Assessing the Influence of a CADx Scheme on Radiologists' Analysis of Breast Nodules in Digital Mammography Using Specialized Feedback Software

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Abstract: The study main purpose is to address the effectiveness of a computer-aided diagnosis (CADx) scheme developed to assist radiologists in evaluating nodules in digital mammography images. Unlike traditional CADe systems, which focus primarily on detection, this scheme offers interpretative support, providing additional diagnostic insights for more accurate decisions. This work presents a custom evaluation software designed to facilitate the testing of the CADx scheme influence on radiologists´opinion by allowing them to assess mammograms independently, register their initial opinions, review the CADx output, and log their final decisions. Through this software the study involved radiologists analysing mammograms before and after reviewing the CADx-generated data. The results showed a scheme positive influence on diagnostic accuracy. Radiologists who used the CADx data exhibited in average improved sensitivity and specificity rates, with an overall reduction in error rates, for the images set under investigation. Although the scheme is still a research prototype, it demonstrates strong potential for broader application in clinical practice, offering efficiency and cost-effectiveness, especially for screening operations. The procedure described in this work indicates that, despite the need for some fine-tuning, particularly in minimizing false positives, our CADx system shows promise as a supplemental diagnostic tool that could enhance radiologists´performance.

1 INTRODUCTION

It is well known that hundreds of computer-aided detection (CAD) schemes have been used all over the world. The CAD scheme performance should not be equal or better than the radiologists' one; but the result provided by such a scheme should be useful to the radiologist in determining the diagnosis as well as aiding in improving the performance in detecting suspect signals in mammography (Doi, 2004). Despite this, as stressed by (Karssemeijer, 2011), a decrease in works searching for improvements in CAD algorithms has been observed. In fact, most of radiologists using this technique consider that there is a need of many improvements and, although generally satisfied with CAD performance in detecting clustered microcalcifications, they are less confident in mass detection (Karssemeijer, 2011). False positive detections are the main concern in most of these cases, which are considered the main cause for radiologists confusion or time-consuming visual analysis (Gillies, Kinahan and Hricak, 2016; Katzen and Dodelzon, 2018).

Screening programs are also "modeling" CAD schemes technology, so that commercial CAD systems users are instructed to apply them as a checker to avoid missing signals, but not as an interpretation aid tool. Many perception studies have demonstrated that the most of errors in diagnosis are due to an examiner insufficient capability in interpreting suspected regions already detected (Karssemeijer, 2011; Kooi, Mordang and Karssemeijer, 2017). Therefore an important consideration should be stressed: the issue related to the findings classification in CADx schemes.

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In clinical practice there are some radiologists using CAD schemes as an aid in interpretation when familiar with the technique. However, many other specialists hesitate to use this technology, due to considerable false positive rates. Even so, observations we have made of experienced radiologists have shown that they tend to be more receptive to CAD in assisting their analyses, primarily because they consider useful the provided quantitative data on density and other findings – as well as the likelihood of corresponding to a given category (Schiabel, Matheus and Verçosa, 2014).

The current model of our CADx scheme is based in these features (Matheus and Schiabel, 2013; Schiabel et al., 2012). The main characteristic is that it represents not an automatic diagnosis computer system in mammography, but a supplemental information system for the medical report. In a previous work (Matheus, Gonçalves and Schiabel, 2015) we have shown and discussed the evaluation of one of the modules of our CADx scheme – the mass segmentation evaluation – comparing the module results with experienced radiologists interpretation. The evaluation was essentially the comparison between the classification of nodules contours given by the scheme and that considered by the radiologists in order to check not only the level of efficacy of the automatic classification, but also to show how this result can influence the radiologist evaluation. Considering the separation between benign and malignant signals at classifying the nodule contour, the results have indicated 82 % of agreement between CADx and radiologists (Matheus, Gonçalves and Schiabel, 2015). As a consequence of this research, we introduced another investigation into the analysis: how much this CADx scheme can aid the diagnostic accuracy? This led to the development of a single application, that we called "Driven CADx", in order to determine whether or not a given detected nodule was clinically suspicious (Schiabel et al., 2012; Schiabel, Matheus and Cardoso, 2023). The use of this app was proposed as a CADx tool to help the radiologist more immediately during the analysis of a mass detected in the exam, providing information on the classification of the structure as suspicious or not, working as a kind of second opinion.

Therefore, by using the "Driven CADx" app (Schiabel et al., 2012; Schiabel, Matheus and Cardoso, 2023), a test scheme to answer the previous question about its influence on the radiologist performance was designed. Procedures involve firstly classifying detected masses in a selected digital mammograms set by using the app, and registering the result. Considering a number of collaborators radiologists, the images set was then introduced set in order to get their opinion about the suspiciousness rate of each case. In conclusion, the radiologist final opinion was registered, after knowing the CADx evaluation result.

However, as one major issue is usually getting the radiologist to carry out this visual analysis in the laboratory, we have developed a simple software to assist in performing such a test so that the procedures can be made by the radiologist at his own workplace (for example, in the reporting room at a hospital or radiology clinic). The software design, the test scheme methodology and results are described in the next sections.

2 METHODOLOGY

The software design to gather the radiologists' opinion on the detected masses in digital mammograms was directed by a senior radiologist collaborator of our group. The procedure is based on a semi-automatic process, considering the following model: from a selected region of interest in the image, the evaluator performs his visual analysis and produces information whether or not the detected mass is a suspicious signal. Next, the result provided by the Driven CADx analysis is shown to the observer who is asked whether considers – based on such an information – to maintain or change the previous opinion. All these results – from the isolated CADx analysis, from the isolated observer analysis, and from the observer final opinion after knowing the CADx evaluation – are registered to proceed with the statistical investigation.

The current version of this scheme was developed using a Java tool and the Macros programming language of the free software ImageJ (https://imagej.nih.gov) and made intuitive for generic users. The main requirement for its use is to have ImageJ installed on the computer where the evaluation will be carried out. To enable the evaluation, first, a folder is created containing the entire set of images (in DICOM files) that will be part of the process, in addition to a blank text file for recording the information regarding the evaluation data. Prior to the medical visual analysis, the complete set of digital mammographic images is submitted to the Driven CADx scheme application developed (Schiabel et al., 2012; Schiabel, Matheus and Cardoso, 2023) so that the evaluations of each case are recorded in a single text file.

The evaluation procedure in the main program requests firstly the folder where the images to be analyzed are stored. Then, it requests subsequently the location of: (a) the text file with the recorded data from Driven CADx evaluation; and (b) the name of the text file to record all the evaluation results. After that, the software immediately shows in the display the first image of the set with a delimited mass. In a checking box superimposed on the image, the observer will be able to choose one of two options according to his opinion about the selected region: suspicious or non-suspicious mass. Depending on the option chosen, the software checks whether the information is identical or conflicts with that produced by the Driven CADx application on that case, alerting the observer.

If the medical opinion is the same as that from the CADx, the information "The CADx also made the same assessment in this case" appears and then it will display the next image in the set. Otherwise, the software returns information that the CADx evaluation was different, asking the observer the agreement with such an evaluation. At this point, the observer will be able to mark in the corresponding checking box the final opinion (which may or may not be different from the first one, once the image is re-analyzed based on the discordant information from the CADx). With the new record, the software thus proceeds to the next image successively until the end of the folder images set. Fig. 1 illustrates some screens snapshots of this process, in which an image is shown and, superimposed on it, the window with the information or options described above.

When the process ends, i.e, all the images in the folder are evaluated, the outcome text file has registered all the opinions gathered during the analysis for each image: (a) the Driven CADx evaluation; (b) the observer original opinion and (c) the observer final opinion – after knowing the CADx evaluation. These data can be then organized and confronted with the true classification (based on the confirmed reports given by an experienced radiologist/breast specialist) of each case as this information is saved separately.

3 EXPERIMENTAL ANALYSIS AND RESULTS

3.1 Images Set

Digital mammography images composing the database to be evaluated were obtained from exams performed in a GE Senographe Essential mammography unit. All of the cases were previously diagnosed according to the BIRADS standard by an expert radiologist, who provided information on the characteristics and location of detected nodules. These data were our ground truth for the statistical analysis on sensitivity, specificity and accuracy rates regarding the Driven CADx application results as well as the evaluators opinions given during the experimental evaluation procedure.

A total of 70 images were selected to form the folder to be managed during the tests. All of them presented one delimited mass to be analyzed by the CADx scheme and by the observer. All the images files were saved in tiff format, keeping the original image characteristics (12-bit contrast resolution, 0.1mm spatial resolution in the *for presentation* image file, for example).

After applying the Driven CADx scheme to all the selected ROIs in the set, a file with its classification was saved. This file, together with the folder with the images and the management program described in the previous section were recorded in the computer at the radiology reporting room at a local hospital. Such a computer is coupled to a 5MP EIZO Radiforce display used to the visual analysis of the digital mammography images.

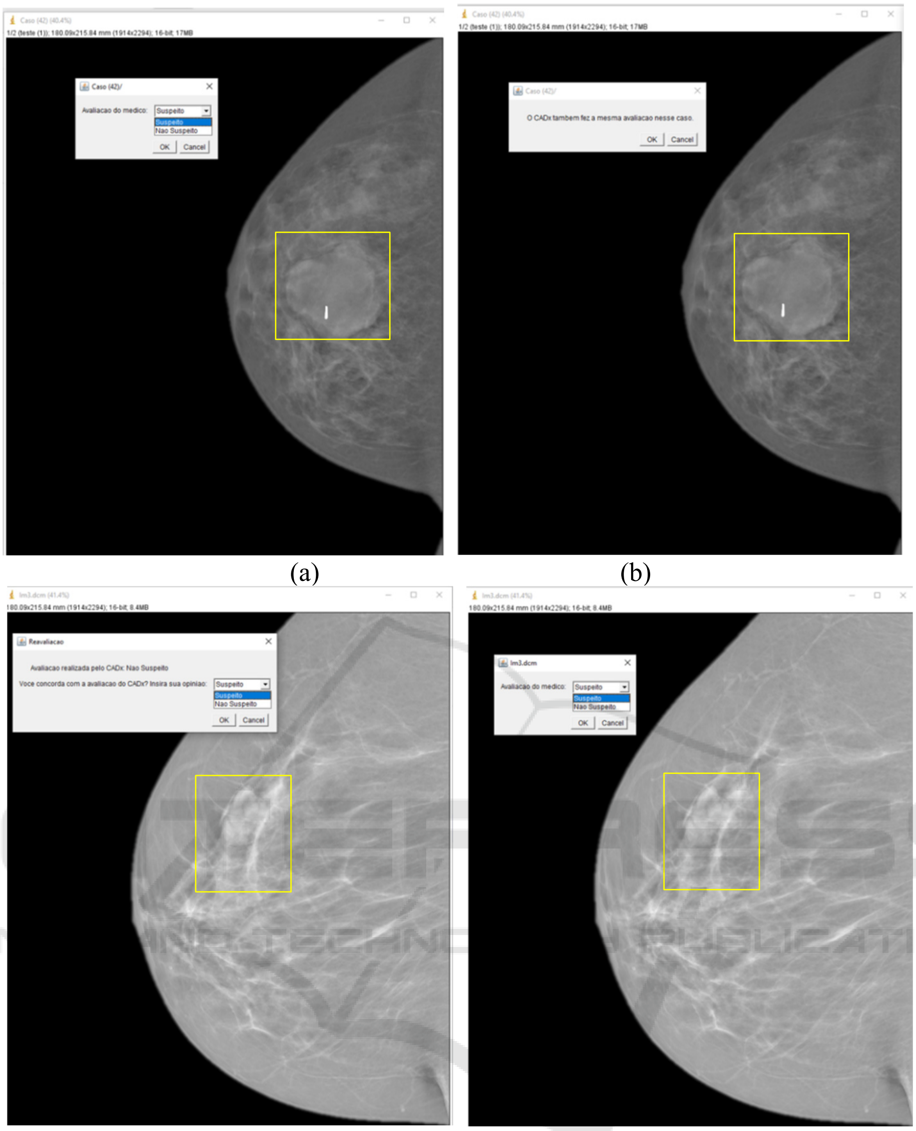
3.2 Images Evaluations

A group of 10 collaborators proceeded with the analysis by using the evaluation program. Table 1 describes the main categorization of each one.

All of them used the program to register their opinion on each image (or each delimited ROI on the images) as a suspect or not suspect nodule. The average time expended to the evaluation was about 15-20 min by observer. From observations during the tests, we could conclude that no one showed difficulties in using the program or performing the evaluation as determined by the program steps.

Table 1: Categorization of evaluation collaborators.

(1)	Mammography specialist radiologist (> 20 y.)
(2)	Mammography specialist radiologist (> 20 y.)
(3)	Mammography specialist radiologist (> 20 y.)
(4)	General radiologist (> 10 y.)
(5)	General radiologist (> 10 y.)
(6)	General radiologist (> 10 y.)
(7)	General radiologist (> 10 y.)
(8)	Mammography specialist (> 20 y.)
(9)	Mammography specialist (> 20 y.)
(10)	Mammography specialist (> 20 y.)



(a) (b) (c) (d)

Figure 1: Screens shown by the software developed to gather the radiologist opinion in a semi-automatic way: (a) and (b) image with a checking box for marking the nodule evaluation as well as the report from the human analysis, indicating that it is an identical result produced by the evaluation of the CADx scheme; (c) another image with the same opinion choice box, but with an indication in (d) that the CADx assessment is discordant – and the option to keep or not the original choice.

3.3 Data Analysis

From the data recorded in the experiments, the statistical analysis is shown in Tables 2-4, with the hit rates regarding the Driven CADx scheme and the group of evaluators.

It is interesting to note, in relation to Table 2, that the Driven CADx scheme exhibits accuracy patterns for the digital image set that align with its previous performance (Matheus, Gonçalves, and Schiabel, 2015), using the image database employed during its development – digitized film images, particularly from the DDSM database (Heath, M. et al., 2001).

Table 2: Performance of the Driven CADx scheme with the images set used in the test.

Nodules	Number of correct classifications
Not suspect	28/35 (80,0%)
Suspect	28/35 (80,0%)

Table 3: Number of correct classifications for collaborator. The column *original* indicates the hit rate regarding the first opinion compared to the true information. The column *after CADx* otherwise indicates the hit rate relative to final opinion.

Evaluator	Original	After CADx
(1)	66%	70%
(2)	67%	69%
(3)	71%	71%
(4)	69%	70%
(5)	67%	69%
(6)	74%	78%
(7)	56%	61%
(8)	67%	67%
(9)	71%	77%
(10)	61%	63%
Average	67 (± 5.2)%	70 (± 5.3)%

In order to detail the individual rates with correspondence to the number of true suspect and true not suspect cases, Table 4 shows the sensitivity and specificity rates – as well as the false positive and false negative rates – determined for each evaluator.

The columns in Table 4 were divided into *pre* and *post* corresponding rates, indicating the percentage of correct classifications and errors, for both, respectively, the first and the final opinion (after knowing the CADx results). Data compared to the ground truth information obtained for the entire set of images when selected the cases and ROIs under analysis.

Summarizing these cases, we noticed that, among the 70 images (35 featuring suspicious nodules and 35 without), there were 27 instances where the observer's perspective has changed as a result of knowing the CADx evaluation: 22 “positive” changes – corresponding to cases when the final opinion was different from the first and matches with the true classification – and only 5 “negative” ones, attributable to false classification by the scheme. It was also observed that there was not necessarily an influence of the scheme on changing opinions for a single particular image.

For only 3 images a change in the final opinion occurred compared to the original assessment by two different observers. This suggests a variability in the images (and respective nodules) of the datasets used in the evaluation process, indicating that the cases selection helped avoid potential biases that could impact the results and their analysis.

Table 4: Sensitivity (Sens.) and specificity (Spec.) rates for each evaluator, along with their respective error rates (FP – false positive; and FN – false negative).

Observer	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Sens. (pre) (%)	71.4	60.0	51.4	62.8	74.3
Sens. (post) (%)	74.3	62.8	51.4	65.7	77.1
Spec. (pre) (%)	62.8	77.1	91.4	74.3	63.6
Spec. (post) (%)	65.7	77.1	91.4	74.3	63.6
FN (pre) (%)	28.6	40.0	48.6	37.1	25.7
FN (post) (%)	25.7	37.1	48.6	34.3	22.9
FP (pre) (%)	37.2	22.8	8.6	25.7	36.4
FP (post) (%)	34.3	22.8	8.6	25.7	36.4

Observer	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
Sens. (pre) (%)	91.4	71.4	48.6	60.0	74.3
Sens. (post) (%)	91.4	71.4	48.6	65.7	74.3
Spec. (pre) (%)	60.0	40.0	85.7	82.8	48.6
Spec. (post) (%)	65.7	48.6	85.7	88.6	51.4
FN (pre) (%)	8.6	28.6	51.4	40.0	25.7
FN (post) (%)	8.6	28.6	51.4	34.3	25.7
FP (pre) (%)	40.0	60.0	14.3	17.1	51.4
FP (post) (%)	34.3	51.4	14.3	11.4	48.6

Observer	**Averages (± SD) (%)**	**Increase***
Sens. (pre)	66.6 (± 12.6)	-
Sens. (post)	68.3 (± 12.5)	(+1.7%)
Spec. (pre)	68.6 (± 16.5)	-
Spec. (post)	71.2 (± 14.8)	(+2.6%)
FN (pre) (%)	33.4 (± 12.6)	-
FN (post) (%)	31.7 (± 12.5)	(-1.7%)
FP (pre) (%)	31.4 (± 16.6)	-
FP (post) (%)	28.8 (± 14.8)	(-2.6%)

The automated analysis procedure yielded a valuable dataset that allows for interpreting the individualized behavior of the evaluators and how the results of the Driven CADx system influenced their opinions. Table 3 primarily focuses on the evaluators' accuracy rate (regardless of whether it was a true positive or negative), while Table 4 provides a more detailed breakdown of individual behaviors.

Upon closer examination of the data in Tables 3 and 4, a few cases stand out:

- In Table 3, there is an increase in accuracy rates for evaluators (1) and (2) (by 4% and 2%,

* *The percentile values given next to the columns* ”Sensitivity (post)” and “Specificity (post)” represent how much these respective rates have increased (in average) in relation to those recorded for the observers first opinion. The same values are shown next to the FN (post) and FP (post) columns, but with opposite signal, since they represent the respective reductions in these rates as a consequence of those increases.

respectively); evaluator (3) did not show any change in their accuracy rates, while evaluator (6) recorded the highest accuracy rate, which further increased by 4% after being informed of the CADx results for each case. Evaluator (9) exhibited the highest increase in accuracy rates before and after being informed of the CADx results (approximately 6%).

- In Table 4, there is an observed increase in both sensitivity (positive cases) and specificity (negative cases) by about 3% for evaluator (1) when comparing the pre- and post-CADx data. For evaluator (2), the same percentage increase was recorded in sensitivity, though not in specificity. For evaluator (6), who had the highest overall accuracy rate among all evaluators according to Table 3, this result could be attributed to their sensitivity rate, which remained unchanged after reviewing the CADx data, in contrast to specificity, which increased by approximately 6%. Finally, for evaluator (9), who had been previously mentioned, their high accuracy rate was associated with specificity (83%). Nevertheless, both their sensitivity and specificity rates increased after considering the CADx data, by around 6%. And evaluator (3) is confirmed not to have been influenced by the CADx data, as none of their rates changed before or after reviewing the corresponding information.

The detailed results given in terms of sensitivity, specificity and error rates, before and after the observer being informed of the Driven CADx application results, as shown in Table 4, indicates: (a) that our software is able to aid in the mass categorization, and (b) the overall positive influence of this Driven CADx scheme on the observers analysis, as there was an average increase of 2 to 3% in both sensitivity and specificity rates (with a proportional reduction in error rates) recorded for the participant group in the evaluation process. As a next step, more tests like these should be performed, increasing the number of not only observers as well as the images to be analysed.

4 CONCLUSIONS

We consider the primary contribution of this work to be focused on two key aspects: the effectiveness of the software developed to assess observer behavior in the visual analysis of images for nodules categorization, and the influence of our Driven CADx scheme (Schiabel, Matheus and Cardoso, 2023) on the evaluators' classification regarding the suspicion level of those same nodules. It is important to highlight that the software enables the entire process – image reading, initial classification, information on CADx evaluation outcome, and final opinion recording – to be carried out almost automatically by the observer alone. Furthermore, the process demonstrated that the Driven CADx application performed as a diagnostic aid tool in mammography, particularly in interpreting whether a finding is suspicious – needing a further investigation – or not.

Unlike most schemes that focus on detection, the interpretative approach of our system allows for a more detailed evaluation of findings, providing a more accurate suggestion for biopsy in cases with a higher likelihood of malignancy.

Another important insight from the data, particularly from Tables 3 and 4 (as discussed in the previous section), is that the CADx results positively influenced the radiologists' evaluations. In many cases, the use of the system not only led to changes in opinion but also resulted in an increase in accuracy rates.

Although currently formatted as a research prototype, the system has demonstrated efficiency, with the potential not only to generate more extensive results but also to support screening operations for more routine cases. Standardizations developed during the Driven CADx project have also contributed to significant cost reductions – an important concern for acquiring such commercial systems in Brazil and many other countries. Despite needing some adjustments, particularly to reduce false positive rates, the tests have pointed to the model's feasibility.

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