Computed Tomographic Features of Lung Parenchyma Over Time after Cardiopulmonary Resuscitation

Hyeon Mi Ryu, MD, Jin Young Yoo, MD*, Sung Jin Kim, MD
Department of Radiology, Chungbuk National University Hospital, Cheongju, Korea

Purpose To identify the key CT features of lung parenchyma over time after cardiopulmonary resuscitation (CPR).

Materials and Methods In total, 72 patients underwent CT after CPR. Because the median time from return of spontaneous circulation (ROSC) to CT was 1 h 3 min, we divided patients into two groups: ≤ 1 h (group 1) and > 1 h (group 2), based on the ROSC to CT time. We analyzed and compared various lung parenchymal CT findings between groups.

Results Each group included 36 patients. Using statistical analysis, we identified seven statistically significant imaging features. Gradient (p = 0.010), lobular gradient (p = 0.017), diffuse pattern (p = 0.000), upper distribution (p = 0.032), and peripheral portion sparing (p = 0.000) were more common in group 1 than in group 2. Dependent density (p = 0.010) and lobular consolidation (p = 0.010) were more common in group 2 than in group 1.

Conclusion The gradient and lobular gradient tended to disappear over time after ROSC. In terms of distribution, a diffuse pattern with upper predominance and peripheral portion sparing tended to disappear over time. However, the dependent density and lobular consolidation tended to increase over time in the lung parenchyma after CPR.

Index terms Cardiopulmonary Resuscitation; Tomography; Lung

INTRODUCTION

Many patients receive cardiopulmonary resuscitation (CPR) due to cardiac arrest of various causes. Because CPR involves artificially circulating blood by repetitive ster-
num compression to revive the patient from cardiac arrest, the process may result in excessive physical force to the patient’s thorax. Thus, physical injury to the thorax is an inevitable complication of the chest compression during CPR.

However, parenchymal lung injury associated with CPR has hardly been addressed to date. Additionally, there are no studies assessing the changes in imaging findings of the lung parenchyma over time after CPR.

The limited understanding of the CT findings related to the lung parenchyma after CPR as well as the changes in these patterns could lead to misdiagnosis and inappropriate or excessive treatment.

Therefore, we sought to identify the key CT features of lung parenchyma over time after CPR.

**MATERIALS AND METHODS**

**SETTING AND SUBJECTS**

Our retrospective study was approved by our hospital’s Institutional Review Board (IRB No. 2018-06-005). This study was conducted at the tertiary care emergency department of a university hospital in Cheongju, Republic of Korea. We enrolled out-of-hospital cardiac arrest patients who had been admitted to the emergency department and were successfully resuscitated by CPR from February 2012 through February 2017.

A total of 72 patients were included. The following patients were excluded: patients who failed to achieve hemodynamic stabilization after return of spontaneous circulation (ROSC); patients who did not undergo a chest CT after ROSC; patients for whom the interval between ROSC and CT (ROSC to CT interval) was not noted; patients who showed negative findings on CT (no remarkable finding of the lung parenchyma on chest CT, or no changes in the lung parenchyma since a previous CT examination); and patients who had preexisting parenchymal pulmonary disease.

Because the median ROSC to CT interval of the 72 enrolled patients was 1 h 3 min, we divided patients into two groups on the basis of the ROSC to CT interval: ≤ 1 h (group 1) and > 1 h (group 2).

**CT EXAMINATIONS**

CT scans were performed with a 64-channel multidetector CT (MDCT) unit (Brilliance 64; Philips Medical Systems, Cleveland, OH, USA). The scanning protocol included data acquisition in one or two phases: the unenhanced and enhanced phases (65-s delay after contrast injection) depending on the situation, and the image was evaluated with a lung window setting (window width: 1500, level: -700). The scanning parameters were as follows: pitch, 1.5; X-ray tube voltage, 120 kV; and tube current, 140 mA (249 mA). The slice thickness of the axial image was 2.5 mm. Intravenous contrast agent was administered to 60 patients and no contrast media was administered to 12 patients.

**IMAGE ANALYSIS**

Two radiologists with 30 and 10 years of experience in pulmonary radiology and a forth-
year radiology resident analyzed the images and were blinded to the ROSC to CT interval. The imaging review was performed in two sessions. In the first session, each of the three assessors reviewed each selected image separately, after which the three assessors reached a consensus over cases in which their evaluations were not consistent.

We analyzed various CT findings of the lung parenchyma for each group, including the distribution (sparing of the peripheral portion, dependent density, gradient, lobular gradient or consolidation, and along the bronchovascular bundle) of ground-glass attenuation (GGA) or consolidation, and the presence of pleural effusion, centrilobular nodules, and thickening of the interlobular septum or bronchovascular bundle. We defined the peripheral-sparing portion as the GGA/consolidation that was present in less than one-third of the periphery of the lung parenchyma (periphery: within 5 mm from the pleura). The gradient was defined as GGA/consolidation that was minimal in the anterior part of the whole lung and became greater toward the dependent part of the lung. The lobular gradient was defined as GGA/consolidation that was minimal in the anterior part of the secondary pulmonary lobules and became greater toward the dependent part within the secondary pulmonary lobule (Figs. 1, 2). Lobular consolidation was defined as consolidation filling the secondary pulmonary lobules in the absence of a gradient (Fig. 3), and lobular density was defined as a combination of lobular gradient and lobular consolidation. The dependent density was defined as GGA/consolidation seen only on the dependent portion of both upper lobes or both lower lobes (Fig. 4). Air-bronchogram was defined as a phenomenon in which air-filled bronchi are made visible by the opacification of the surrounding alveoli.

We categorized the imaging findings as “yes” and “no,” and we scored the finding as “1” if it was predominant.

STATISTICAL ANALYSIS
We compared various imaging parameters of pulmonary CT, regardless of the pathophysiology, between groups 1 and 2. We compared the values for each parameter using Student’s t test. All analyses were performed with SPSS (version 23.0; IBM Corp., Armonk, NY, USA) and p values of less than 0.05 were considered to be statistically significant.

RESULTS

DEMOGRAPHIC FEATURES
Our study enrolled 72 patients who underwent CPR. The mean age of the patients was 57.4 ± 19.53 years, and the mean ages in groups 1 and 2 were 63.5 years (range: 22 to 92 years) and 51.3 years (range: 1 to 76 years), respectively (p = 0.610) (Table 1). Of the 72 patients, 44 were males and 28 were females. In both groups, the male-to-female ratio was the same (22:14).

Patients included in the study had experienced cardiopulmonary arrest due to various causes: cardiac arrest (25 patients, 34.7%), asphyxia (8 patients, 11%), trauma (5 patients, 6.9%), hanging (5 patients, 6.9%), drowning (4 patients, 5.6%), brain injury (2 patients, 2.7%), metabolic causes (4 patients, 5.5%), operation-related (2 patients, 2.7%), and unknown causes (17 patients, 23.6%; patients who died after arrest).
OVERALL PULMONARY CT FEATURES OF POST-ROSC PATIENTS

Of the 72 patients, 64 (88.9%) showed bilateral GGA/consolidation on CT scans and the remaining 8 patients (11.1%) showed unilateral GGA/consolidation (Table 2).

The localization of GGA/consolidation was divided into three categories: diffuse, focal, and mixed. Diffuse GGA/consolidation was defined as even GGA/consolidation on the axial plane, regardless of anatomical barriers. Focal GGA/consolidation was defined as uneven GGA/consolidation on the axial plane. Mixed type was defined as a mixture of diffuse and focal types on the axial plane. Seventeen patients showed diffuse GGA/consolidation (23.6%) and 40 showed focal GGA/consolidation (55.6%).

The distribution of GGA/consolidation was categorized into upper, middle, and lower, based on the total height divided by three, rather than by lobe. The three groups, upper, middle, and lower, accounted for nearly similar percentages: 63 patients (87.5%), 66 patients (91.7%), and 66 patients (91.7%), respectively.

Another categorization of GGA/consolidation distribution was based on lobar anatomy: lobar, random, and whole. Lobar distribution was defined as GGA/consolidation filling one or more lobes. Whole distribution was defined as GGA/consolidation that filled one or both lungs. GGA/consolidation that was not categorized as showing a lobar or whole distribution was defined as having a random distribution. Lobar distribution accounted for 16.7% (12 patients), whole distribution accounted for 43.1% (31 patients), while a random distribution was seen in 33.3% (24 patients). Only 3 patients (4.2%) in this study demonstrated sparing of the peripheral portion. Forty-five patients (62.5%) showed dependent density. A gradient was seen in 29 patients (40.3%).

Lobular density was seen in 34 patients (47.2%). A lobular gradient was seen in 22 patients.

Table 1. Demographic Features and Causes of Arrest of the Enrolled Post-ROSC Patients

|                        | Total    | Group 1  | Group 2  |
|------------------------|----------|----------|----------|
| Age, years             | 57.4 ± 19.5 | 63.5 ± 17.8 | 51.3 ± 19.6 |
| Sex                    |          |          |          |
| Male                   | 44       | 22       | 22       |
| Female                 | 28       | 14       | 14       |
| Cause, n (%)           |          |          |          |
| Cardiac arrest         | 25 (34.7) | 13 (36.1) | 12 (33.3) |
| Myocardial infarction  | 20 (27.8) | 12 (16.7) | 8 (11.1)  |
| Arrhythmia             | 4 (5.6)  | 2 (2.8)  | 2 (2.8)  |
| Variant angina         | 2 (2.8)  | 2 (2.8)  | 0 (0)    |
| Asphyxia               | 8 (11)   | 3 (8.3)  | 5 (13.9) |
| Trauma                 | 5 (6.9)  | 3 (8.3)  | 2 (5.6)  |
| Hanging                | 5 (6.9)  | 2 (5.6)  | 3 (8.3)  |
| Drowning               | 4 (5.6)  | 1 (1.3)  | 3 (8.3)  |
| Brain injury           | 2 (2.7)  | 0 (0)    | 2 (5.6)  |
| Metabolic              | 4 (5.5)  | 3 (8.3)  | 1 (1.3)  |
| Operation-related      | 2 (2.7)  | 2 (5.6)  | 0 (0)    |
| Unknown                | 17 (23.6)| 9 (25)   | 8 (22.2) |

ROSC = return of spontaneous circulation
(30.6%), and 28 patients (38.9%) showed lobular consolidation.

Only 11 patients (15.3%) showed GGA/consolidation mainly along the bronchovascular bundle.

Forty-nine patients (68.1%) showed air-bronchogram, a phenomenon in which air-filled bronchi are made visible by opacification of the surrounding alveoli. Pleural effusion, unilateral or bilateral, was seen in 19 patients (26.4%). Nine patients (12.5%) showed centrilobular nodules. Thickening of the interlobular septum was seen in 26 patients (36.1%), and thickening of the bronchovascular bundle was seen in 10 patients (13.9%).

### CHANGES IN POST-ROSC PULMONARY CT FEATURES OVER TIME

The incidences of gradient and lobular gradient were significantly higher in group 1 than in group 2 (p for gradient = 0.010; p for lobular gradient = 0.017), which might suggest that the
gradient and lobular gradient decrease over time (Table 3).

On the other hand, dependent density and lobular consolidation (both \( p = 0.010 \)) were significantly more common in group 2 than in group 1, which might suggest that both these fea-

| CT Finding                              | ROSC to CT Time, Hour | Mean   | Standard Deviation | \( p \)-Value |
|-----------------------------------------|-----------------------|--------|--------------------|---------------|
| Bilateral                               | \( \leq 1 \)         | 0.889  | 0.3187             | 0.178         |
|                                         | \( > 1 \)             | 0.833  | 0.3870             |               |
| Unilateral                              | \( \leq 1 \)         | 0.111  | 0.3187             | 0.178         |
|                                         | \( > 1 \)             | 0.167  | 0.3780             |               |
| Diffuse                                 | \( \leq 1 \)         | 0.333  | 0.4781             | 0.000         |
|                                         | \( > 1 \)             | 0.139  | 0.3507             |               |
| Focal                                   | \( \leq 1 \)         | 0.471  | 0.5000             | 0.068         |
|                                         | \( > 1 \)             | 0.694  | 0.4672             |               |
| Mixed                                   | \( \leq 1 \)         | 0.250  | 0.4392             | 0.264         |
|                                         | \( > 1 \)             | 0.194  | 0.4014             |               |
| Upper                                   | \( \leq 1 \)         | 0.917  | 0.2803             | 0.032         |
|                                         | \( > 1 \)             | 0.833  | 0.3780             |               |
| Middle                                  | \( \leq 1 \)         | 0.944  | 0.2323             | 0.090         |
|                                         | \( > 1 \)             | 0.889  | 0.3187             |               |
| Lower                                   | \( \leq 1 \)         | 0.889  | 0.3187             | 0.090         |
|                                         | \( > 1 \)             | 0.944  | 0.2323             |               |
| Gradient                                | \( \leq 1 \)         | 0.444  | 0.5040             | 0.010         |
|                                         | \( > 1 \)             | 0.278  | 0.4543             |               |
| Lobular gradient                        | \( \leq 1 \)         | 0.389  | 0.4944             | 0.017         |
|                                         | \( > 1 \)             | 0.250  | 0.4392             |               |
| Lobular consolidation                   | \( \leq 1 \)         | 0     | 0                  | 0.000         |
|                                         | \( > 1 \)             | 0.083  | 0.2803             |               |
| Dependent                               | \( \leq 1 \)         | 0.444  | 0.5040             | 0.000         |
|                                         | \( > 1 \)             | 0.778  | 0.4216             |               |
| Peripheral portion sparing              | \( \leq 1 \)         | 0.083  | 0.2803             | 0.000         |
|                                         | \( > 1 \)             | 0      | 0                  |               |
| Along the bronchovascular bundle        | \( \leq 1 \)         | 0.194  | 0.4014             | 0.050         |
|                                         | \( > 1 \)             | 0.111  | 0.3187             |               |
| Air-bronchogram                         | \( \leq 1 \)         | 0.694  | 0.4672             | 0.620         |
|                                         | \( > 1 \)             | 0.667  | 0.4781             |               |
| Pleural effusion                        | \( \leq 1 \)         | 0.278  | 0.4543             | 0.599         |
|                                         | \( > 1 \)             | 0.250  | 0.4392             |               |
| Centrilobular nodules                   | \( \leq 1 \)         | 0.167  | 0.3780             | 0.599         |
|                                         | \( > 1 \)             | 0.083  | 0.2803             |               |
| Thickening of the interlobular septum   | \( \leq 1 \)         | 0.250  | 0.4392             | 0.585         |
|                                         | \( > 1 \)             | 0.222  | 0.4216             |               |
| Thickening of the bronchovascular bundle| \( \leq 1 \)         | 0.167  | 0.3780             | 0.519         |
|                                         | \( > 1 \)             | 0.139  | 0.3507             |               |

ROSC = return of spontaneous circulation
CT Features of Lung Parenchyma Over Time after CPR

In terms of distribution, a diffuse, upper distribution, and peripheral-portion sparing were significantly more common in group 1 than in group 2 (p for diffuse distribution = 0.000, p for upper distribution = 0.032, and p for peripheral-portion sparing = 0.000).

No other CT features differed significantly between the two groups (p ≥ 0.05).

**DISCUSSION**

With thinner image slices, faster speed, and multifaceted reconstitution capacity, MDCT is becoming increasingly useful for patients who have experienced cardiopulmonary arrest or trauma. MDCT is particularly useful for emergency patients, because it requires minimal effort and allows rapid examination. In this study, we found CT features that were significantly different between groups defined by their ROSC to CT interval. Interestingly, the gradient of both the whole lung parenchyma and of the secondary pulmonary lobule tended to decrease over time after ROSC.

Cho et al. (1) reported that the most common findings of lung injuries after CPR were bilateral ground-glass opacity and consolidation, usually in the dependent area of both lungs. They divided imaging features into patterns (consolidation only, GGA only, or both), distribution (unilateral/bilateral, dependent area, and peribronchovascular), and associated thoracic findings (none, pleural effusion/hemothorax, pneumothorax, rib fracture, and sternal fracture). We defined patterns by subdividing these categories of imaging findings.
In another previous study, Cha et al. (2) reported that CPR-related lung contusion was primarily observed in the posterior half of the lung. This may be because an increase in the intrathoracic pressure generated by chest compression exerts a high hydrostatic pressure on this area of the lung; this pressure is further increased because of the patient’s supine position during CPR. However, in our study, the findings for group 1 showed that more changes in lung parenchyma occurred in the upper regions. In group 2, an upper distribution was significantly less frequently observed. On the other hand, the frequency of dependent density was significantly greater in group 2 than in group 1, which is similar to the findings of the previous study by Cha et al. (2) This result for group 1 in our study seems to be different from that of the previous study because it takes into account the time taken from ROSC to CT.

The mechanism underlying lung injury caused by chest compressions involves three pathways. First, it can represent pulmonary hemorrhage and edema caused by the destruction of the alveolar follicular membrane as a result of the force of chest compressions. Blood and proteins can often accumulate in the air space by direct blowing out to the chest wall, with in-

Fig. 3. CT features of a 1-year-old boy whose return of spontaneous circulation to CT interval was 1 h 22 min; lobular consolidation in the right middle and both lower lobes. On chest CT with lung setting, consolidation fills the secondary pulmonary lobules, without a gradient (arrows).

Fig. 4. CT features of a 79-year-old woman whose return of spontaneous circulation to CT interval was 2 h 21 min, with only dependent density in both lower lobes. On chest CT with lung setting, there are consolidations in dependent portion of both lower lobes (arrows).
jury to the adjacent or opposite lung regions (3). The second possible mechanism is reperfusion injury of the lungs after cardiac arrest. Oxidative stress caused by the oxidation of lipids or proteins, by intracellular free radical generation, can reduce membrane function. Local inflammatory mechanisms, including release of cytokines, upregulation of cell adhesion molecule expression, and subsequent induction of leukocyte accumulation, are believed to contribute to reperfusion injury (4). Third, aspirated gastric fluid or oropharyngeal secretions may damage the lungs. Patients who have received CPR often experience mental changes, and thus show difficulty in swallowing. Image findings of respiratory pneumonitis are difficult to distinguish from image findings of lung injury, and it is possible that these entities may exist simultaneously in patients who have experienced loss of consciousness in a situation involving CPR (5, 6).

This study had several limitations. First, this was a retrospective study; therefore, it is possible that unforeseen confounders might have been included. Second, we did not compare the CT findings of a given patient over time, but compared CT features of patients in the two groups defined by their ROSC to CT interval; therefore, this study reflects trends rather than actual changes. Third, the number of patients included is small, limiting the statistical analysis. Finally, different causes for arrest may result in different trends; in the future, subgroup studies of each cause should be performed.

In conclusion, gradient and lobular gradient on CT tend to disappear over time after ROSC. However, dependent density and lobular consolidation tend to increase over time.

Conflicts of Interest
The authors have no potential conflicts of interest to disclose.

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심폐소생술 후 시간의 흐름에 따른 폐 실질의 전산단층촬영 소견 변화에 관한 연구

류현미 · 유진영* · 김성진

목적 본 연구는 심폐소생술 후 시간이 지남에 따른 폐 실질의 전산화단층촬영 소견의 변화 양상을 확인하고자 시작되었다.

대상과 방법 심폐소생술 후 전산화단층촬영을 한 72명의 환자를 대상으로 하였다. 자발 순환 회복부터 전산화단층촬영을 하기까지 걸린 시간의 중앙값이 1시간 3분이므로, 자발 순환 회복부터 전산화단층촬영까지 걸린 시간을 기준으로 1시간 이하인 그룹(그룹1)과 1시간 초과인 그룹(그룹2) 두 그룹으로 나누어 각 그룹의 다양한 영상 소견을 비교하였다.

결과 두 그룹에는 각각 36명의 환자가 속하였으며 통계학적인 분석을 통해서 두 그룹을 비교하였을 때 총 7가지 영상의학적 소견이 유의한 차이를 보였다. 먼저 그룹 1에서는 농도 경사(gradient, $p = 0.010$)와 소엽성 농도 경사(lobular gradient, $p = 0.017$)가 통계학적으로 유의하게 그룹 2보다 많았다. 그 외 체위 의존 음영(dependent density, $p = 0.010$)과 소엽성 경화(lobular consolidation, $p = 0.010$)는 통계학적 분석으로 통해 그룹 2에서 유의미하게 높게 나타났다. 음영의 분포는 그룹 1에서 미만성($p = 0.000$) 그리고 상부($p = 0.032$)에 통계학적으로 유의하게 높게 나타났으며 반면부 보존(sparing peripheral portion, $p = 0.000$)은 그룹 1에서 더 유의하게 높게 나타났다.

결론 농도 경사와 소엽성 경사는 자발 순환 회복 후 시간이 지남에 따라 사라지는 경향이 있다. 음영의 분포는 미만성, 상부, 그리고 반면부 보존이 시간이 지남수록 사라지는 경향이 있다. 반면 체위 의존 음영과 소엽성 경화는 시간이 지남수록 더 증가하는 경향이 있다.

충북대학교병원 영상의학과

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