially. E, Atelectasis grade 4. Lobar or multisegmental obscuring large regions of one or both lungs.



**Fig. 2.** Key driver diagram. The key driver diagram summarizes specific interventions targeting the specific aim of improving the quality of chest CT imaging in children undergoing evaluation for possible pulmonary metastatic disease.

**Image Capture Techniques**

Before 2014, a 16-detector row CT scanner with 4cm of coverage and the traditional helical scan were utilized to capture images. In 2014, we imaged patients using a 320-detector row volume CT (Aquilion ONE, Toshiba Medical Systems, Nasu, Japan). This protocol allowed the advantage of 16-cm scanner coverage and reduction in exposure time to approximately 0.3 s. By subsequently incorporating an electrocardiogram-gated target mode, both motion and radiation dose were able to be further minimized. Multiple authors have described this technique, and the use of iterative reconstruction techniques

to reduce noise within the images.<sup>12-15</sup> We reconstructed images in the axial plane at 2.5- and 1-mm contiguous images, and in the coronal plane at 2.5- and 5-mm-thick maximum intensity projection images. We evaluated images for quality before completion of the study, and repeat imaging rarely performed as required.

**Data Analysis**

Results were tracked over time using statistical process control methodology with control charts (P charts and XBar-S chart) per established QI practices.<sup>16,17</sup> Primary and secondary outcome measure data were collected and evaluated



every month. P charts were used to display the percentage of CT image scores 0 or 1 (primary outcome measure), CT sedation rates, and compliance rates with anesthesia chest CT protocol. An XBar-S chart was used to display chest CT average image quality score. We conducted statistical analysis to verify the special cause variation between baselines and process stages for the outcome and balancing measure data after four years of prospective data collection (32 mo for CT sedation and compliance rates). Categorical variables were analyzed using unpaired *t* test.

**Ethical Issues**

This QI project involved implementing evidence-based interventions or best practices designed to improve the quality of chest CTs in children. Interventions did not involve multiple device comparisons or therapies, and patients were not subjected to randomization. QI and epidemiology staff members accessed medical records as part of their normal responsibilities. This QI initiative was not human subjects research. Therefore, Institutional Review Board approval was not required.

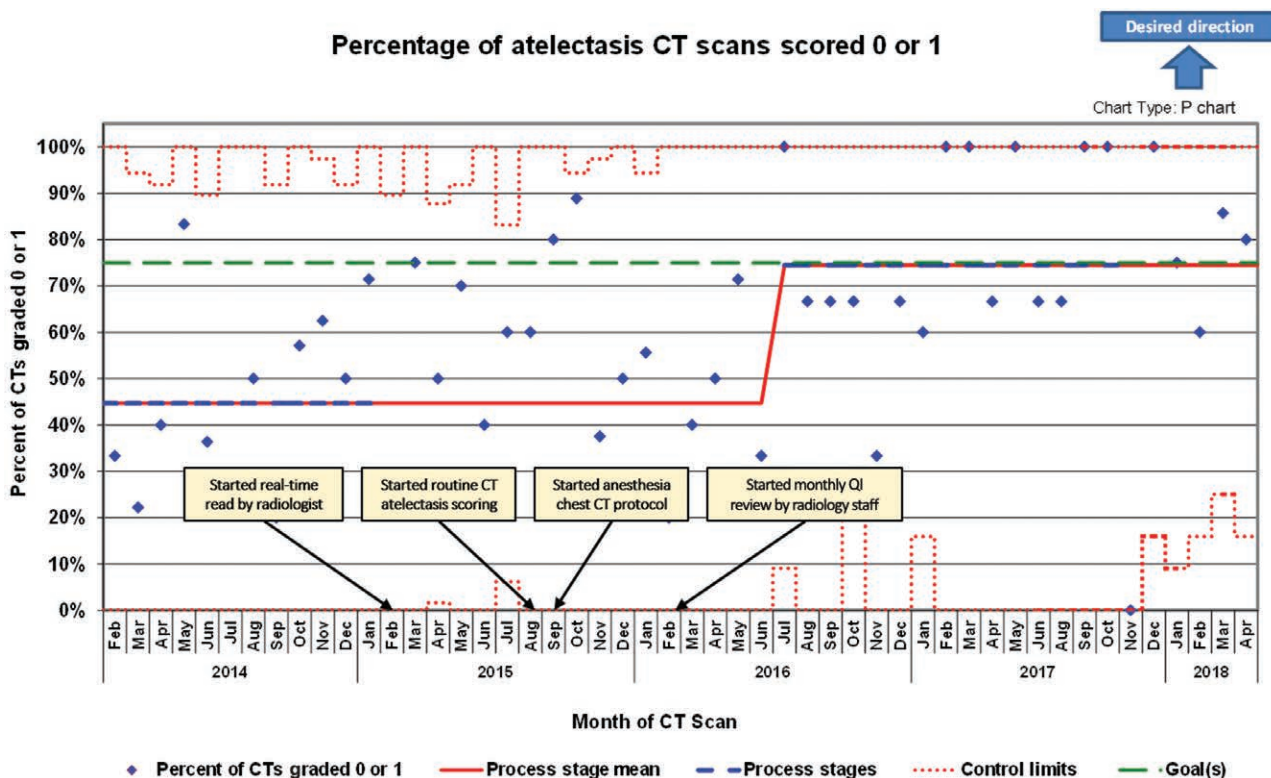
**RESULTS**

Retrospective baseline data identified 94 patient events meeting inclusion criteria between February 2014 and January 2015. After protocol implementation, we prospectively identified 195 patient events between February

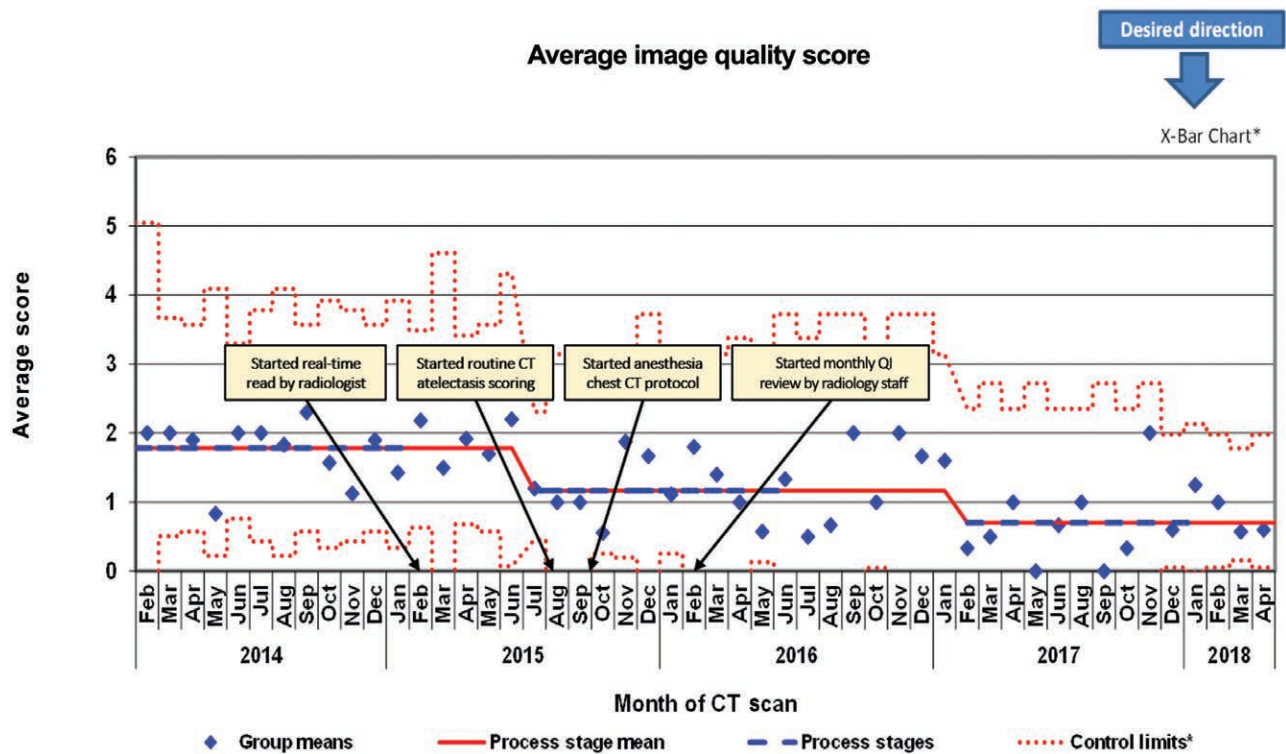
2015 and April 2018. There was no difference in average age between the retrospective cohort ( $2.1 \pm 1.1$  y) and the prospective cohort ( $2.9 \pm 1.3$  y,  $P = 0.26$ ). Primary tumors for children in the retrospective cohort included adrenal ( $n = 61$ , 64.9%), kidney ( $n = 22$ , 23.4%), liver ( $n = 7$ , 7.4%), and bone ( $n = 4$ , 4.3%). In the prospective cohort, tumor origin was: kidney ( $n = 75$ , 38.5%), adrenal ( $n = 73$ , 37.4%), bone ( $n = 38$ , 19.5%), and liver ( $n = 9$ , 4.6%). Patients in the 1-year baseline cohort had an average number of 2.7 scans per patient (range 1–6) compared with 3.1 (range 1–11) in the prospective cohort that included 3 years of scan data ( $P = 0.57$ ).

During this study, statistical analysis revealed correlating baseline shifts in all tracked data metrics. We noted a significant baseline shift in July 2016 for the main outcome measure, the mean percentage of CT scans with atelectasis scores of 0 or 1, which improved from 44.7% to 75% following protocol implementation (Fig. 3). Statistical analysis of chest CT average image quality score revealed 2 favorable baseline shifts during the study (Fig. 4). From an initial average atelectasis score of 1.79, we found the first shift to a mean of 1.17 following implementation of radiologists real-time reads and routine atelectasis scoring of all scans. We found a second shift to a mean of 0.7 following monthly radiology QI meetings, and as sedation rates declined.

Compliance with the anesthesia protocol was initially low at 20%, but improved to 75% following education



**Fig. 3.** Trends in Atelectasis Scoring. The annotated P chart displays the percentage of CT scans with an atelectasis score of 0 or 1 over time in children undergoing chest CT for evaluation of pulmonary malignancy. The time point of protocol implementation and specific interventions are noted.



**Fig. 4.** Trends in average image quality score. The X-Bar chart displays the average image quality score over time in children undergoing chest CT for evaluation of pulmonary malignancy. \*A  $\sqrt{(b+ax)}$  transform for right skew was used to determine control limits. Control limits were then reverse transformed to reflect original data metrics.

efforts among anesthesia providers, streamlined electronic charting, and compliance results reporting at faculty meetings (Fig. 5). Importantly, we detected a significant baseline shift in the number of CT scans performed without sedation over time (Fig. 6). In the retrospective cohort, 73.5% of patients received sedation, which was a default practice pattern in our institution at the time. Following protocol implementation and with careful patient selection, only 26.5% of patients required sedation for imaging, reflecting an awareness of the issues regarding sedation leading to poorer quality of scans and additional cost and morbidity for the patient. Notably, over the most recent 18 months of the study, only 2 (5%) patients required sedation, and no patient has required sedation in the last 12 months. There were no procedure-related adverse events in any of the patients during the study.

The need for repeat scans or prone positioning was not routinely documented before study implementation. Three patients required prone positioning to optimize imaging after protocol implementation. All of these occurred soon after study implementation. No studies required prone positioning or early repeat imaging secondary to poor quality during the last 2 years of the protocol.

## DISCUSSION

The presence of a single small lung nodule in a child with a known or suspected malignancy can have significant

prognostic and therapeutic implications.<sup>18,19</sup> Unlike adults, pulmonary nodules less than 5 mm in children are equally likely to represent benign or malignant processes.<sup>20-23</sup> For this reason, high-quality cross-sectional imaging is mandatory in the surveillance of children with certain malignancies.<sup>8,24-27</sup> To obtain images with little motion artifact, very young or uncooperative children may require sedation or general anesthesia.<sup>1,28</sup> Atelectasis is a known complication and sequelae of these interventions<sup>29,30</sup> and impairs the ability to accurately interpret cross-sectional imaging for the presence of malignancy, resulting in additional maneuvers and/or repeat imaging with increased radiation exposure.<sup>31</sup>

Previous studies have attempted to identify the optimal ventilation technique to minimize atelectasis, emphasizing optimal inspiratory pressures and lung recruitment maneuvers.<sup>3,5</sup> Our protocol is similar to the Stanford model that was previously shown to improve radiographic atelectasis in children aged 2 months to 5 years.<sup>2</sup> The majority of patients in that model underwent CT imaging for cystic fibrosis or interstitial lung disease. The authors reported 70% of CTs in patients undergoing protocol-driven ventilation were rated very good to excellent quality, compared to 24% for nonprotocol studies.<sup>2</sup> However, the most effective method of reducing the risk of sedation-induced atelectasis is to avoid sedation completely. With the evolution of faster CT scanners, comforting immobilization

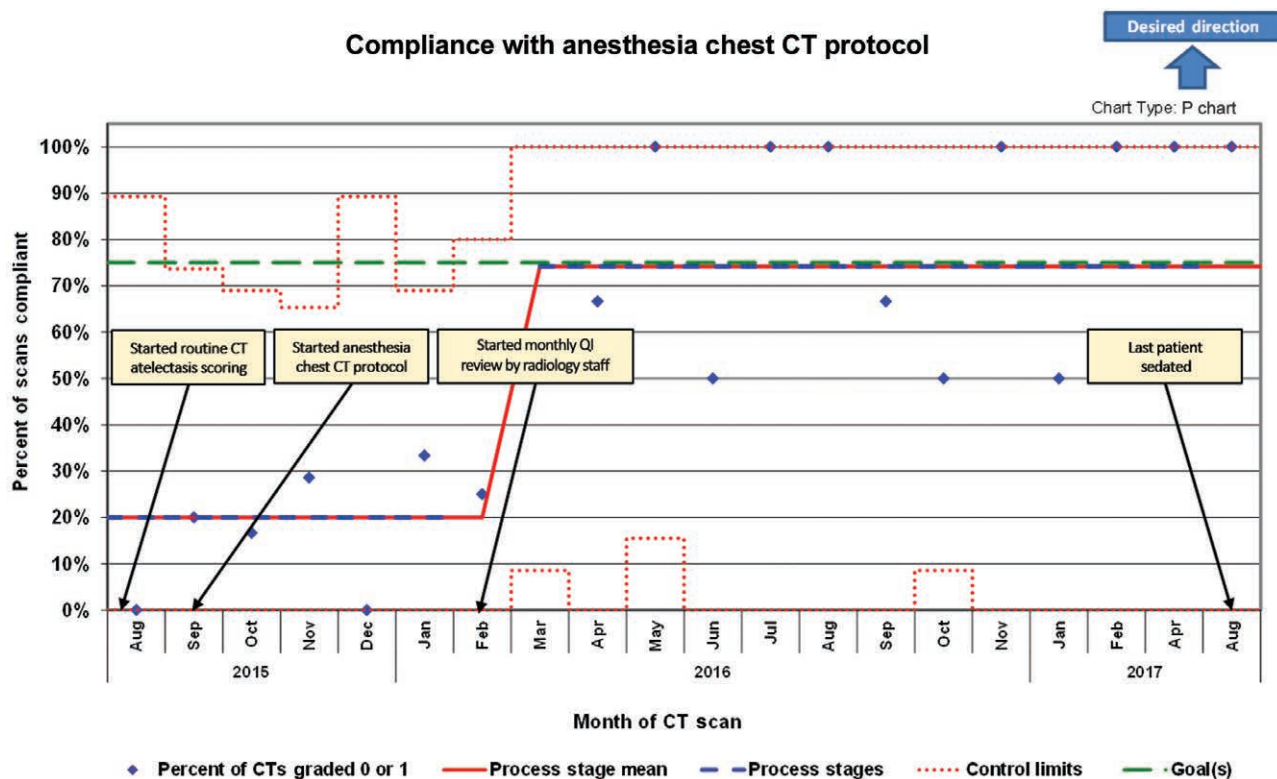
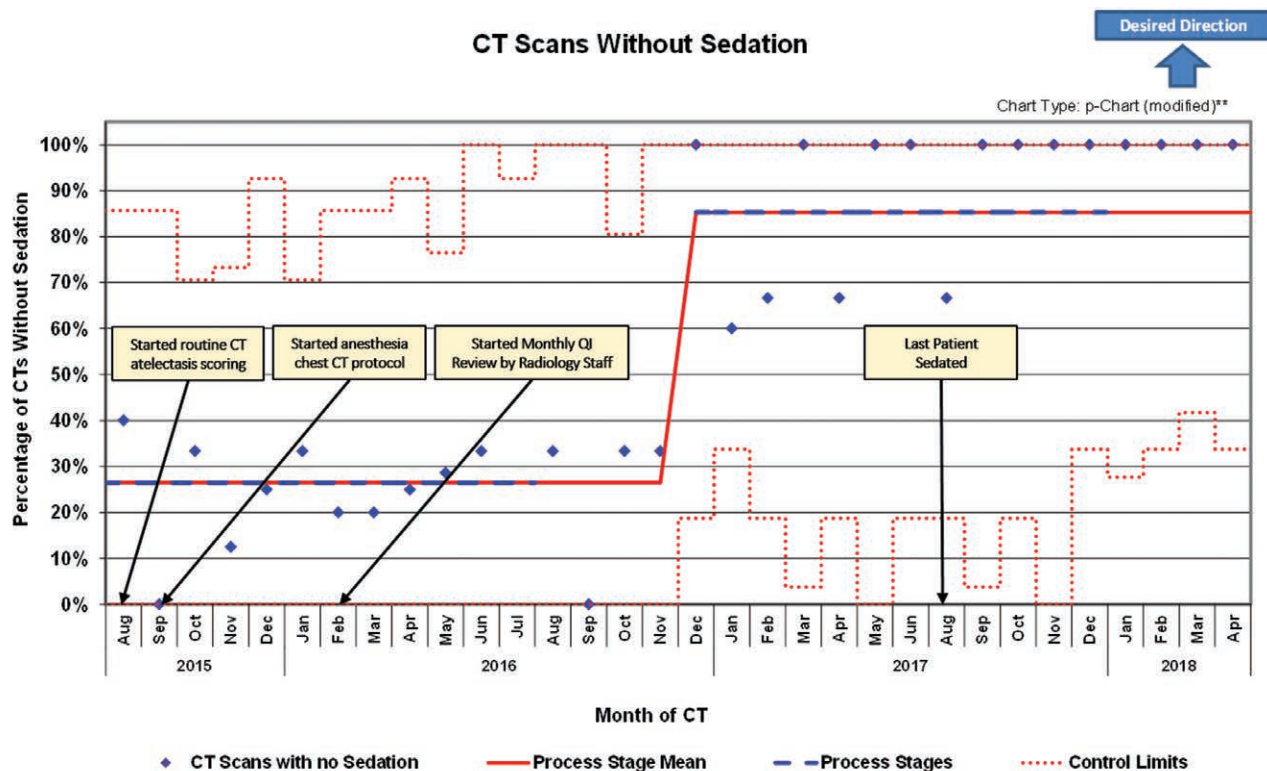


Fig. 5. Trends in compliance with the anesthesia protocol. The annotated P chart displays the percentage of CT scans obtained with compliance to the anesthesia chest CT protocol over time in children undergoing chest CT for evaluation of pulmonary malignancy.



\*\*Control Limits are wider than standard because the number of 0%'s (or 100%'s) is sufficient to skew probabilities. Standard limits would yield false special cause flags.

Fig. 6. Trends in percentage of CT scans performed without sedation. The annotated P chart displays the percentage of CTs performed without sedation over time in children undergoing chest CT for evaluation of pulmonary malignancy. \*\*Control limits are wider than standard because the number of 0%'s (or 100%'s) is sufficient to skew probabilities. Standard limits would yield false special cause flags.



devices, and child life preparation, several institutions have shown a reduced need for sedation in this young population.<sup>32–34</sup> Although the standardization of anesthesia delivery in this study did contribute positively to improved atelectasis scores, the introduction of subsecond volumetric CT imaging and a change in the default pathway to attempt initial imaging without anesthesia (anesthesia standby) produced additional improvement in these scores. As a result of this change, no patient in this study has required sedation since August 2017.

Using QI methodology, we have demonstrated a significant increase in the percentage of high-quality chest CT imaging for the evaluation of pulmonary nodules in patients age 0–5 years with malignancy, from 45% to 75%. Our protocol highlights the importance of a multidisciplinary approach to QI initiatives. Real-time radiology review and communication between the anesthesia provider and the CT technicians have improved the ability to obtain high-quality images. With the aid of faster and improved scanning technology and the involvement of child life services, the number of scans done without the need for sedation has dramatically improved without compromising image quality.

As with all QI initiatives, the relationship between evidence-based interventions and outcomes demonstrates correlation but not necessarily causation. This study does not have a control group but rather compares outcomes before and after protocol implementation. Therefore, we cannot identify whether any one or combination of interventions is causal. These and other QI initiatives do not attempt to control all variables. Rather, the effort is to improve compliance with evidence-based interventions, standardize care, and identify favorable special cause variation that is consistent with improvement in the outcome of interest. Also, power analyses are not typically performed for QI studies. Instead, specific interventions are instituted, and we track the effect over time. QI methodology aims to achieve a sustained improvement over a specified period. An intervention is interpreted to be successful if the improvement and minimization of process variability are sustained. Although randomization or obtaining scans with and without protocol would answer questions more definitively, this would also subject patients to unnecessary radiation exposure, sedation, and cost. We acknowledge that a single radiologist reviewing retrospectively limits interrater variability calculations, compared to multiple radiologists reviewing prospectively. This would be better addressed in a direct prospective comparison and was not the aim of the current study. We also noted a variety of tumor types between baseline and prospective cohorts, but are not aware of any existing data regarding the type of tumor impacting atelectasis during routine staging for pulmonary metastases. Finally, tracking full protocol compliance is challenging given numerous components, and so a certain level of protocol noncompliance is expected.

In conclusion, through the use of QI methodology and multidisciplinary collaboration, we have been able to achieve high-quality cross-sectional thoracic imaging for very young patients for the evaluation of malignancy, and have markedly decreased and recently eliminated the need for sedation or anesthesia to achieve this. Sustainability of this protocol has been demonstrated for 2 years at our institution, and can likely be generalizable to other similar pediatric hospitals. Further areas of study will include increasing the goal further to achieve 90%–100% high-quality scans in this population and expanding this protocol to imaging studies for other patient populations including patients with cystic fibrosis and those with neurologic or developmental delays. Also, monitoring compliance with all aspects of the protocol will continue to be tracked to ensure high-quality care is delivered to serve these patients best.

## DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

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