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Optimizing Triage in Chemical Disasters: Validation of Modified IGSA Criteria for Hydrofluoric Acid Exposure

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Abstract

Objective: This study aimed to develop and validate the modified irritant gas syndrome agent (IGSA) criteria, utilizing readily available triage information and epidemiologic data to efficiently segregate patients based on the severity of hydrofluoric acid (HFA) exposure.
Methods: A retrospective analysis of 160 patients exposed to HFA was performed to develop the criteria and assess the criteria's efficacy, focusing on age, respiratory rate, and compliance with IGSA standards. The criteria's validity was assessed by comparing clinical outcomes between patients meeting the modified IGSA (mIGSA) criteria and those who did not as external and internal.
Results: The mIGSA criteria (or AIR criteria) consisting of the 3 clusters of age greater than 49, IGSA criteria satisfied, and respiratory rate greater than 19 was developed. The area under curve of receiver operating characteristic curve for prediction of the risk of confirmed HFA injury according to AIR criteria was 0.8415 at the external validation.
Conclusions: The mIGSA criteria offer a significant improvement in the triage of HFA exposure incidents, facilitating rapid identification and prioritization of patients with potentially severe outcomes. Future research should aim to further validate these criteria across diverse emergency scenarios, reinforcing their utility in global health emergency preparedness.

Hydrogen fluoride (HFA) is an industrial chemical used as a source of fluorine. HFA is a typical inorganic acid used for manufacturing, etching, and cleaning electronic products, and vaporizes at a room temperature of 19.5°C or greater.[1–4] On September 27, 2012 at 15:43, 2 workers at Hube Globe chemical factory in Gumi City tried to transfer aqueous HFA without personal protective equipment (PPE), and explosive vaporization occurred.[5–7] Approximately 8 tons of HFA leaked, and factory workers as well as thousands of rural residents nearby were exposed to HFA gas for nearly 4 hours. The length of exposure was partly due to a delay because of the local governmental scale determination of HFA exposure range, and evacuation decision-making for residents had been delayed due to late disaster situation identification and analysis.[5,6] Finally, policemen evacuated some 600 residents within a radius of 0.3 kilometers from the HFA leak area.[8] Due to a lack of proper PPE and delayed use of calcium hydroxide (acid neutralizer), the HFA leak lasted over 8 hours.[5,6] At that time, there was no provision on PPE against an HFA leak to the local community. Consequently, 5 workers died on scene and at least 18 were injured, and there was extensive physical and environmental damage to crops and the nearby residential community.[5,6]

Due to the HFA leak, many patients visited the local hospitals, resulting in outpatient clinic and emergency department (ED) overcrowding, causing a major disruption to hospital functioning. Evaluating the severity of the patients' condition in the early stages of exposure without an ED examination was difficult, except for patients with extensive exposure causing abnormal vital signs or mental status. Although there have been several reports on the chronic psychological impact as well as the occupational and environmental medicine effects of the 2012 Gumi City HFA leak disaster, acute timeline studies are limited.[6,9,10]

Exposure to HFA can cause damage to the eyes, skin, respiratory system, and digestive tract, and is associated with burns when it comes in contact with skin or is inhaled.[4,11–15] A prior study[16] presented a chemical triage criteria, which considered 2 of the 3 clusters of signs and symptoms (**respiratory**: shortness of breath, wheezing, coughing, and choking; **chest**

discomfort: tightness, pain, and burning; **eye, nose and/or throat**: pain, irritation, and burning). These were used to create the irritant gas syndrome agent (IGSA) triage criteria.

The aim of this study is to develop and validate a modified IGSA (mIGSA) criteria, specifically tailored for triage in HFA exposure incidents. The revised criteria, also referred to as AIR criteria, aims to provide a swift and accurate method for classifying the severity of exposure and prioritizing patient treatment in chemical disaster scenarios. The need for such criteria arises from the limitations observed in existing IGSA protocols during the 2012 Gumi City chemical spill incident.

Methods

Study Design

This study used a retrospective medical chart review of all living patients > 18 years of age who visited the ED of the Soonchunhyang Gumi University Hospital after the HFA spill at the Hube Globe chemical factory from 16:00 on September 27, 2012, to 16:00 on September 28, 2012, with chief complaints of direct or indirect exposure to HFA. Soonchunhyang Gumi University Hospital has 400 inpatient beds, 20 ED beds, and a secondary tiered hospital. Direct exposure to HFA was defined as inhalation, splashing on skin, etc. Indirect exposure to HFA was defined as ingestion or contact with fruits exposed by HFA, etc.

Sample Size and Selection

The sample size was determined using comparison of the area under the curve (AUC) with a null hypothesis value. Area under receiver operating characteristic (ROC) curve was set at 0.8, null hypothesis AUC value 0.5, prevalence (ratio of positive cases/total sample size) 0.5, with an alpha error probability of 0.05, and power (1 - beta probability) was designated as 0.8. As a result, the calculated appropriate total sample size was determined to be 32, with a number of positive cases (n = 16) and a number of negative cases (n = 16). This study focused on a total of 160 patients who were exposed to HFA within the specified period. For the validation of the mIGSA criteria, the authors included 58 patients, dividing them into confirmed HFA injury (n = 41) and no HFA injury (n = 17) based on retrospective medical chart reviews.

Triage Criteria Development

The development of the mIGSA began with the previously developed IGSA criteria which considered satisfied when including 2 of the 3 clusters of signs and symptoms (**respiratory**: shortness of breath, wheezing, coughing, and choking; **chest discomfort**: tightness, pain, and burning; **eye, nose and/or throat**: pain, irritation, and burning).[16]

External Validation

When validating the mIGSA criteria, HFA injury was used as the dependent variable.[16] The area under the ROC curve (AUC) for the IGSA criteria was calculated using data from a total of 58 patients, including those with confirmed HFA injury and those without (Figure 1; Table 1). Comparing the analysis of symptoms, signs, and the 3 clusters of IGSA criteria, as well as IGSA criteria for a total of 58 actual patients comprised of confirmed HFA injury and no HFA injury is covered in Supplementary Table 1.

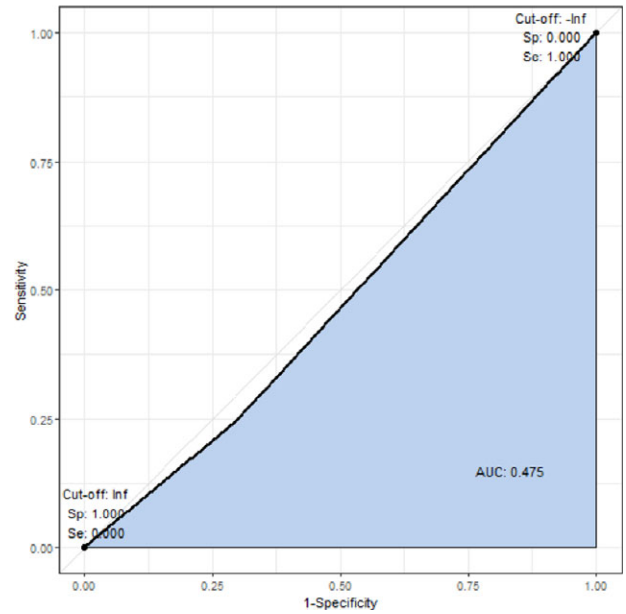

Figure 1. External validation of the IGSA criteria for a total of 58 actual patients for predicting the risk of confirmed HFA injury. AUC, the area under the curve; IGSA, irritant gas syndrome agent; Satisfying IGSA criteria[16] means meeting 2 out of 3 clusters of signs and symptoms criteria (respiratory: shortness of breath, wheezing, coughing, and choking; chest discomfort: tightness, pain, and burning; eye, nose and/or throat: pain, irritation, and burning); HFA, hydrofluoric acid; Se, sensitivity; Sp, specificity; ROC, receiver operating characteristic; For external validation of the IGSA criteria for a total of 58 actual patients to predict the confirmed HFA injury, the AUC with sensitivity and specificity in the ROC curve was conducted.

The development of the modified IGSA criteria

Gender, age, the IGSA criteria, vital signs (including systolic blood pressure [SBP], diastolic blood pressure [DBP], heart rate [HR], respiratory rate [RR], oxygen saturation, and body temperature [BT]), and patient distance from the location of the incident were set as independent variables.[16] The dependent variable was set as the presence or absence of confirmed HFA injury. This was compared to the IGSA criteria[16] for 58 patients (41 with confirmed HFA injury and 17 with no HFA injury) (Table 1). Univariate logistic regression analysis (ULRA) and multivariate logistic regression analyses (MLRA) were performed to determine which independent variables significantly affected the rate of HFA injury (Table 2). Statistical significance was determined to be P < 0.05. The sensitivity and specificity in the ROC curve of the continuous value of independent variables significant (P < 0.05) in Table 2 were investigated for predicting the risk of confirmed HFA injury (Figure 2). In the MLRA, the full model was defined as the model that included independent variables found to be statistically significant (P < 0.05) in the ULRA (Univariate Logistic Regression Analysis). The final model was defined as the model where continuous variables in the full model were replaced with categorized variables based on the cutoff values presented in Figure 2 (Table 2). The ROC curve for predicting the risk of confirmed HFA injury according to MLRA as the full model and final model was investigated for AUC evaluation (Figure 3). The nomogram of logistic regression in the final model for predicting the risk of confirmed HFA injury was investigated for establishing the definition of the mIGSA criteria as satisfactory if over 80% probability (Figure 4).

Internal validation of the modified IGSA criteria

Calibration plots with local regression with 500 bootstrapping samples were performed to get the nomogram for internal validation of the mIGSA criteria using the 58 patient data to confirm HFA injury status (Figure 5).

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Table 1. Comparing analysis of gender, age, IGSA criteria, vital signs, patient distance from the location of the incident, and oxygen saturation for a total of 58 actual patients comprised of confirmed HFA injury and no HFA injury

Independent variables	Subgroup	Total (*n* = 58)	Confirmed HFA injury group (*n* = 41)	Confirmed no HFA injury group (*n* = 17)	*P* value
Gender	*n* (%)	58 (100%)	41 (100%)	17 (100%)	**0.0055**[†]
	Male	44 (75.86%)	27 (65.85%)	17 (100%)	
	Female	14 (24.14%)	14 (34.15%)	0	
Age	Median (Q1, Q3)	44 (37.5, 56.75)	49 (41, 67)	40 (31, 46)	**0.0235**[‡]
IGSA criteria[§]	*n* (%)	58 (100%)	41 (100%)	17 (100%)	>0.9999[†]
	Satisfying	14 (24.14%)	10 (24.39%)	4 (23.53%)	
	Not satisfying	44 (75.86%)	31 (75.61%)	13 (76.47%)	
Vital signs	Median (Q1, Q3)				
	SBP (mmHg)	130 (120, 140)	130 (120, 140)	120 (110, 130)	**0.0478**[‡]
	DBP (mmHg)	80 (80, 90)	80 (80, 90)	80 (70, 80)	0.3808[‡]
	HR (beats per minute)	72 (64.25, 80)	72 (65, 80)	71 (62, 80)	0.7645[‡]
	RR (breaths per minute)	20 (18, 20)	20 (19, 20)	18 (18, 20)	**0.0046**[‡]
	BT (°C)	36.6 (36.4, 36.7)	36.6 (36.3, 36.7)	36.6 (36.5, 36.7)	0.5598[‡]
Patient distance from the location of the incident	*n* (%)	58 (100%)	41 (100%)	17 (100%)	**0.0004**[§§]
	More than 100 m away	22 (37.93%)	22 (53.66 %)	0	
	Within 100 m	36 (62.07%)	19 (46.34%)	17 (100%)	
Oxygen saturation	Median (Q1, Q3)	98 (97, 98)	98 (97, 98)	97.5 (97, 98)	>0.9999[‡]

HFA, hydrofluoric acid; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; RR, respiratory rate; BT, body temperature.
[†]Fisher's exact test.
[‡]The Mann–Whitney *U* test.
[§]IGSA criteria, irritant gas syndrome agent criteria suggested by Culley et al,[16] satisfying means meeting 2 or more clusters among 3 clusters of signs and symptoms criteria (respiratory: shortness of breath, wheezing, coughing, and choking; chest discomfort: tightness, pain, and burning; eye, nose, and/or throat: pain, irritation, and burning).
[§§]Chi-square test with Yate's continuity correction;
Significance of bold values means p-value < 0.05.

Application of the modified IGSA criteria as a chemical triage

Basic demographic characteristics and injury-related variables by the validated modified IGSA criteria for the 160 HFA exposed patients. The mIGSA criteria were set as a severity norm of HFA exposed patients as an initial ED triage tool for chemical disaster and was used as a dependent variable. The basic demographic characteristic variables included gender, age, patient classification (factory worker, resident, firefighter, emergency medical service person, policemen, reporter, and unknown), and vital signs at initial ED visit (SBP, DBP, HR, RR, and BT). Injury-related variables included the incident material state (gas only vs complex), patient injury mechanism (inhalation only vs complex), patient distance from the location of the incident (more than 100 m away or within 100 m), and oxygen saturation. Complex exposures or injuries were defined as the combined status of the presence of a non-gaseous incident material state or patient injury mechanism, whether there were gaseous exposures/injuries or not. Chemical triage by the mIGSA criteria was compared to basic demographic characteristics and injury-related variables for analysis of 160 HFA exposed patients (Table 3).

Development of chemical triage

Based on the above results, the authors presented evidence-based prehospital and hospital measures to establish chemical triage (Figure 6).

The HFA injury risk prediction of the chemical triage was defined as follows:

(1) High Risk: 80% or more
(2) Moderate Risk: 30%-79%
(3) Low Risk: 0%-29%

Statistical methods

Data were reported as the mean ± standard deviation (SD) for parametric continuous variables, median (Q1, Q3) for nonparametric continuous variables, and frequency (percentage) for categorical variables. *P* values were calculated using Student's *t*-test or the Mann–Whitney *U* test for continuous variables, the χ^2 test with Yate's continuity correction, or Fisher's exact test for categorical variables. ULRA and MLRA were also used to find the predictors of confirmed HFA injury. The discriminatory power of the final model was measured by the AUC in the ROC curve. The optimal cut-off value was determined according to the Youden index.[17] A nomogram analysis for internal validation was conducted with a bootstrapping method (500 repetitions) to obtain unbiased estimates of the model's performance (calibration plot). Statistical analyses were performed using R version 3.6.3 (The R Foundation for Statistical Computing, Vienna, Austria). A *P* value < 0.05 was considered to show statistical significance.

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Table 2. Univariate and multivariate logistic regression analyses for IGSA criteria with independent variables for predicting the risk of confirmed HFA injury

Univariate	Odds ratio* (95% CI)	P value	Multivariate (full model)	Odds ratio* (95% CI)	P value	Multivariate (final model)	Odds ratio* (95% CI)	P value
Gender (male)	1.373x10–08 (0–Infinite)	0.9917						
The IGSA criteria satisfied†	0.7742 (0.2188–2.7390)	0.6914	The IGSA criteria satisfied†	1.9315 (0.3957–9.4296)	0.4158	The IGSA criteria satisfied†	1.6311 (0.3206–8.2984)	0.5556
Age (year)	1.0572 (1.0082–1.1086)	**0.0216**	Age (year)	1.0685 (1.0096–1.1309)	**0.0220**	Age more than 49 (Satisfying)	14.8871 (1.6829–131.6902)	**0.0152**
RR (breaths per minute)	2.3893 (1.2771–4.4701)	**0.0064**	RR (breaths per minute)	2.6786 (1.273–5.6361)	**0.0094**	RR more than 19 (Satisfying)	7.1351 (1.6075–31.6709)	**0.0098**
SBP (mmHg)	1.0465 (0.9994–1.0958)	0.0531						
Patient distance from the location of incident (within 100 m)	$3.555\text{x}10^{-09}$ (0–Infinite)	0.9932						

CI, confidence interval; IGSA, irritant gas syndrome agent; HFA, hydrofluoric acid; SBP, systolic blood pressure; RR, respiratory rate.
*Wald confidence intervals were calculated; Simple regressions with a single covariate were conducted, and coefficients from each regression were summarized;
†IGSA criteria, IGSA criteria by Culley et al,[16] satisfying means meeting 2 or more clusters among 3 clusters of signs and symptoms criteria (respiratory: shortness of breath, wheezing, coughing, and choking; chest discomfort: tightness, pain, and burning; eye, nose and/or throat: pain, irritation, and burning).
Full model: multivariate logistic regression analysis of IGSA criteria, age, and RR for predicting the risk of confirmed HFA injury.
Final model: multivariate logistic regression analysis of IGSA, age more than 49, and RR more than 19 criteria for predicting the risk of confirmed HFA injury.

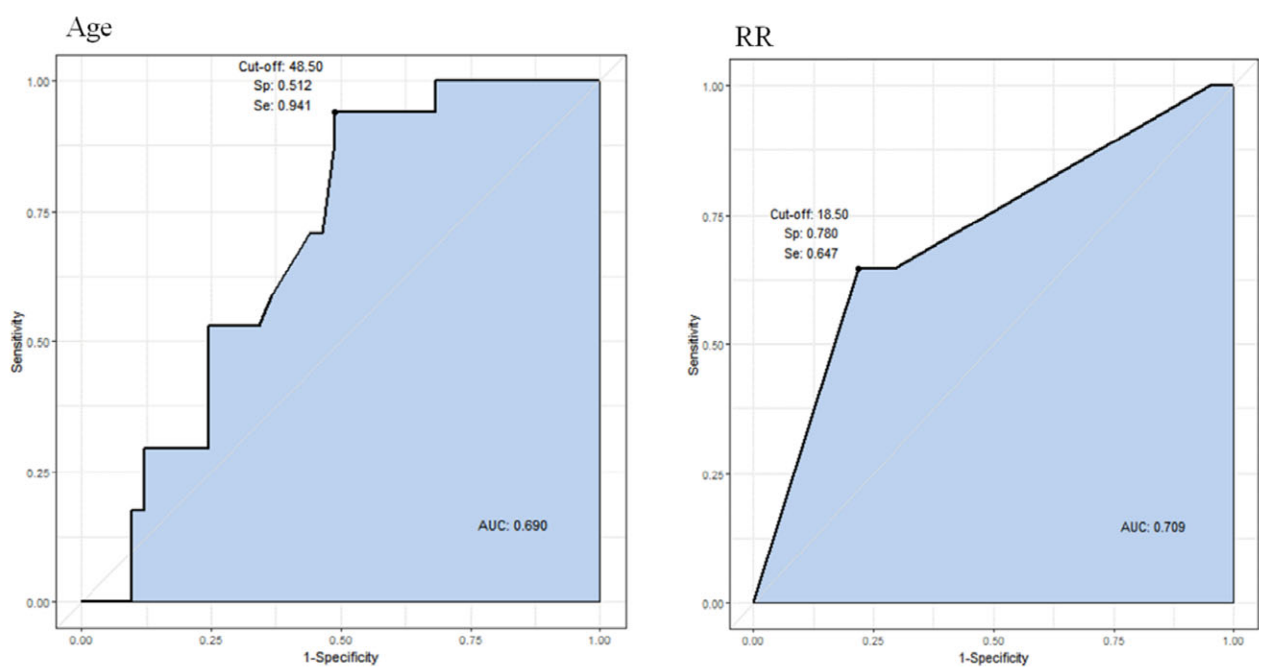

Figure 2. The cut-off value with sensitivity and specificity in the ROC curve of age and RR for predicting the risk of confirmed HFA injury. AUC, the area under the curve; HFA, hydrofluoric acid; ROC, receiver operating characteristic; RR, respiratory rate; Sp, specificity; Se, sensitivity; Youden index was applied to calculate the cut-off value in the ROC curve of age and RR for predicting the risk of confirmed HFA injury.[20]

Results

Results for Development of the Modified IGSA Criteria Under Validation as a Chemical Triage for HFA Induced MCI or Disaster

Results of external validation of the IGSA criteria for a total of 58 actual patients comprised of confirmed HFA injury and no HFA injury

The AUC (sensitivity; specificity) in the ROC curve of the IGSA criteria for predicting the risk of confirmed HFA injury was 0.475 (1; 0) (Figure 1).

Results of the Development of the Modified IGSA Criteria

Independent variables in terms of gender; age; SBP, and RR among vital signs; and patient distance from the location of incident were associated with confirmed HFA injury for a total of 58 actual patients ($P < 0.05$) (Table 1). The odds ratios (ORs) (95% confidence interval [CI]; P value) of age and RR among these variables were associated with predicting the risk of confirmed HFA injury in the ULRA respectively as 1.0572 ([1.0082–1.1086] of 95% CI; $P = 0.0216$) and 2.3893 ([1.2771–4.4701] of 95% CI; $P = 0.0064$) (Table 2). The cut-off values (sensitivity; specificity) for predicting

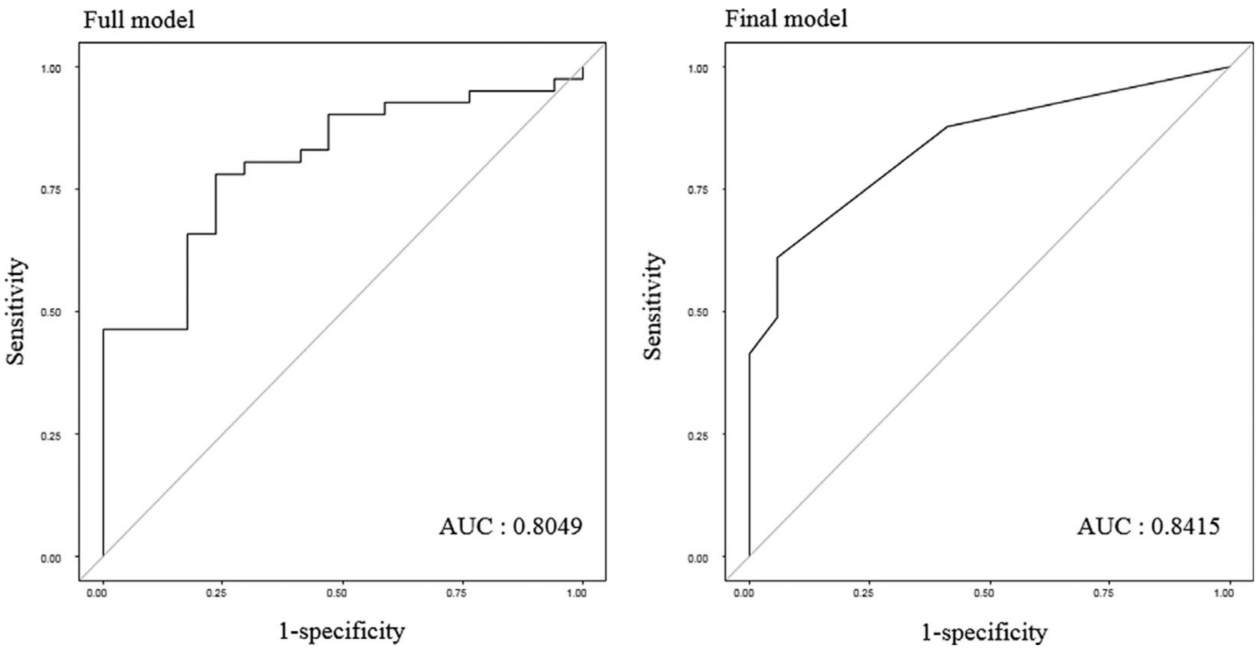

Figure 3. AUC of ROC curve for prediction of the risk of confirmed HFA injury according to multivariate logistic regression analysis as the full model and final model. AUC, the area under the curve; HFA, hydrofluoric acid; IGSA, irritant gas syndrome agent; ROC, receiver operating characteristic; RR, respiratory rate**. Full model**: multivariate logistic regression analysis of IGSA criteria, age, and RR for predicting the risk of confirmed HF injury. **Final model**: The final model is a multivariate logistic regression analysis that incorporates the IGSA criteria, age over 49, and a respiratory rate (RR) greater than 19 as predictors for the risk of confirmed HFA injury.

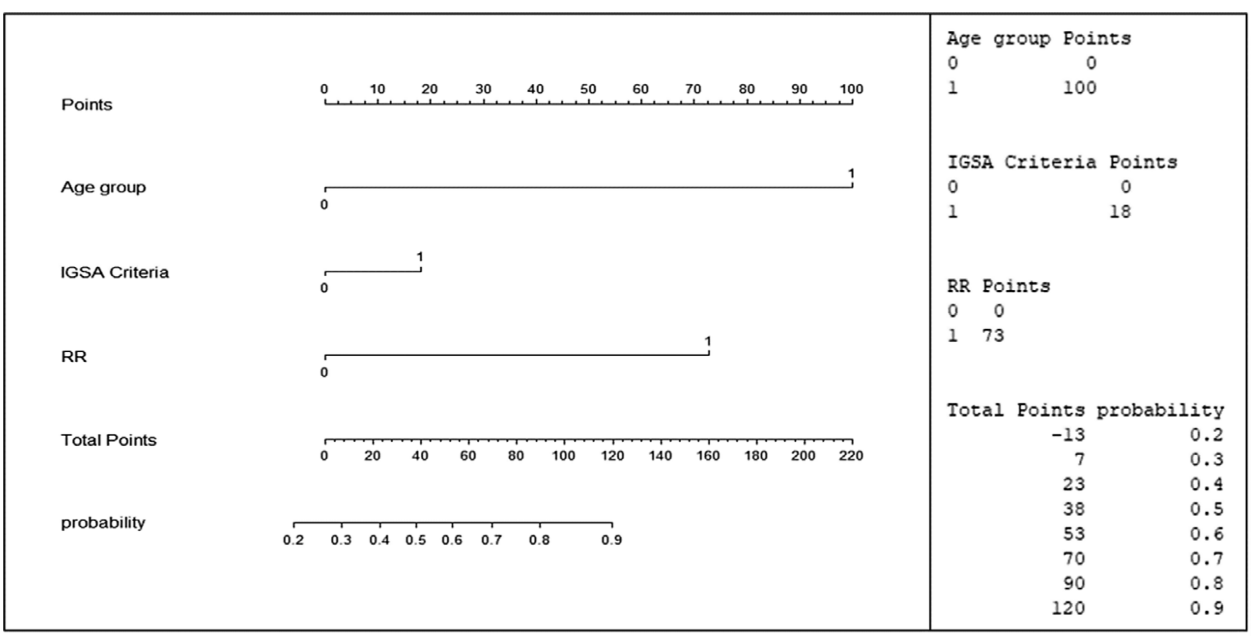

Figure 4. Nomogram of logistic regression in the final model for predicting the risk of confirmed HFA injury. IGSA, irritant gas syndrome agent; Satisfying IGSA criteria[16] means meeting 2 out of 3 clusters of signs and symptoms criteria (respiratory: shortness of breath, wheezing, coughing, and choking; chest discomfort: tightness, pain, and burning; eye, nose and/or throat: pain, irritation, and burning); HFA, hydrofluoric acid; RR, respiratory rate. **Final model**: multivariate logistic regression analysis of IGSA, age greater than 49, and RR greater than 19, criteria for predicting the risk of confirmed HFA injury. Age group coding: 0 = age under 49; 1 = age more than 49; IGSA criteria coding: 0 = not satisfying; 1 = satisfying; RR coding: 0 = RR under 19; 1 = RR more than 19.

the risk of confirmed HFA injury by using Youden's index in the ROC curve of age and RR were 48.50 (0.941; 0.512) and 18.50 (0.647; 0.780), (Figure 2) respectively. ULRA and MLRA showed that age and RR were significant and independent predictors of predicting the risk of confirmed HFA injury (Tables 2, 3). The authors defined the final model as "the modified IGSA criteria" (mIGSA, or AIR criteria) consisting of the 3 clusters of age greater than 49, IGSA criteria satisfied, and RR greater than 19 (Table 2; Figure 3). The AUC of ROC curve for prediction of the risk of confirmed HFA injury according to MLRA as the full model and final model was 0.8049 and 0.8415 respectively (Figure 3). Satisfying the mIGSA/AIR criteria as defined as meeting 2 or more of the

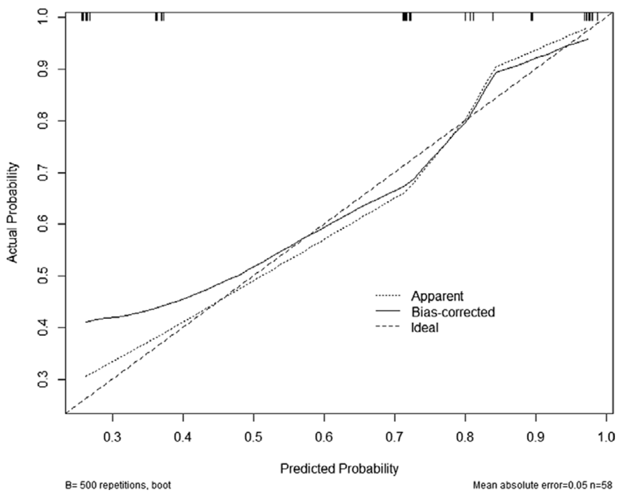

Figure 5. Calibration plots with local regression of the nomogram for internal validation of the mIGSA criteria. Perfect prediction corresponds to the 45° line. Points estimated below the 45° line represent overprediction, whereas those above the 45° line represent underprediction. Calibration plot with 500 bootstrapping samples. IGSA, irritant gas syndrome agent; Satisfying IGSA criteria[16] means meeting 2 out of 3 clusters of signs and symptoms criteria (respiratory: shortness of breath, wheezing, coughing, and choking; chest discomfort: tightness, pain, and burning; eye, nose and/or throat: pain, irritation, and burning).

3 clusters of age greater than 49, IGSA criteria satisfied, and RR greater than 19, correlated with at least 90 points indicating an over 80% probability for predicting the risk of confirmed HFA injury in the nomogram (Figure 4).

Results Of Internal Validation of the Modified IGSA Criteria

The bias-corrected plot approximates the ideal plot, showing high agreement between predicted probabilities and actual probabilities in the calibration plots with local regression with 500 bootstrapping samples (Figure 5).

Results of Application of the Modified IGSA Criteria as a Chemical Triage

Results of basic demographic characteristics and injury-related variables by the validated modified IGSA criteria for the 160 HFA exposed patients

The SD between the mIGSA group and the non-modified IGSA group of age and RR on initial ED admission was 55.26 (15.27) versus 35.81 (9.12), $P < 0.0001$, and 19.1 breaths per minute (1.44) versus 19.15 (1.06), $P < 0.0018$ (Table 3). There was a significant difference observed between the modified IGSA group and the non-modified IGSA group of patient classification and patient distance from the location of the incident (Table 3), with $P < 0.05$.

Development of chemical triage

The authors have developed and validated a detailed triage algorithm for predicting HFA injury risk (Figure 6). The triage algorithm considers the following criteria:

1. Age > 48: 100 points
2. IGSA Criteria (+): 18 points
3. Respiratory Rate > 18: 73 points

Based on the total points, the HFA injury risk prediction is categorized as follows:

1. High Risk: 80% or more (≥ 90 points)
2. Moderate Risk: 30%-79% (7-89 points)
3. Low Risk: 0%-29% (0-6 points)

The algorithm proceeds as follows:

1. Initial Assessment:
    - Assess the age of the patient.
    - Evaluate IGSA criteria satisfaction.
    - Measure the respiratory rate.
2. Risk Classification:
    - High Risk (≥ 90 points, ≥ 80%): Immediate critical care and continuous monitoring.
    - Moderate Risk (7-89 points, 30%-79%): Symptom treatment, observation, and possible IV therapy.
    - Low Risk (0-6 points, 0%-29%): Outpatient follow-up and self-care instructions

Discussion

Efficient planning for the utilization of hospital resources is critical to effectively manage the surge in patient demand that occurs when a disaster results in a large influx of casualties to the ED. This study was initiated by questioning whether it is possible to differentiate between patients with potential severity and those without, using parameters available during initial ED triage, such as vital signs and epidemiological information, in the context of a mass influx of patients following HFA inhalation exposure. The authors developed the mIGSA/AIR criteria as a new model for chemical triage in cases of mass inhalational HFA exposure. This model was deemed satisfactory if it identified 2 or more of the following clusters: age greater than 49, satisfaction of the IGSA criteria, and an RR greater than 19, upon validation. In applying the mIGSA criteria to 160 patients exposed to HFA, it was found that both age and RR were significantly higher in the mIGSA group compared to the group that did not meet the mIGSA criteria. Additionally, the highest proportion of patients with unknown classification status was observed in both the mIGSA group and the non-modified IGSA group.

At specific temperatures, chemical substances can be in solid, liquid, or gas form. In gas form, chemical substances can be hazardous to the community when not contained.[18] The 2014 HFA leakage that occurred in Zhejiang Province, China, was like the 2012 Gumi HFA leak disaster, where a large amount of HFA gas at room temperature caused a wide range of toxic hazards to the community.[3,5] In that accident, a multi-vehicle chain collision that occurred at the Pujiang section of the Hangjinqu expressway caused a crack in a tank of the vehicle carrying HFA; a large amount of HFA leaked, resulting in chemical injuries to 253 individuals, including 3 deaths.[3]

The proportion of males was higher in both groups. This was similar to the results of a prospective study from 2008 to 2009 of 527 patients admitted to 25 hospitals in Zhejiang Province, China, due to chemical injuries, which showed that most patients were male in both non-severe and severe patient groups.[12] As expected, factory workers were among the most prevalent patient classifications in both groups, with the unknown or missing value being the most common. Unfortunately, the unknown patient classification was most prevalent in both groups because of medical documentation failure due to ignorance and a lack of education on hospital-based data collection after a chemical disaster. However, some

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Table 3. Basic demographic characteristics and injury-related variables by the validated modified IGSA criteria for the 160 HFA-exposed patients

Variable	Total (*n* = 160)	Modified IGSA group (*n* = 46)	No modified IGSA group (*n* = 114)	*P* value
Age (years)	41.40 ± 14.26	55.26 ± 15.27	35.81 ± 9.12	**<0.0001**†
Gender				0.0897‡
Male	108 (67.5%)	26 (56.52%)	82 (71.93%)	
Female	52 (32.5%)	20 (43.48%)	32 (28.07%)	
Patient Classification				**0.0064**§
Factory worker	42 (26.25%)	8 (17.39%)	34 (29.82%)	
Resident	10 (6.25%)	5 (10.87%)	5 (4.39%)	
Firefighter	15 (9.38%)	0	15 (13.16%)	
Emergency medical service person	3 (1.88%)	2 (4.35%)	1 (0.88%)	
Policemen	5 (3.12%)	2 (4.35%)	3 (2.63%)	
Reporter	2 (1.25%)	1 (2.17%)	1 (0.88%)	
Unknown	83 (51.88%)	28 (60.87%)	55 (48.25%)	
Vital signs at the initial ED visit				
SBP (mmHg)	124.59 ± 14.74	127.72 ± 16.18	123.33 ± 14.00	0.0887†
DBP (mmHg)	79.34 ± 9.10	79.89 ± 10.57	79.12 ± 8.47	0.6616†
Heart rate (beats per minute)	74.29 ± 10.96	73.30 ± 12.89	74.68 ± 10.11	0.4728†
RR (breaths per minute)	19.37 ± 1.23	19.91 ± 1.44	19.15 ± 1.06	**0.0018**†
BT (°C)	36.54 ± 0.29	36.49 ± 0.33	36.55 ± 0.27	0.2290†
Incident material state				0.2875§
Gas	193 (99.0%)	53 (96.4%)	144 (100.0%)	
Complex (more than 2)	6 (1.0%)	2 (3.6%)	0 (0.0%)	
Patient injury mechanism				0.4936§
Inhalation	158 (98.75%)	45 (97.83%)	113 (99.12%)	
Complex (more than two)	2 (1.25%)	1 (2.17%)	1 (0.88%)	
Patient distance from the location of the incident				**0.0009**‡
More than 100 m away	73 (45.62%)	31 (67.39%)	42 (36.84%)	
Within 100 m	87 (54.37%)	15 (32.61%)	72 (63.16%)	
Oxygen saturation (%)	98 (97, 98)	98 (96.75, 98)	98 (97, 98)	0.1696‡

Data were reported as the mean ± standard deviation for continuous variables and frequency (percentage) for categorical variables. *P* values were calculated using Student's *t*-test or the Mann–Whitney *U* test for continuous variables and the chi-square test with Yate's continuity correction or Fisher's exact test for categorical variables.
BT, body temperature; DBP, diastolic blood pressure; ED, emergency department; HFA, hydrofluoric acid; IGSA, irritant gas syndrome agent; SBP, systolic blood pressure; RR, respiratory rate.
†Student's *t*-test.
‡Chi-square test with Yate's continuity correction.
§Fisher's exact test.
‡Mann–Whitney *U* test;

studies suggest that the initial main victim of this Gumi City HFA leak in 2012 were factory workers, and later as time goes by, the damage was extended to community residents nearby the HFA leak area, both physically and mentally.[5,6,9,10]

In the present study, the most common identifiers for patients in both groups were injury by inhalation of the gaseous form of HFA. The results from a previous study showed that the number of patients who visited the ED in nearby hospitals within 24 h after the release of a large amount of vinyl chloride gas in a 2012 New Jersey train derailment was similar to the epidemiological characteristics observed in the present study.[19]

In previous literature concerning chemical triage, Craig *et al.*[20] compared and evaluated various ED triage methods such as START, ESI, CBRN, and SALT to find the most suitable model. The authors used data extracted from medical records of the patients from the 2005 Graniteville train derailment chlorine disaster in their study. Another effort to address this challenge was Culley *et al.*,[16] who retrospectively analyzed patient data from the same 2005 chlorine leak disaster in Graniteville and made an announcement that it was considered that IGSA exposure could be validated, and ED care should be given priority if the patient met at least 2 out of 3 clusters of symptoms and signs, which constituted respiratory, chest discomfort, eye, and nose and/or throat.

The development and validation of the mIGSA criteria represents a significant advancement in the triage of patients exposed to HFA during chemical disasters. This work is particularly relevant in the context of increasing industrial accidents and the need for effective emergency response strategies. This study's findings align

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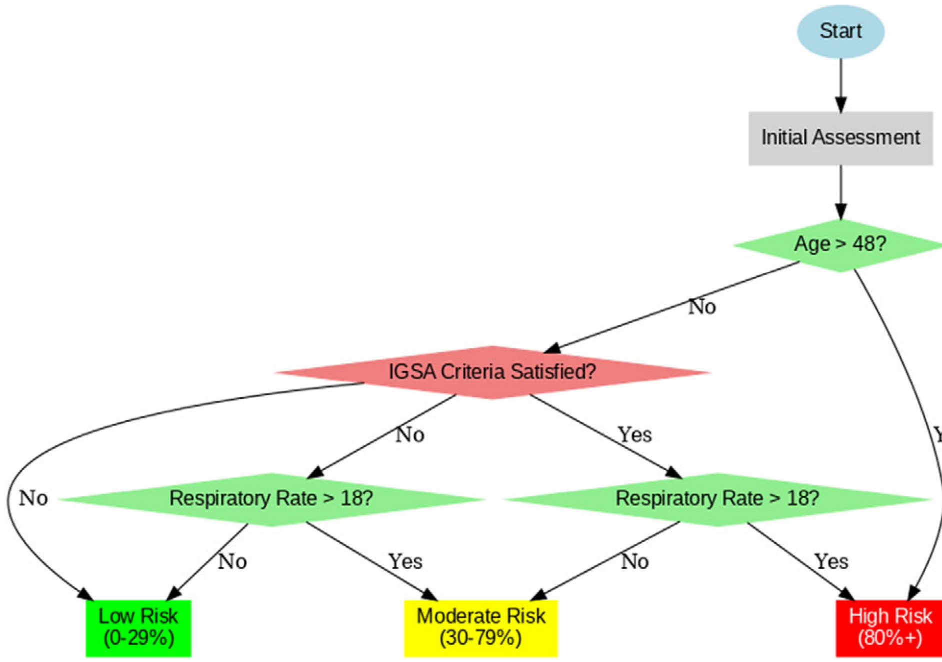

Figure 6. AIR triage algorithm for victims under HFA exposure based on HFA injury prediction modeling. AIR, age, IGSA criteria, respiratory rate; HFA, hydrofluoric acid; IGSA criteria, irritant gas syndrome agent criteria suggested by Culley et al,[16] satisfying means meeting 2 out of 3 clusters of signs and symptoms criteria (respiratory: shortness of breath, wheezing, coughing, and choking; chest discomfort: tightness, pain, and burning; eye, nose and/or throat: pain, irritation, and burning).
Initial Assessment:

1. Assess the age of the patient.
2. Evaluate IGSA criteria satisfaction.
3. Measure the respiratory rate.

Risk Classification based upon nomogram of logistic regression in the final model for predicting the risk of confirmed HFA injury (Figure 4):

1. High Risk (≥ 80%): Immediate critical care and continuous monitoring.
2. Moderate Risk (30%-79%): Symptom treatment, observation, and possible IV therapy.
3. Low Risk (0%-29%): Outpatient follow-up and self-care instructions.

Expectant Category:
Critical symptoms include:

1. Profound respiratory failure
2. Unresponsiveness
3. Severe burns covering large body areas
4. Multiple organ failures with minimal response to initial treatments

with previous research indicating the critical role of early and accurate triage in managing chemical exposure incidents and reducing morbidity and mortality rates. For instance, the work by Zhang *et al.*[3] on a serious HFA leak highlights the challenges and importance of immediate medical intervention in chemical spill scenarios. Similarly, Culley *et al.*[16] emphasized the necessity for validated signs and symptoms to prioritize ED care for patients exposed to irritant gases, underlining the need for robust triage criteria, such as the mIGSA criteria developed in our study.

Moreover, the mIGSA criteria's emphasis on age, respiratory rate, and the satisfaction of IGSA criteria as pivotal determinants for triage decisions echoes the findings of studies such as those by Shumate *et al.*,[19] which documented the health care response to a vinyl chloride release, and by Craig *et al.*,[20] who explored hospital-based data mining methods to study triage after chemical disasters. These studies collectively underscore the importance of incorporating diverse and practical variables into triage systems to enhance their effectiveness in real-world emergency scenarios.

Ethical considerations in deploying mIGSA criteria, especially concerning resource allocation and equity in patient care, are crucial. The review by Fishe *et al.*[21] on implementing prehospital evidence-based guidelines (EBGs) discusses the challenges and emphasizes the importance of ethical considerations in the adoption of EBGs, which could be extrapolated to the ethical deployment of mIGSA criteria.

Integrating the mIGSA criteria into prehospital care protocols necessitates a multifaceted approach, encompassing training, logistics, and communication enhancements.[22,23] The consensus underscores the importance of adaptable and responsive prehospital care systems that can seamlessly incorporate innovative triage tools.[22–24] The role of technology and innovation, especially in data analytics and real-time monitoring, in enhancing the mIGSA criteria's effectiveness is supported by mHealth applications for EMS activation in low-income and middle-income countries, suggesting the potential of technology in improving disaster response outcomes, as well as in review, which underscores the need for scalable and adaptable tools for chemical triage to improve global preparedness.[23,24] The criteria's design for easy integration promises to streamline emergency responses, ensuring timely and appropriate care for HFA exposure victims.

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Our triage scheme considers both resource availability and symptom severity. The algorithm prioritizes immediate critical care for high-risk patients and allocates resources accordingly to ensure effective treatment.

Based on the mIGSA/AIR criteria, the authors recommend the following management protocols for HFA exposure: High-risk patients should receive immediate administration of calcium gluconate, both topically and intravenously, to neutralize fluoride ions. These patients should also receive respiratory support, including oxygen therapy and mechanical ventilation, if necessary, along with continuous ECG and vital sign monitoring in an intensive care setting. Pain management using analgesics and sedatives is essential.[25–27] Moderate-risk patients should have close monitoring of respiratory function and vital signs for 24 hours, symptomatic treatment with bronchodilators and analgesics, and intravenous therapy with calcium gluconate as needed. Low-risk patients can be managed with outpatient follow-up and home care instructions, including the application of calcium gluconate gel to affected areas, and should be advised to monitor their symptoms and return to the hospital if conditions worsen.[25–27]

Decontamination procedures based on exposure levels are as follows: High-risk exposures, involving a large area of skin (> 10% of total body surface area), sensitive areas such as the eyes or respiratory tract, or high concentration of HFA, require full decontamination with water and neutralizing agents, such as calcium gluconate gel, to prevent further absorption and mitigate severe systemic effects.[28,29] Moderate-risk exposures, characterized by smaller skin areas (1-10% of total body surface area), lower concentrations, and no involvement of sensitive areas, require thorough washing with water and soap, followed by observation for delayed symptoms.[30,31] Low-risk exposures, involving minimal skin contact (<1% of total body surface area), very low concentrations, and no involvement of sensitive areas, can be managed with home decontamination practices, such as thorough washing with soap and water, to prevent irritation and mild symptoms.[32,33]

The PPE requirements for managing HFA exposure are as follows: Prehospital providers involved in initial containment and decontamination efforts should use Level A PPE, which includes fully encapsulating chemical protective suits with self-contained breathing apparatus (SCBA). For secondary care and transport, it is recommended that providers use Level B PPE, consisting of hooded chemical-resistant clothing with SCBA or powered air-purifying respirator (PAPR). Hospital providers managing moderate to low-risk patients should use Level C PPE, which includes non-encapsulating, splash-protective chemical-resistant clothing with an air-purifying respirator. In emergency departments, Level B PPE is required for handling high-risk patients requiring intensive decontamination and treatment.[34–36]

Critical symptoms in placing patients in the expectant category include profound respiratory failure, unresponsiveness, severe burns covering large body areas, or multiple organ failures with minimal response to initial treatments.[37–39]

By presenting the author's findings within this study, it becomes clear that the mIGSA (or AIR) criteria could serve as a valuable tool for EDs worldwide, facilitating the prompt and efficient allocation of medical resources during chemical incidents. This contribution is both timely and critical, given the global trends in industrialization and the increasing potential risks of chemical exposure.

Limitations and Strengths

The present study was limited due to the retrospective design, which might have introduced information and selection bias. One of the limitations of our study involves the statistical methodologies applied for external and internal validations. Because there was no preestablished, integrated, specified, disaster patient data collecting system in the hospital (and among community hospitals), we had to determine patient classification by retrospective chart review, with insufficient information. Additionally, there were many patient follow-up losses, totaling 102 out of 160 patients. While we have utilized ROC curves for external validation and calibration plots with bootstrapping for internal validation, the relatively small sample size of confirmed HFA injury patients ($n = 58$) may limit the generalizability and robustness of our findings. Specifically, the external validation process, which utilized the AUC of the ROC to assess the predictive power of the mIGSA criteria, may be influenced by sample size limitations, potentially affecting the accuracy of our model's predictive capabilities. Similarly, the internal validation, which relied on 500 bootstrapping samples to assess the calibration of the mIGSA criteria, may not fully account for overfitting or variability inherent in small sample sizes. These statistical considerations underscore the necessity for cautious interpretation of our validation results, and highlight the need for further research with larger datasets to validate and refine the mIGSA criteria effectively. Moreover, future studies should consider employing advanced statistical techniques or alternative validation methods that can mitigate the challenges posed by small sample sizes and enhance the reliability of triage criteria in chemical disaster scenarios. Even so, the authors believe this study will serve as chemical triage guidance and a basis for understanding the characteristics of the patients that visit the ED after HFA inhalation. Also, the findings from this study can be used in future multidisciplinary data collection for the development of integrated field or hospital chemical disaster triage for HFA injury patients.

Conclusion

The authors developed the mIGSA/AIR criteria as a new model of triage for inhalational mass HFA exposure. The model proved as satisfied if they met 2 or more clusters of age greater than 49, IGSA criteria satisfied, and RR greater than 19, under validation. Mean age and RR were higher in the mIGSA group rather than the non-modified IGSA group. To maximize the quality of patient care, future studies should continue to characterize chemical triage development and validation, as well as specified a preestablished data collecting system setup for various types of major chemical contamination events.

Data availability statement. Data sharing is not applicable as no data sets were generated or analyzed during this study.

Author contribution. HJS participated in the Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, and Writing – review & editing; SKO, HYL, HJC, and HDK contributed to Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Writing – review & editing; JEM contributed to Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Writing – review & editing, Supervision, Visualization; HJS contributed the manuscript as a First Author and Corresponding Author. All authors read the manuscript and approved its submission.

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Ethical standard. This study was supported by the Soonchunhyang University Research Fund and was approved by the Institutional Review Board of Soonchunhyang University Gumi Hospital **(IRB Number: SCHUH 2019-17)**. All participants provided consent to participate in this study. All methods were carried out in accordance with relevant guidelines and regulations. This study was performed in accordance with the Declaration of Helsinki.

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