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# Computer-Aided Reporting of Chest Radiographs: Efficient and Effective Screening in the Value-Based Imaging Era

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**Abstract** In the post-PACS era, mammography is unique in adopting specialized ergonomic interfaces to improve efficiency in a high volume setting. Chest radiography is also a high volume area of radiology. The authors hypothesize that applying a novel interface for chest radiography interpretation and reporting could create high productivity while maintaining quality. A custom version of the ClearCanvas open source software, EzRad, was created with a workflow re-designed specifically for tuberculosis screening chest radiographs, which utilized standardized computer generated reports. The preliminary reports from 881,792 studies evaluated by radiology residents over a nine-year period were analyzed for productivity as RVU/FTE and compared to the finalized reports from a subspecialty attending chest radiologist for accuracy. Radiology residents were able to produce 7480 RVU/FTE per year in screening chest radiography productivity when using a custom interface at a large academic medical center with a miss rate of 0.1%. Sensitivity was 77% and specificity was 99.9%. An ergonomic user interface allowed high productivity in interpretation of chest radiography for tuberculosis screening while maintaining quality.

**Keywords** Screening chest radiograph · Computer aided reporting · Value based care · Tuberculosis · Productivity · Big data

## Introduction

In the era of value-based care, more efficient and accurate reporting can create added value by increasing quality and decreasing cost [1]. Population growth, the availability of new diagnostic techniques that improve patient care, and radiologist's own efforts to increase efficiency have resulted in yearly increases in productivity among radiologists in terms of relative value units (RVUs) [2, 3]. Still, the single greatest increase in radiologist productivity was with the advent of the electronic picture archival and communication system (PACS) [4, 5]. The advent of PACS demonstrated a 70% increase in radiologist productivity [6]. The creation of new and more efficient workflows for radiologists has the potential to dramatically increase overall efficiency.

PACS with dictation has remained the mainstay of radiologist workflow in the USA for over 20 years since the first full implementation of PACS at the Baltimore Veterans Affairs Medical Center [7]. Modern workflow updates supported by the Radiological Society of North America (RSNA), and the American College of Radiology (ACR) include standardized reporting, structured reporting, computer-aided diagnosis and more recently computer-aided reporting, and natural language

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Hypothesis: A "computer-aided reporting" mechanism, as defined by the Radiological Society of North America (RSNA), creating an efficient workflow for high volume tuberculosis (TB) screening chest radiographs can create added value through high productivity and quality.

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generation [8–10]. Despite these efforts, progressive methods of diagnostic image interpretation have predominantly only become adopted in the realm of breast imaging. There is limited data to evaluate the impact of new reporting methods on efficiency.

The key goal of Imaging 3.0 is to increase health care service quality provided by radiologists in order to increase the value provided by radiology practice [11]. This goal in part advocates for radiologists to provide additional non-interpretive services such as participating in multidisciplinary care conferences care coordination and healthcare administration. However, radiologist time is limited. Increasing efficiency of image interpretation has the potential to help radiology practices handle the increasing demand for interpretive services and free radiologist time for providing additional non-interpretive services that provide added value [12].

In this study, the implementation of custom software for computer-aided reporting of screening chest radiographs for tuberculosis (TB) was evaluated for its ability to provide efficient reporting while maintaining high quality results. It was hypothesized that the creation of custom software and workflow tailored for high volume TB screening chest radiographs could maximize the productivity of reporting without sacrificing quality.

## Methods

A custom software package, EZrad, was developed for providing a workflow tailored specifically to the interpretation and reporting of high volume chest radiographs screening for TB in a high risk population (Fig. 1). A resident was assigned to provide a complete preliminary interpretation for these studies in the evenings and overnight between the hours of 5 pm–8 am 365 days per year. Each morning, using the same custom interface, an

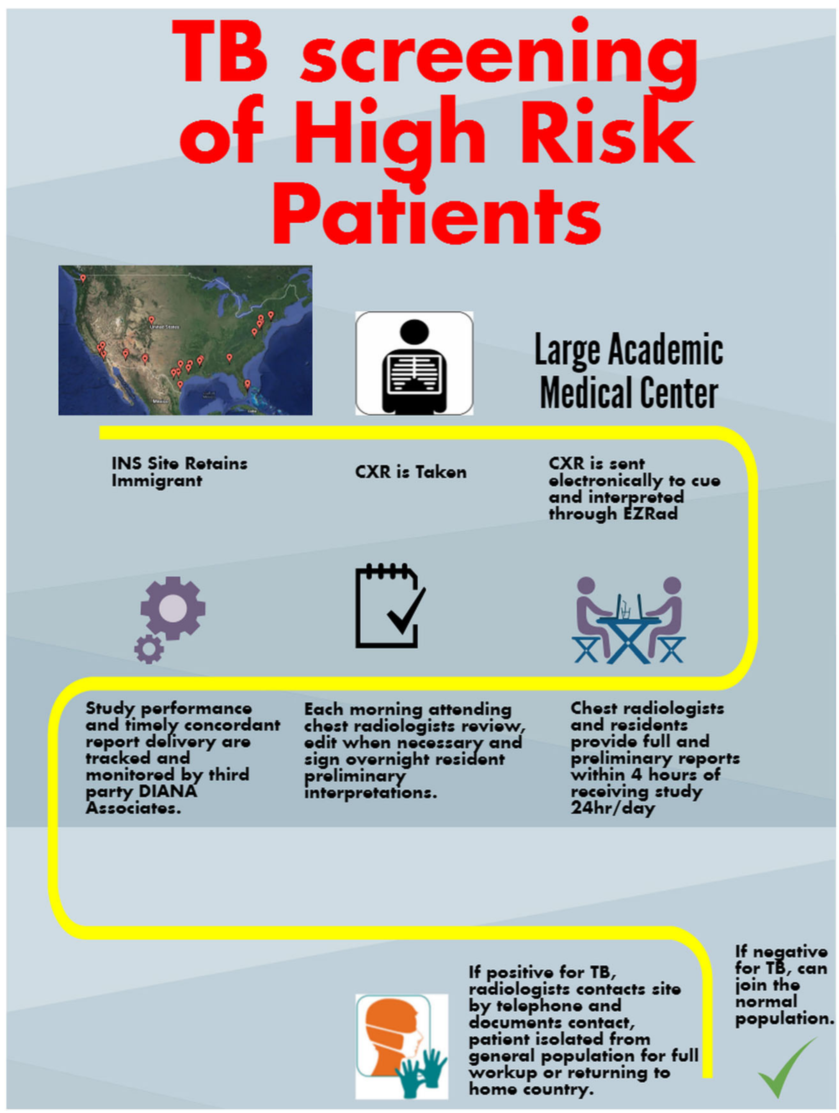


Fig. 1 Flow chart demonstrating the customized workflow created and implemented for high volume screening TB radiography interpretation 24 h a day 7 days a week

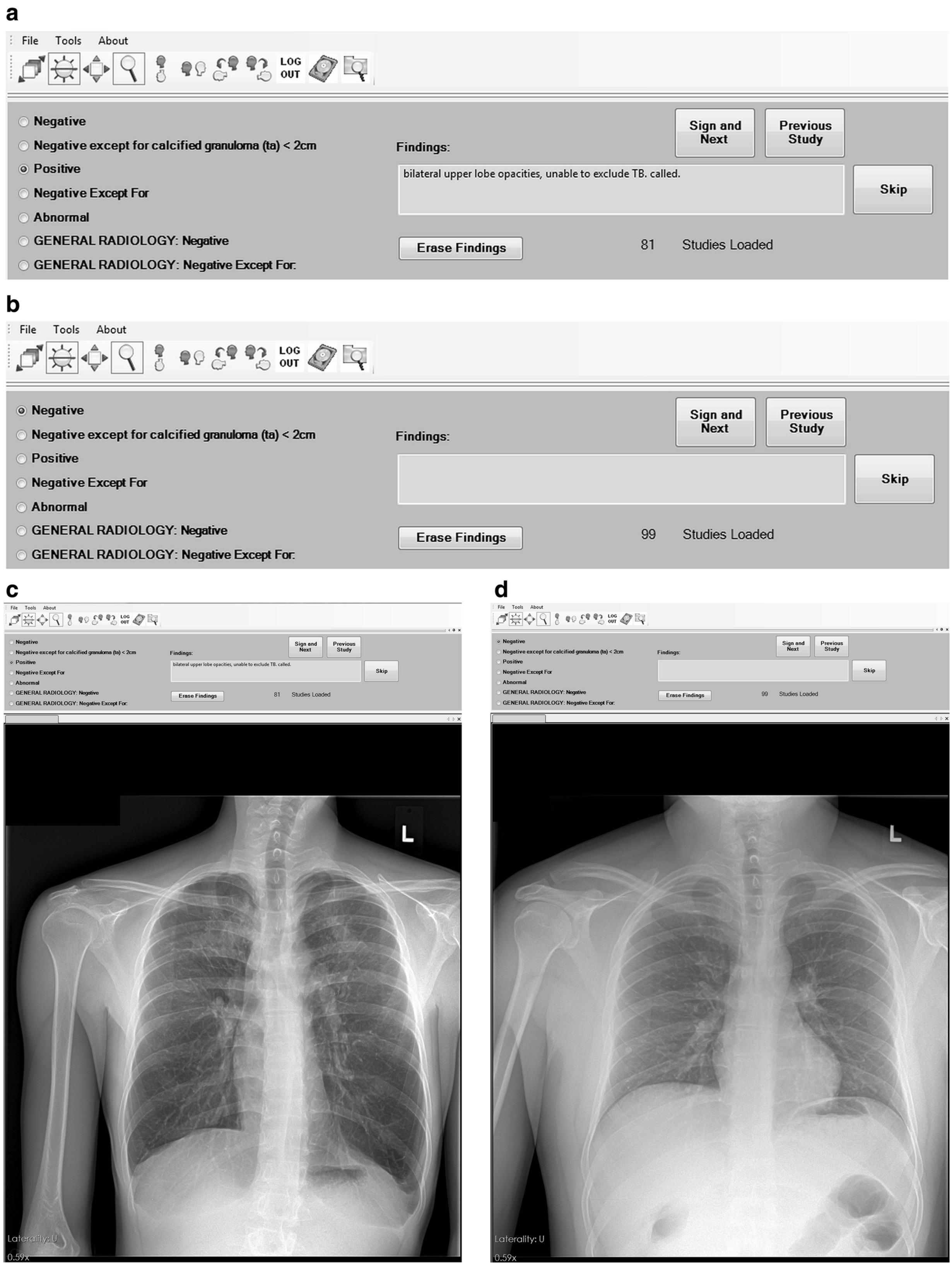


**Fig. 2** Two screen shots of the EzRAD software interface. **a** Close up of the interface when a positive study is identified with an associated free text comment provided by the radiologist. **b** Close up of the interface when a negative study is selected. **c** PA radiograph given preliminary read of positive due to findings of bilateral upper lobe opacities that are suspicious for TB. **d** PA radiograph with no concerning findings for TB

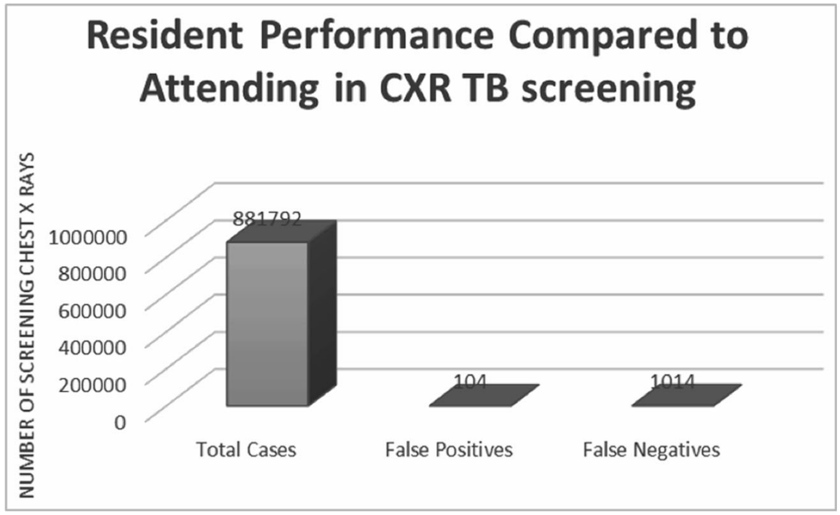


**Fig. 3** *Bar graph* demonstrating a miss rate of 0.1% with the majority of screening cases (881,792) interpreted preliminarily by residents matching the attending radiologist interpretation

attending subspecialty chest radiologist would over read each case given a preliminary report by a resident and either agree with the resident's interpretation or issue a modified report. The initial and finalized reports were stored in a relational database that allowed residents to compare their initial read to the attending's finalized report.

EZrad is a customized extension of the open source project ClearCanvas (https://github.com/ClearCanvas). EZrad is only a viewer/client. The logic and report sending to the customers is managed on the backend. The backend is a RubyOnRails application providing web services and report management. Additionally, a modified DCM4CHEE (dcm4che.org) instance for inbound DICOM images and image storage management.

A retrospective evaluation of the productivity of residents in terms of chest radiographs interpreted using the custom interface was compared to the miss rate. The chest radiograph is current procedural terminology (CPT) code 71010, and each code represents 0.18 RVUs for the professional component [13]. The miss rate was considered the percentage of studies initially interpreted incorrectly for TB screening by the resident's preliminary report when compared to the attending final report.

In order to perform this analysis, a relational database of reports for TB screening chest radiographs at a large academic medical center over a period from 05/30/2007–07/25/2016 was used. During this time period, residents provided 286 preliminary reports per night on average. Aggregated anonymous data within a MySQL database was queried using ruby script without accessing any private health information. Queries were performed on resident preliminary interpretations, which were provided using the EZRad software.

An algorithm was constructed to determine the number of preliminary interpretations initially considered suspicious for TB by the resident that were later changed to negative for TB in the attending's final report (false positives). Similarly, the number of preliminary interpretations considered negative by the resident and later considered positive for TB by an

**Fig. 4** Chart demonstrating the sensitivity, specificity, positive predictive value, and negative predictive value of resident performance using EZrad when compared with finalized attending interpretations

| | **Positive Attending Read** | **Negative Attending Read** | **SUM** | |
|---|---|---|---|---|
| **Positive Resident Read** | 3461 **(True Positives)** | 104 **(False Positives)** | 3565 | PPV = 3461/3565 **(97%)** |
| **Negative Resident Read** | 1014 **(False Negatives)** | 877207 **(True Negatives)** | 878221 | NPV = 877207/878221 **(99.8%)** |
| **SUM** | 4475 | 877311 | **881786 (Total Cases)** | |

Sensitivity = 3461/4475 **(77%)** Specificity = 877207/877311 **(99.9%)**

attending was determined (false negatives). The miss rate, defined as the sum of the false positives and false negatives divided by the total cases, was evaluated as well as the total number of final reports modified (Eq. 1).

$$\text{Missrate} = (\text{False positives} + \text{False negatives})/\text{Total cases} \quad (1)$$

## Results

The EZRad software was successfully implemented at the University of Maryland Medical Center and used as the exclusive workflow for interpretation of TB screening chest radiographs from 2007 to 2015. The software provides computer-aided reporting through a click interface for common findings such as suspicious for TB, negative, presence of granulomatous disease, among others (Fig. 2). Once the findings are selected, the user can add additional free text comments, if needed, and sign the report from within the interface.

Between 2007 and 2015, residents reported on 881,792 TB screening chest radiographs. This represents an average of 96,266 studies interpreted by residents per year, translating into 17,328 RVUs per year.

Among 881,792 reports, there were 1014 false negatives and 104 false positives for TB when comparing the resident preliminary report to the final attending report (Fig. 3). This resulted in an overall miss rate of 0.1% among residents at a large academic medical center when using the EzRad computer-aided reporting software for TB screening chest radiograph interpretation. The total number of final reports that were positive for TB was 4481. This meant the overall sensitivity for residents to correctly identify chest radiographs concerning for TB in preliminary interpretations was 77% (Fig. 4).

## Discussion

Computer-aided reporting through the custom EZRad software provided a productive method for residents to interpret a high volume of screening chest radiographs in a patient population at high risk for TB. A standardized report was generated based on the radiologist's selection in the user interface. Although this type of workflow is well documented in breast cancer screening, to the best of our knowledge, this is the first description of a similar workflow for reporting chest radiographs. The sensitivity among resident preliminary interpretations was comparable to that reported for screening mammography [14, 15] and within the range reported for screening chest radiographs, which both range in sensitivities from the low seventy to high ninety percentages, with average percentages in the eighties [16]. Data regarding resident sensitivity using computer aid reporting was not directly compared to traditional dictation in this study.

On average residents produced 17,328 RVUs in 5475 working hours per year, which corresponds to $620,841 in professional fees alone according to the most recent edition of the Medicare physician payment schedule [17]. This would translate to 35 RVU per day in a typical 10-h work day. If there are typically 220 10-h working days per year, this level of productivity would result in 7580 RVUs per year [1]. The number of RVUs per full time equivalent varies between academic and private practice groups; however, ranges from about 6000 RVUs per full time equivalent (FTE) in academic centers to about 10,000 RVUs on average overall [6, 18]. In summary, with the use of a computer-aided reporting system ergonomically integrated into a PACS interface, radiology residents at a large academic medical center exceeded the range of a typical academic FTE with chest radiograph reporting. This is in addition to their usual on-call emergency department and emergent inpatient responsibilities, which were not quantified for analysis in this study.

In this study, resident chest radiograph preliminary interpretations were retrospectively compared to attending final interpretations as the gold standard. This study design was chosen due to limitations of the available database such as the absence of sputum analysis or culture results. Future incorporation of a peer review process into the custom user interface could provide useful information on interobserver variability. Data regarding resident productivity via traditional dictation was not available for analysis, however could also be considered in a future study.

Decreased reliance on dictation and typographically correct report transcription, which can be error prone and tedious, allows the radiologist to focus completely on the image interpretation and clinical diagnosis. Through reduction of unnecessary attention costs, the radiologist becomes fully immersed in the feeling of involvement, enjoyment and focus, as conceptualized by Mihaly Csikszentmihalyi in the definition of "flow" [19, 20]. The process of image interpretation becomes much more efficient, as clearly reflected in the high productivity found in this study. Indeed, pruning of workflow is an inevitable part of process redesign to gain maximum performance by not only contained and channeled emotions but also positive and aligned mind.

Similar to mammography, this computer-aided reporting approach was tailored to a specific screening workflow for TB. Since screening chest radiographs are also often performed in the critical care setting, a similar computer-aided reporting mechanism tailored toward intensive care units might bring similar efficiencies. Further studies for additional use cases and imaging modalities may be beneficial in demonstrating value.

## Conclusion

Computer-aided reporting increased the efficiency of reporting TB screening chest radiographs among residents with expected accuracy when compared to final reports modified by an attending radiologist. New custom workflows such as this can provide valuable additional radiologist time. Efficiencies such as these will be needed in order for radiologists to adapt to the increasing demand for high quality interpretive and non-interpretive services in the Era of Imaging 3.0.

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**Compliance with Ethical Standards**

**Conflict of Interest** The authors declare that they have no conflict of interest.

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