Chest x-ray in the COVID-19 pandemic: Radiologists’ real-world reader performance

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Purpose: To report real-world diagnostic performance of chest x-ray (CXR) readings during the COVID-19 pandemic.

Methods: In this retrospective observational study we enrolled all patients presenting to the emergency department of a Milan-based university hospital from February 24th to April 8th 2020 who underwent nasopharyngeal swab for reverse transcriptase-polymerase chain reaction (RT-PCR) and anteroposterior bedside CXR within 12 h. A composite reference standard combining RT-PCR results with phone-call-based anamnesis was obtained. Radiologists were grouped by CXR reading experience (Group-1, >10 years; Group-2, <10 years), diagnostic performance indexes were calculated for each radiologist and for the two groups.

Results: Group-1 read 435 CXRs (77.0 % disease prevalence): sensitivity was 89.0 %, specificity 66.0 %, accuracy 78.4 %. Group-2 read 100 CXRs (73.0 % prevalence): sensitivity was 89.0 %, specificity 40.7 %, accuracy 76.0 %. During the first half of the outbreak (195 CXRs, 66.7 % disease prevalence), overall sensitivity was 80.8 %, specificity 67.7 %, accuracy 76.0 %. Group-1 sensitivity being similar to Group-2 (80.6 % versus 81.5 %, respectively) but higher specificity (74.0 % versus 46.7 %) and accuracy (78.4 % versus 69.0 %). During the second half (340 CXRs, 81.8 % prevalence), overall sensitivity increased to 92.8 %, specificity dropped to 53.2 %, accuracy increased to 85.6 %, this pattern mirrored in both groups, with decreased specificity (Group-1, 58.0 %; Group-2, 33.3 %) but increased sensitivity (92.7 % and 93.5 %) and accuracy (86.5 % and 81.0 %, respectively).

Conclusions: Real-world CXR diagnostic performance during the COVID-19 pandemic showed overall high sensitivity with higher specificity for more experienced radiologists. The increase in accuracy over time strengthens CXR role as a first line examination in suspected COVID-19 patients.

1. Introduction

Since the start of the COVID-19 pandemic, international recommendations [1,2] have repeatedly stated that the diagnosis of SARS-CoV-2 infection should primarily rely on viral testing rather than on chest imaging.

This endorsed reference standard, i.e. reverse transcriptase-polymerase chain reaction (RT-PCR) on nasal or throat swabs, has become essential in the triage and monitoring phases of patients with suspected SARS-CoV-2 infection [3], but is encumbered by a sensitivity oscillating between 38 % and 89 % [4–6]. Moreover, during the pandemic peak, RT-PCR response times became often incompatible with appropriate triaging and management of the high number of suspect COVID-19 cases simultaneously presenting to emergency departments [7–9], forcing the incorporation of imaging in the diagnostic pathway to compensate the aforementioned shortcomings of RT-PCR [2,10,11].

While the use of chest CT – even as a triaging test – was almost ubiquitous [11–13], both initial reports from China and a recent
performance in CXR reading during the COVID-19 pandemic, distinguish hospital mainly focusing on cardiovascular diseases but promptly converted to a primarily COVID-19-dedicated hospital during the pandemic peak. An anamnestic data and patient follow-up, as well as by RT-PCR repetition in specific patients, using a composite reference standard (RT-PCR supplemented by chest x-ray (CXR) reading experience: Group 1 included 4 radiologists (R1, R2, R3, and R4) with 10 or more years of experience in CXR reading; Group 2 included 3 (R5, R6, and R7) radiologists with less than 10 years of experience in CXR reading. All radiologists were board-certified: if a resident was in charge of drafting a first version of the report, the report was always checked by a board-certified radiologist and the final version was signed by the same board-certified radiologist. Only one of the seven radiologists (in Group 1) has a particular dedication to breast imaging but practices at least half of his time as a general radiologist. Overall and patient-sex-specific diagnostic performance indexes were calculated for each radiologist and for the two groups over the 6-week timeframe and according to the first and second half of all CXRs read by each radiologist. Data are presented as sensitivity, specificity, positive predictive value, negative predictive value, accuracy, positive likelihood ratio, negative likelihood ratio, and their 95% confidence intervals (CI). Statistical analyses were performed using Microsoft Excel 2019 (Microsoft Corporation, Redmond, WA, USA).

3. Results

In the six-week study period, R1 read 180 CXRs, with a 79% disease prevalence, R2 read 147 CXRs with a 70% disease prevalence, R3 read 65 CXRs with an 80% disease prevalence, and R4 read 43 CXRs with an 88% disease prevalence. Overall, readers from Group 1 read 435 CXRs with a 77.0% disease prevalence, obtaining an 89.0% sensitivity (95% CI 85.2%–91.9%), a 66.0% specificity (95% CI 56.3%–74.5%), an 83.7% accuracy (95% CI 77.9%–86.9%), an 89.0% positive predictive value (95% CI 86.0%–92.6%), a 64.1% negative predictive value (95% CI 54.5%–72.7%), a 2.62 positive likelihood ratio (95% CI 1.99–3.45), and a 0.17 negative likelihood ratio (95% CI 0.12–0.23). In Group 2, R5 read 59 CXRs with a 78% disease prevalence, R6 read 27 CXRs with a 70% disease prevalence, R7 read 14 CXRs with a 57% disease prevalence; overall, readers from Group 2 read 100 CXRs with a 73.0% disease prevalence, obtaining an 89.0% sensitivity (95% CI 79.8%–94.3%), a 40.7% specificity (95% CI 24.5%–61.0%), a 76.0% accuracy (95% CI 66.8%–83.3%), an 80.2% positive predictive value (95% CI 70.3%–87.5%), a 57.9% negative predictive value (95% CI 36.3%–76.9%), a 1.50 positive likelihood ratio (95% CI 1.09–2.08), and a 0.27 negative likelihood ratio (95% CI 0.12–0.60). Fig. 1 shows an example of a true positive and of a false positive case both for Group 1 and Group 2. Table 1 details overall performance indexes of all readers, and Table 2 shows the results of readers performance evaluation according to patient subgroups and different timeframes (i.e. the first and second three-week periods).

Considering the first half and the second half of all CXRs read by each radiologist, we observed an increase in disease prevalence for 5 out of 7 readers: disease prevalence in the CXR subset read by R1 increased from 77% to 81%, from 64% to 77% for R2, from 86% to 90% for R4, from 70% to 86% for R5, from 64% to 77% for R6, while decreasing from 85% to 75% for R3 and from 71% to 43% for R7. Group 1 readers attained an 87.2% sensitivity (95% CI 81.2%–91.5%), a 71.4% specificity (95% CI 58.5%–81.6%), an 83.2% accuracy (95% CI 77.7%–87.5%), an 89.9% positive predictive value (95% CI 84.3%–93.7%), a 65.6% negative predictive value (95% CI 53.0%–76.3%), a 3.05 positive likelihood ratio (95% CI 2.01–4.64), and a 0.18 negative likelihood ratio (95% CI 0.12–0.28) in the first half of all their reported CXRs, while in the second half they reached a 90.6% sensitivity (95% CI 85.3%–94.2%), a 59.1% specificity (95% CI 44.4%–72.3%), an 84.2% accuracy (95% CI 78.7%–88.5%), an 89.6% positive predictive value (95% CI 84.2%–93.3%), a 61.9% negative predictive value (95% CI 46.8%–75.0%), a 2.22 positive likelihood ratio (95% CI 1.55–3.17), and a 0.16 negative likelihood ratio (95% CI 0.09–0.27). Conversely, Group 2 readers had an 82.9% sensitivity (95% CI 67.3%–91.9%), a 43.8% specificity (95% CI 23.1%–66.8%), a 70.6% accuracy (95% CI 57.0%–81.3%), a 76.3% positive predictive value (95% CI 60.8%–87.0%), a 53.8% negative predictive value (95% CI 29.1%–76.8%), a 1.47 positive likelihood ratio (95% CI 0.93–2.33), and a 0.39 negative likelihood ratio (95% CI 0.16–0.98) in the first half of all their reported CXRs, while in the second half they showed a 94.7% sensitivity (95% CI 82.7%–98.5%), a 36.4% specificity (95% CI 15.2%–64.6%), a 81.6% accuracy (95% CI 68.6%–90.0%), an 83.7% positive predictive value (95% CI 70.0%–91.9%), a 66.7% negative predictive value (95% CI 30.0%–90.3%), a 1.49 positive likelihood ratio (95% CI 0.95–2.34), and a
0.14 negative likelihood ratio (95% CI 0.03–0.69). Table 3 details performance indexes both overall and for each reader in the first and second half of their CXR subset, sensitivity, specificity, and accuracy being also plotted in Figs. 2, 3 and 4, respectively.

4. Discussion

The role of CXR in COVID-19 imaging could be paramount in settings with temporarily- or permanently-limited RT-PCR availability, as anticipated by Murphy et al. [24], who also warned against potential low diagnostic performance of CXR when reported by non-dedicated chest radiologists. Real-world data from this study, albeit conducted in a high-prevalence region and during a SARS-CoV-2 pandemic peak, seem to provide a better scenario, in which radiologists with less than 10 years of experience matched the 89.0% sensitivity attained by radiologists with more than 10 years of experience, with similar disease prevalence in the CXR subsets read by each group (73% versus 77%, respectively). A non-negligible cost for Group 2 to attain such a sensitivity was a consistently lower specificity (41%, 95% CI 25%–59%)—a value similar to the pooled specificity reported for chest CT by a meta-analysis of 3 studies from non-high-epidemic areas and 2 studies from high-epidemic areas (37%, 95% CI 26%–50%) [14]—while Group 1 showed a smaller difference.
between sensitivity and specificity, with a constantly higher accuracy (Table 2). Such pattern was also observed comparing different timepoints or the total number of CXRs read by each radiologist: between the first and second half of the six-week study period overall accuracy increased from 76 % to 86 %, with corresponding increases both in Group 1 and Group 2; between the first and second half of CXRs read by each reader, overall accuracy increased from 81 % to 84 %, again with corresponding increases in both groups, albeit more pronounced in the less experienced Group 2 (1% difference for Group 1, 11 % difference for Group 2). This trend was most likely driven in both groups by an adaptation to the escalation of examined cases (from 195 in the first three weeks to 340 in the following three), with an increase in sensitivity and accuracy mirrored by a specificity decrease. Of note, we can observe how in both groups there was a comparable number of readers exhibiting an inverse tendency towards a decrease in
Diagnostic performance indexes for chest x-ray reading for each radiologist and for the two experience-tiered groups.

| Disease prevalence | TP (95% CI) | TN (95% CI) | FP (95% CI) | FN (95% CI) | Specificity (95% CI) | PPV (95% CI) | NPV (95% CI) | Accuracy (95% CI) |
|-------------------|-------------|-------------|-------------|-------------|-----------------------|--------------|--------------|------------------|
| Overall           | 298/66/34 37 | 89.0%       | 66.0%       | 89.8%       | 64.1%                 | 83.7%        | 87.2%        | 87.9%            |
| Reader 1          | 131/26/12 11 | 92.3%       | 68.4%       | 91.6%       | 70.3%                 | 87.2%        | 81.6%        | 81.3%            |
| Group 1           | 86/30/14 17 | 83.5%       | 68.2%       | 86.0%       | 63.8%                 | 78.9%        | 71.6%        | 78.4%            |
| Reader 2          | 47/5/8 5    | 90.4%       | 38.5%       | 85.5%       | 50.0%                 | 80.0%        | 68.7%        | 68.7%            |
| Reader 3          | 34/5/0 4    | 89.5%       | 100.0%      | 100.0%      | 55.6%                 | 90.7%        | 78.4%        | 78.4%            |
| Reader 4          | 65/11/16 8 | 89.0%       | 40.7%       | 80.2%       | 57.9%                 | 76.0%        | 66.8%        | 57.9%            |
| Group 2           | 40/5/8 6    | 87.0%       | 38.5%       | 83.3%       | 45.5%                 | 76.8%        | 64.0%        | 64.0%            |
| Reader 5          | 19/3/5 0    | 100.0%      | 37.5%       | 79.2%       | 100.0%                | 81.5%        | 63.3%        | 63.3%            |
| Reader 6          | 6/3/3 2     | 75.0%       | 50.0%       | 66.7%       | 60.0%                 | 64.3%        | 38.8%        | 38.8%            |

TP = true positives, TN = true negatives, FP = false positives, FN = false negatives, CI = confidence interval, PPV = positive predictive value, NPV = negative predictive value.

Diagnostic performance indexes for chest x-ray reading between radiologists’ groups according to different patients’ characteristics and timeframe.

| Disease prevalence | TP | TN | FP | FN | SN | SP | PPV | NPV | ACC | LR+ | LR− |
|--------------------|----|----|----|----|----|----|-----|-----|-----|-----|-----|
| Overall            | 76.3% | 363/77/50 45 | 89.0% | 60.6% | 87.9% | 63.1% | 82.2% | 3.3 | 0.6 |
| G1 (Exp. > 10y)    | 75.0% | 298/66/34 37 | 89.0% | 68.9% | 89.8% | 64.1% | 83.7% | 2.6 | 0.2 |
| G2 (Exp. < 10y)    | 73.0% | 65/11/16 8 | 89.0% | 40.7% | 80.2% | 57.9% | 76.0% | 1.5 | 0.3 |
| Male patients      | | | | | | | | | |
| Overall            | 79.7% | 243/42/27 28 | 89.7% | 60.9% | 90.0% | 60.0% | 83.8% | 3.3 | 0.2 |
| G1 (Exp. > 10y)    | 81.2% | 202/35/17 22 | 90.2% | 67.3% | 92.2% | 61.4% | 85.9% | 2.8 | 0.1 |
| G2 (Exp. < 10y)    | 73.4% | 41/7/10 6 | 87.2% | 41.2% | 80.4% | 53.8% | 75.0% | 1.5 | 0.3 |
| Female patients    | | | | | | | | | |
| Overall            | 70.3% | 120/35/23 17 | 87.6% | 60.3% | 83.9% | 67.3% | 79.5% | 2.2 | 0.2 |
| G1 (Exp. > 10y)    | 69.8% | 96/31/15 15 | 86.5% | 64.6% | 85.0% | 67.4% | 79.9% | 2.4 | 0.2 |
| G2 (Exp. < 10y)    | 72.2% | 24/4/6 2 | 92.3% | 40.0% | 80.0% | 66.7% | 77.8% | 1.5 | 0.2 |
| First three weeks (24/02 - 15/03) | | | | | | | | | |
| Overall            | 66.7% | 105/44/21 25 | 80.8% | 67.7% | 83.3% | 63.8% | 76.4% | 2.5 | 0.3 |
| G1 (Exp. > 10y)    | 67.3% | 83/37/13 15 | 80.6% | 74.0% | 86.5% | 64.9% | 78.4% | 3.1 | 0.3 |
| G2 (Exp. < 10y)    | 64.3% | 22/7/8 5 | 81.5% | 46.7% | 73.3% | 58.3% | 69.0% | 1.5 | 0.4 |
| Second three weeks (16/03 - 08/04) | | | | | | | | | |
| Overall            | 81.8% | 258/33/29 20 | 92.8% | 53.2% | 89.9% | 62.3% | 85.6% | 2.0 | 0.1 |
| G1 (Exp. > 10y)    | 82.3% | 215/29/21 17 | 92.7% | 58.0% | 91.1% | 63.0% | 86.5% | 2.2 | 0.1 |
| G2 (Exp. < 10y)    | 79.3% | 43/4/8 3 | 93.5% | 33.3% | 84.3% | 57.1% | 81.0% | 1.4 | 0.2 |

TP = true positives, TN = true negatives, FP = false positives, FN = false negatives, SN = sensitivity, SP = specificity, PPV = positive predictive value, NPV = negative predictive value, ACC = accuracy, LR+ = positive likelihood ratio, LR− = negative likelihood ratio, G1 = Radiologists’ group 1, G2 = Radiologists’ group 2, Exp. = experience.
result herein reported should be considered in light of the pandemic peak – with very high disease prevalence – and could be not reproducible in low prevalence settings [25,26]. Being this a real-world data study, our results rely on a practical dichotomization of CXR reports: their potential generalizability must be therefore very carefully considered, especially when, in case of suspected COVID-19, we have a non-typical CXR for SARS-CoV-2 pneumonia. Clinical translation of our findings would still result in at least two different scenarios, also taking into account the unspecific nature of CXR findings in COVID-19 pneumonia and other viral pneumonias. First, when a patient displays suspicious symptoms for COVID-19 that can however be justified by alternative pathological CXR findings pointing to another disease (such as pleural effusion, pneumothorax, bacterial pneumonia), the management of the patient would remain the one that would have normally been followed in the detected condition. Otherwise, if in a general situation of increased patient influx to emergency departments a patient presents with suspicious symptoms for COVID-19 but no suggestive CXR findings or other findings that can justify a COVID-19 diagnosis, the use of chest CT could be considered [2,14]. However, taking into account the suboptimal diagnostic performance of chest CT – in particular the potentially low specificity and positive predictive value [14] – if the patient’s clinical conditions are stable and it is therefore possible to wait for RT-PCR confirmation of SARS-CoV-2 infection, preventive isolation would

| Group          | Reader          | Disease prevalence | TP    | TN    | FP    | FN    | SN    | SP    | PPV   | NPV   | ACC   |
|----------------|-----------------|--------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| First half of chest x-rays for each reader | Overall         | 73.4 %             | 172   | 47    | 25    | 27    | 86.4 %| 65.3 %| 87.3 %| 63.5 %| 80.8 %|
|                | Reader 1        | 76.9 %             | 64    | 14    | 7     | 6     | 91.4 %| 66.7 %| 90.1 %| 70.0 %| 85.7 %|
|                | Reader 2        | 63.5 %             | 35    | 20    | 7     | 12    | 74.5 %| 74.1 %| 83.3 %| 62.5 %| 74.3 %|
|                | Reader 3        | 84.8 %             | 26    | 3     | 2     | 2     | 92.9 %| 60.0 %| 92.9 %| 60.0 %| 87.9 %|
|                | Reader 4        | 86.4 %             | 18    | 3     | 0     | 1     | 94.7 %| 100.0 %|100.0 %|75.0 %  |95.5 % |
|                | Reader 5        | 70.0 %             | 16    | 4     | 5     | 5     | 76.2 %| 44.4 %| 76.2 %| 44.4 %|66.7 % |
| G1 (Exp. > 10y)| Reader 6        | 64.3 %             | 9     | 2     | 3     | 0     | 100.0 %|40.0 % |75.0 % |100.0 %|78.6 % |
|                | Reader 7        | 71.4 %             | 4     | 1     | 1     | 1     | 80.0 %| 50.0 %| 80.0 %| 50.0 %|71.4 % |
| Second half of chest x-rays for each reader | Overall         | 79.2 %             | 191   | 30    | 25    | 18    | 91.4 %| 54.5 %| 88.4 %| 62.5 %| 83.7 %|
|                | Reader 1        | 80.9 %             | 67    | 12    | 5     | 5     | 93.1 %| 70.6 %| 93.1 %| 70.6 %| 88.8 %|
|                | Reader 2        | 76.7 %             | 51    | 10    | 7     | 5     | 91.1 %| 58.8 %| 87.9 %| 66.7 %| 83.6 %|
|                | Reader 3        | 75.0 %             | 21    | 2     | 6     | 3     | 87.5 %| 25.0 %| 77.8 %| 40.0 %| 71.9 %|
|                | Reader 4        | 90.5 %             | 16    | 2     | 0     | 3     | 84.2 %| 100.0 %|100.0 %|40.0 %  |85.7 % |
|                | Reader 5        | 86.2 %             | 24    | 1     | 3     | 1     | 96.0 %| 25.0 %| 88.9 %| 50.0 %| 86.2 %|
| G2 (Exp. < 10y)| Reader 6        | 76.9 %             | 10    | 1     | 2     | 0     | 100.0 %|33.3 % |83.3 % |100.0 %|84.6 % |
|                | Reader 7        | 42.9 %             | 2     | 2     | 2     | 1     | 66.7 %| 50.0 %| 66.7 %| 57.1 %|57.1 % |

TP = true positives, TN = true negatives, FP = false positives, FN = false negatives, SN = sensitivity, SP = specificity, PPV = positive predictive value, NPV = negative predictive value, ACC = accuracy, G1 = Radiologists’ group 1, G2 = Radiologists’ group 2, Exp. = experience.

Table 3

Different diagnostic performance indexes for chest x-ray reading between the first and second half of interpreted chest x-rays for each reader and both radiologists’ groups.

Fig. 2. Sensitivity of each radiologist in each one’s first and second half of interpreted chest x-rays.
Fig. 3. Specificity of each radiologist in each one's first and second half of interpreted chest x-rays.

Fig. 4. Accuracy of each radiologist in each one's first and second half of interpreted chest x-rays.
remain the safest approach.

To summarize, the real-world diagnostic performance of CXR during the COVID-19 pandemic peak reached a relatively well-balanced overall accuracy (76%–86%), with an 89% sensitivity and a higher specificity for the more experienced radiologists (66%), lower for the less experienced radiologists (41%). Such data play in favour of the use of CXR as first line examination when chest imaging is required to aid the triage process of suspected COVID-19 patients during a pandemic peak.

CRediT authorship contribution statement
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Declaration of Competing Interest
A. Cozzi, F. Arpaia, G. Della Pepa, S. Tritella, P. Bertolotti, L. Menicagli, C.G. Monaco, L.A. Carbonaro, R. Spairani, and B. Babaei Paskeh, all declare that they have no conflict of interest and that they have nothing to disclose.

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S. Schiaffino declares to have received travel support from Bracco Imaging and to be member of speakers’ bureau/advisory board for Bayer Healthcare, Bracco, and General Electric Healthcare.

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