



Admission chest CT findings and risk assessment for stroke-associated pneumonia

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Abstract

Introduction Stroke-associated pneumonia (SAP) is a significant cause of morbidity and mortality after stroke. Various factors, including dysphagia and stroke severity, are closely related to SAP risk; however, the contribution of the baseline pulmonary parenchymal status to this interplay is an understudied field. Herein, we evaluated the prognostic performance of admission chest computed tomography (CT) findings in predicting SAP.

Methods We evaluated admission chest CT images, acquired as part of a COVID-19-related institutional policy, in a consecutive series of acute ischemic stroke patients. The pulmonary opacity load at baseline was quantified using automated volumetry and visual scoring algorithms. The relationship between pulmonary opacities with risk of pneumonia within 7 days of symptom onset (i.e., SAP) was evaluated by bivariate and multivariate analyses.

Results Twenty-three percent of patients in our cohort ($n = 100$) were diagnosed with SAP. Patients with SAP were more likely to have atrial fibrillation, COPD, severe neurological deficits, and dysphagia. The visual opacity score on chest CT was significantly higher among patients who developed SAP ($p = 0.014$), while no such relationship was observed in terms of absolute or relative opacity volume. In multivariate analyses, admission stroke severity, presence of dysphagia and a visual opacity score of ≥ 3 (OR 6.37, 95% CI 1.61–25.16; $p = 0.008$) remained significantly associated with SAP risk.

Conclusions Pulmonary opacity burden, as evaluated on admission chest CT, is significantly associated with development of pneumonia within initial days of stroke. This association is independent of other well-known predisposing factors for SAP, including age, stroke severity, and presence of dysphagia.

Keywords Acute ischemic stroke · Post-stroke complications · Infection · Pneumonia · Dysphagia

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Introduction

Stroke-associated pneumonia (SAP) is one of the most important complications observed after stroke that contributes to significant morbidity and mortality [1–5]. Various studies have focused on the identification of patients with high risk for this devastating complication and highlighted the role of a multitude of stroke-related features or patient-based characteristics, including but not limited to stroke severity, dysphagia, tube feeding, intubation, age, or atrial fibrillation as the key players in this interplay [6–8].

Despite the growing interest in the field, one major unknown in the development of SAP is the role played by the pre-stroke status of the pulmonary tissue. In this regard, history of chronic obstructive pulmonary disease (COPD) and asthma have been suggested as risk factors for SAP in some studies [4, 9, 10]. However, pulmonary functions and/

or anatomy are generally evaluated by patient history, physical examination, and at most by chest radiography as part of standard stroke care at the acute stage, which all provide very crude information regarding pulmonary pathophysiology. Interestingly, a recent report has shown imaging evidence of pulmonary infections within hours of symptom onset in 15% of stroke patients undergoing chest computed tomography (CT) at the time of admission [11]. More importantly, these patients were more likely to develop clinical signs of pneumonia during follow-up. Although it is not clear whether these CT findings represent signs of recent pulmonary infections predating stroke onset, or hyperacute infections triggered by factors such as aspiration after stroke, this observation highlights the potential of chest CT as an important tool to better understand the concept and pathophysiology of SAP. In this regard, the aim of the current study was to evaluate the prognostic performance of admission chest CT findings other than overt signs of pneumonia in predicting SAP.

Methods

The study was a retrospective analyses of ischemic stroke patients admitted to our tertiary level center between March 2020 and August 2020. After the initial report of COVID-19 in Turkey as of March 11, 2020, an institutional policy change has been made so that chest tomography was added to the acute stroke imaging protocol, which consisted of head CT and craniocervical CT-angiography until that time. This protocol was then employed to all patients admitted with suspicion of acute stroke after March 29, 2020. For the purposes of the current study, we evaluated ischemic stroke patients presenting within 24 h of symptom onset and who were admitted for at least 7 days. The following patients were excluded from the primary analyses: (i) patients with pulmonary imaging findings suggestive of COVID-19 or who were later documented to have a positive polymerase chain reaction result for SARS-CoV-2; (ii) patients with pneumonia at the time of admission, diagnosed either by the medical history prior to stroke or findings on chest CT examination; (iii) inappropriate CT studies with extensive artifacts. The study was approved by the local institutional review board. The data will be available from the corresponding author upon reasonable request.

We abstracted demographic and clinical data (age, gender, stroke risk factors, history of COPD, admission National Institutes of Health Stroke Scale (NIHSS) score, stroke etiology) from our prospectively collected institutional stroke database. We also collected admission white blood cell count, neutrophil-to-lymphocyte ratio, C-reactive protein (CRP), and erythrocyte sedimentation rate (ESR) levels. The presence or absence of dysphagia was determined based on

the results of bedside water swallow tests in our clinic as part of standard clinical care. As a composite metric for assessing risk of SAP, A2DS2 score was calculated in all patients [12]. This score ranging between 0 and 10 has been shown to have good accuracy for the prediction of SAP and relies only on clinical parameters (age ≥ 75 years: 1; atrial fibrillation: 1; dysphagia: 2; male sex: 1; NIHSS score 0–4: 0, 5–15: 3, ≥ 16 : 5), which are readily available for all stroke patients. We also extracted information regarding the use of invasive mechanical ventilation during admission from the electronic medical records of the patients. The development of pneumonia within 7 days of stroke onset was the primary outcome measure [7] and was determined to be present or absent based on the consultation notes of the infectious diseases department and their decision regarding initiation of antibiotic treatment, which is based on standard diagnostic algorithms based on the CDC guidelines taking into account the clinical examination findings and laboratory results of the patient, including radiological evaluation [13].

Chest CT scans were obtained without intravenous contrast administration using Somatom Force or Somatom Perspective CT scanner (Siemens Healthineers, Germany), if possible, during breath-hold. Scanning parameters were as follows: detector collimation 192×0.6 mm or 32×1.2 mm, tube voltage 70–120 kV, modulated mA using 70 mAs as reference (CareDose 4D, Siemens Healthineers), pitch 3 or 1.5, matrix 512×512 and slice thickness 3 mm or 5 mm. Images were reconstructed with a slice thickness of 1 mm or 1.25 mm.

CT findings were evaluated while being blinded to the clinical information. Respiration phase, whether the scan is obtained during inspiration or expiration, was visually assessed based on tracheal configuration. A visual score was used to determine the extent of pulmonary opacities based on the percentage per lobe as follows: 0 (none), 1 (affecting $< 5\%$), 2 (affecting 5–25%), 3 (affecting 26–49%), 4 (affecting 50–75%), and 5 (affecting $> 75\%$). Total CT score was calculated by summing the scores in five lobes (ranging from 0 to 25) [14]. Ground-glass opacities (due to non-infectious causes such as pulmonary edema or interstitial lung diseases), reticular densities, fibrotic changes, linear or dependent atelectatic areas were evaluated as part of this overall opacity score, while pleural pathologies including effusions were not taken into consideration (Fig. 1).

In addition to visual assessment, we also performed quantitative volumetric measurements of lung volumes and opacity volumes via an artificial-intelligence-based algorithm (CT Pneumonia, version 1.0.4, Research Frontier, Syngo.via, VB30, Siemens Healthineers). After lung and lobewise segmentation, two radiologists blinded to patient data (with 9 and 14 years of experience) visually checked the accuracy of segmentation for each slice and made manual corrections if needed. Lung volume, opacity volume, percentage

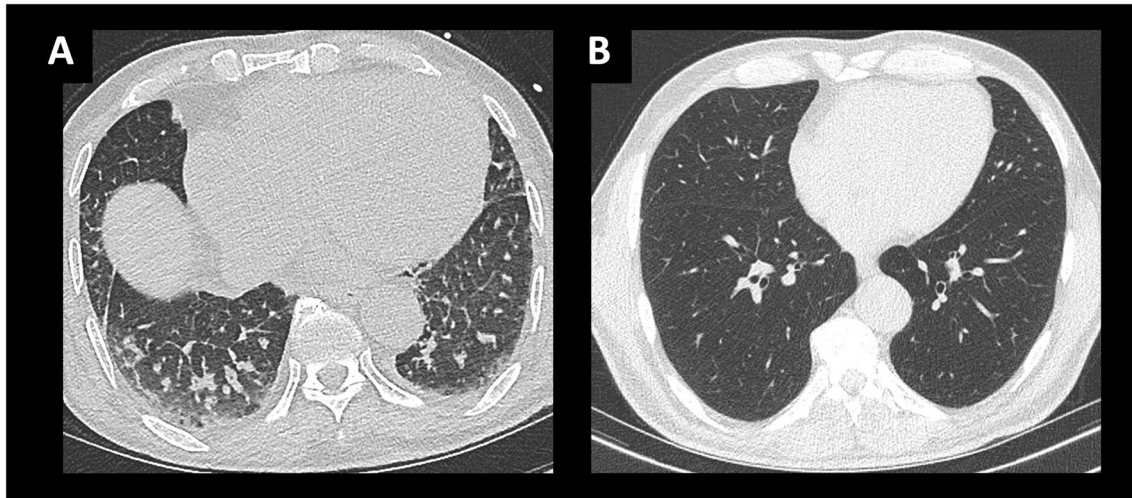


Fig. 1 Examples of the visual scoring algorithm used in the grading of pulmonary opacities. **A** Axial chest CT images of an 81-year-old male patient with left-sided MCA stroke obtained at the time of admission show dependent atelectasis, peribronchial, and slight interlobular septal thickenings in the right lower lobe. Also, atelectasis

was present in the left lower lobe (not shown). A total visual opacity score of 2 was assigned to the patient. **B** Axial CT images of a 54-year-old male patient; the chest CT evaluation was considered to be within normal limits, and a visual opacity score of 0 was assigned

of opacity with respect to lung volume and mean lung opacity (in Hounsfield units) were then automatically calculated by the software.

Statistical analysis

Categorical variables are expressed as n (%), and continuous variables are presented as median (interquartile range, IQR). Chi-square test and Mann–Whitney U test were used to determine group-wise differences. Logistic regression analysis was used for multivariate analysis, where a backward selection algorithm with a retention criteria of $p < 0.10$ was employed. A p value of < 0.05 was considered statistically significant. The analyses were done using IBM SPSS Statistics for Macintosh, Version 23.0 (Armonk, NY: IBM Corp).

Results

A total of 140 ischemic stroke patients within 24 h of symptom onset were admitted during the study period. Four patients with extensive artifacts on chest CT, two patients who had concurrent COVID infection, and additional nine patients with findings consistent with pneumonia were excluded. Of the remaining 125 patients, 100 were admitted for a duration of ≥ 7 days and comprised the final study population [median (IQR) age 75 (62–82) years; gender: 42 females (42%) and 58 males (58%)].

Chest CT imaging was obtained during the inspiratory phase of respiration in 42 patients and expiratory phase

in 58 patients. Automated lung volumetry revealed a total lung volume of 3920 (3212–4621) mL among patients imaged in the inspiratory phase, and 2901 (2362–3219) mL in the expiratory phase (Supplemental Table 1). The opacities in lung parenchyma involved 0.4 (0.0–5.9)% of the total lung volume in the former group, while they involved 3.8 (1.1–7.7)% of the lung when imaging was obtained during expiration. Visual semi-quantitative assessment provided more reproducible results among patients imaged at different phases of respiration (Supplemental Table 1).

During follow-up, a total of 32 patients (32%) were diagnosed with pneumonia; of these 23 (72%) occurred within 7 days and constituted the SAP cohort. The median time to diagnosis was 3 (3–5) days. Table 1 summarizes the characteristics of patients with and without a diagnosis of SAP. Patients developing SAP were more likely to have atrial fibrillation ($p < 0.001$) and history of COPD ($p = 0.010$). They also presented with more severe strokes ($p < 0.001$), and more frequently had dysphagia ($p < 0.001$). Overall, the A2DS2 score was approximately twice higher (8 vs. 4; $p < 0.001$) among patients developing SAP in comparison with patients who had no clinical signs of pneumonia during the first week of hospital stay. Despite numerically higher absolute or relative opacity volume, volumetric assessments regarding pulmonary parameters were not statistically different between both cohorts; however, on semi-quantitative assessment, the overall opacity score [4 (3–5) vs. 2 (1–5); $p = 0.014$] and an opacity score above the median (≥ 3) (78% vs. 43%; $p = 0.003$) was significantly associated with development of SAP on follow-up.

Table 1 Clinical and pulmonary imaging features of patients with and without SAP

	Patients with SAP (<i>n</i> =23)	Patients without SAP (<i>n</i> =77)	<i>p</i>
Age	78 (65–87)	74 (61–81)	0.125
Female gender	9 (39%)	33 (43%)	0.751
Stroke risk factors			
Hypertension	16 (70%)	60 (78%)	0.410
DM	8 (35%)	19 (25%)	0.338
CAD	10 (44%)	34 (44%)	0.954
AF	16 (70%)	21 (27%)	<0.001
History of COPD	7 (30%)	7 (9%)	0.010
Admission NIHSS score	22 (13–24)	6 (2–15)	<0.001
Stroke etiology			0.350
LAA	5 (22%)	20 (26%)	
CE	12 (52%)	26 (34%)	
SAO	0 (0%)	9 (12%)	
Other causes	1 (4%)	4 (5%)	
Undetermined	5 (22%)	18 (23%)	
Dysphagia	19 (83%)	19 (25%)	<0.001
A2DS2 score	8 (7–9)	4 (1–6)	<0.001
Admission WBC count	9.4 (7.6–12.6) × 10 ³ /mm ³	8.7 (7.2–10.4) × 10 ³ /mm ³	0.285
Admission N/L ratio	3.8 (2.3–6.4)	3.2 (2.2–5.0)	0.281
Admission ESR level	28 (13–52) mm/h	12 (5–26) mm/h	0.011
Admission CRP level	1.0 (0.6–7.4) mg/dl	0.9 (0.6–2.1) mg/dl	0.243
Invasive mechanic ventilation	10 (44%)	16 (21%)	0.029
Length of stay	39 (27–55) days	7 (7–16) days	<0.001
In-hospital mortality	3 (13%)	1 (1%)	0.037
Inspiratory-phase CT	7 (30%)	35 (45%)	0.200
Total lung volume	3217 (2598–3742) mL	3185 (2539–4154) mL	0.703
Mean lung density	–713 (–735 to –638) HU	–707 (–747 to –663) HU	0.800
Volume of opacities	89 (38–196) mL	51 (9–197) mL	0.207
Percentage volume of opacities	3.7 (1.1–7.7) %	1.9 (0.2–6.3) %	0.173
Number of pulmonary lobes with opacities	3 (2–4)	2 (1–4)	0.012
Visual opacity score	4 (3–5)	2 (1–5)	0.014
Visual opacity score ≥ 3	18 (78%)	33 (43%)	0.003

All numerical variables are expressed as median (IQR) and categorical variables as *n* (%)

AF atrial fibrillation, CAD coronary artery disease, CE cardio-aortic embolism, COPD chronic obstructive pulmonary disease, CRP C-reactive protein, DM diabetes mellitus, ESR erythrocyte sedimentation rate, LAA large artery atherosclerosis, NIHSS National Institutes of Health Stroke Scale, N/L neutrophil-to-lymphocyte ratio, SAO small artery occlusion, WBC white blood cell

In multivariate analyses, admission NIHSS score, presence of dysphagia and opacity score of ≥ 3 remained significantly associated with the development of SAP (Table 2). Due to the possibility of overfitting, we performed a second multivariate model where A2DS2 score was included as a composite parameter of related clinical features; here again opacity score ≥ 3 (OR 4.80, 95%CI 1.31–17.57), together with A2DS2 score, remained significantly associated with SAP. When the analyses were separately performed with respect to the phase of chest CT studies, an opacity score ≥ 3 increased the odds of SAP development of follow-up, yet the association was significant only in the expiratory phase

group (OR 4.90, 95% CI 1.08–22.26 for expiratory phase patients and OR 3.64, 95% CI 0.56–23.87 for inspiratory phase patients).

Patients developing SAP had a more complicated in-hospital course, with a higher prevalence of invasive mechanical ventilation (*p* = 0.029), a longer length of stay (*p* < 0.001), and a higher mortality rate (*p* = 0.037) (Table 1). However, opacity burden by itself showed no significant association with any of these prognostic endpoints.

We also performed two exploratory analyses to account for selection bias arising from patients not included into the analyses. When we repeated our logistic regression models

Table 2 Variables associated with SAP in multivariate models

Model 1	<i>Independent variables: atrial fibrillation, history of COPD, admission NIHSS score, dysphagia, invasive mechanical ventilation, admission ESR level, number of pulmonary lobes with opacities, visual opacity score ≥ 3</i>	
	OR (95% confidence interval)	<i>p</i>
Admission NIHSS score	1.12 (1.03–1.21)	0.007
Dysphagia	9.39 (2.32–38.00)	0.002
Visual opacity score ≥ 3	6.37 (1.61–25.16)	0.008
Model 2	<i>Independent variables: A2DS2 score, history of COPD, invasive mechanical ventilation, admission ESR level, number of pulmonary lobes with opacities, visual opacity score ≥ 3</i>	
	OR (95% confidence interval)	<i>p</i>
A2DS2 score	1.84 (1.38–2.46)	<0.001
Visual opacity score ≥ 3	4.80 (1.31–17.57)	0.018

COPD chronic obstructive pulmonary disease, *ESR* erythrocyte sedimentation rate, *NIHSS* National Institutes of Health Stroke Scale

without excluding patients with pulmonary imaging findings of pneumonia at admission, the results essentially remained unchanged (Supplemental Table 2). In a separate cox regression model, where patients without a 7-day inpatient follow-up were included, time to development of SAP was significantly associated with A2DS2 score and opacity score ≥ 3 on admission chest CT (Supplemental Table 3).

Discussion

This study can be considered as an opportunistic effort based on the readily available chest CT images that were obtained in acute stroke patients at the time of admission, as part of a policy change due to the COVID-19 pandemic. Our main finding is that pulmonary opacities deemed to be of non-infectious origin are significantly associated with the development of pneumonia within initial days of stroke. This association is independent of other well-known predisposing factors for SAP, including age, stroke severity, and presence of dysphagia, and was robust when the extent of opacities was evaluated by visual semi-quantitative scoring algorithms. Automated lung volumetry, on the other hand, was not helpful to delineate this relationship between SAP risk and pulmonary opacities.

Stroke-associated pneumonia is classically considered a complication that primarily stems from a combination of stroke-induced systemic immunosuppression and increased aspiration of nasopharyngeal contents [1]. Consistent with this pathophysiology, stroke features well-known to be associated with either phenomena such as old age, severe stroke, or impaired swallowing reflex appear as the major risk factors of SAP. In addition to all these factors, a recent study has highlighted that admission chest CT findings of stroke patients can provide valuable information regarding SAP

pathophysiology. In a consecutive series of 200 patients, de Jonge et al. have shown that imaging evidence of pneumonia can be present within hours of symptom onset, and its presence is closely related to clinical signs of pneumonia during follow-up [11]. While it is not unexpected to observe a close relationship between imaging and clinical signs of pneumonia, the role of other features observed in chest CT not considered as signs of overt infection is an unexplored field. Indeed, the recent COVID-19 pandemic has triggered a research interest for analyzing lung tissue that remains within the frame of standard stroke work-up and has shown that abnormal chest CT findings are not uncommon in stroke patients even when analyzed in just the apical segments of lungs, and do not always signify the presence of COVID-19 pneumonia or other infections [15, 16]. Our study is a further effort in this arena and highlights that pulmonary pathologies other than overt signs of infections on chest CT can be predictive of SAP. The use of dedicated chest CT imaging providing full pulmonary tissue coverage and addition of automated volumetric assessments are additional novelties of our research.

The pulmonary opacities evaluated as part of the visual score in our study are indicative of a multitude of pathologies such as infections, chronic interstitial diseases, or acute alveolar pathologies [17, 18]. In our primary analyses, we specifically excluded patients with findings suggestive of infection such as consolidation or centrilobular opacities at the time of admission. Nonetheless, it is still possible that an early-stage pneumonia might have been the culprit of opacities, specifically ground-glass opacities, in some of the remaining patients, and therefore confounded the observations related to the association between the opacity score and SAP. On the other hand, our results suggested that not only the presence but also the extent of opacities were related to SAP risk. Aside from an infectious origin, the opacities

might reflect interstitial disease, edema and/or fibrosis, all of which are related to basal lung reserve. The severity and extent of pulmonary opacities, which can be assessed by various scoring algorithms, are closely associated with disease severity and pulmonary functional capacity both in infectious and non-infectious conditions [19–23]. Furthermore, structural and functional changes observed in lungs due to aging or chronic pulmonary diseases are well known to increase susceptibility to infections [24, 25]. Therefore, it is plausible to think opacity burden as an imaging biomarker of pulmonary tissue with impaired functions and decreased lung aeration, and thereby reflect a milieu prone to pulmonary complications including infections after stroke.

Some limitations of our study merit consideration. First of all, our chest CT protocol was not standardized for the phase of respiration, as our cohort was comprised of acute stroke patients most of whom were not cooperative enough to hold their breath during the examination. This major limitation probably affected the interpretation of the results regarding the automated volumetric analyses and might have contributed to the neutral results in their relationship with SAP risk. The missing of minor pathologies such as linear or subsegmental atelectatic regions by automated volumetric algorithms [26] might have further contributed to the discrepancy with respect to visual assessment and automated quantification. Second, information on development of pneumonia during admission was not collected in a prospective fashion and was abstracted from the medical records of the patients. Although this might have caused an underdiagnosis of pneumonia, the standard of care in our stroke unit and neurocritical care is the consultation of all patients with fever to the infectious diseases department, which has a standard policy in terms of screening, diagnosing and treatment of pneumonia and other infections in stroke patients. However, future studies in this arena should make use of standardized SAP criteria and collect the information in a prospective fashion. Additionally, a pre-stroke pneumonia diagnosis, one of our exclusion criteria, was based on the use of antibiotics at the time of admission; therefore, patients with recent history of pneumonia who have completed their antibiotic regimen could erroneously be included in the study. However, considering that radiological resolution of pneumonia is comparably slower in comparison with clinical improvement and as admission chest CT findings were also used to exclude pneumonia, we believe we have minimized a selection bias in this regard. Finally, we have categorized opacity score arbitrarily based on the group median; this threshold might not reflect the optimal cut-off value in predicting SAP risk; however, it still provides a straightforward approach that can be employed at the bedside especially in comparison with computational volumetric tools.

In conclusion, our findings provide novel information regarding the pathophysiology of SAP. In concordance

with the observations of the study by de Jonge et al., imaging evidence of pneumonia is not uncommon in a significant proportion of stroke patients even at the time of admission [11]. Additionally, pulmonary opacities identified by chest CT, which can be considered as a composite burden of pulmonary pathologies representing either an initial imaging stage of pneumonia or a pulmonary tissue with impaired function due to various etiologies (e.g., chronic lung disease, pulmonary edema, etc.), are a predisposing factor in the development of SAP. Understanding the factors that contribute to the association of pulmonary opacity load with impending risk of pneumonia would not be only important for elucidation of the role of pulmonary reserve in pneumonia risk, but also for pinpointing high-risk patients who are prone to this devastating complication. Considering the cost and associated radiation exposure, it is not prudent to consider routine chest CT as part of standard stroke care for the time being; however, strategies enabling the evaluation of pulmonary tissue and function in a more practical and radiation-free setting (such as lung ultrasonography) could still be developed, especially for high-risk patients or those with known chronic lung disease, with the ultimate goal to optimize clinico-radiologic tools for estimating SAP risk. This optimization is undoubtedly critical for developing and testing strategies aimed to prevent SAP, including oral hygiene interventions or prophylactic antibiotic trials. In addition, these tools could help in close monitoring of high-risk patients or early recognition of SAP, which is a treatable complication of acute stroke, especially with the advent of state-of-the-art rapid microbiological identification and targeted antibiotic treatment strategies.

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Declarations

Conflict of interest SAD, GD; MC, EA have no conflict of interest. MAT received speaker honorarium from Daiichi-Sankyo, Nutricia, Sanofi, Abbott and served on advisory boards of Abbott, Boehringer-Ingelheim, Nutricia, Fresenius, Daichii-Sankyo, Bayer. EMA received speaker honorarium from Daiichi-Sankyo, Nutricia, Abbott, Sanofi and served on advisory boards of Pfizer, Abbott, Nutricia, Fresenius, Daichii-Sankyo, Bayer.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was waived due to the retrospective nature of the study.

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