Derivation and Validation of the SWAP Score for Very Early Prediction of Neurologic Outcome in Patients With Out-of-Hospital Cardiac Arrest

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Study objective: For patients with out-of-hospital cardiac arrest who receive cardiopulmonary resuscitation in an emergency department (ED), the early evaluation of their neurologic prognosis is essential for emergency physicians. The aim of this study is to establish a simple and useful assessment tool for rapidly estimating the prognosis of patients with out-of-hospital cardiac arrest after their arrival at an ED.

Methods: A total of 852 patients admitted from January 1, 2015, to June 30, 2017, were prospectively registered and enrolled in the derivation cohort. Multivariate logistic regression on this cohort identified 4 independent factors associated with unfavorable outcomes: initial nonshockable rhythm (odds ratio [OR] 3.40; 95% confidence interval [CI] 1.58 to 7.32), no witness of collapse (OR 3.19; 95% CI 1.51 to 6.75), older than 60 years (OR 3.65; 95% CI 1.64 to 8.09), and pH less than or equal to 7.00 (OR 3.27; 95% CI 1.42 to 7.54). The shockable rhythm–witness-age-pH (SWAP) score was developed and 1 point was assigned to each predictor.

Results: For a SWAP score of 4, the specificity was 97.14% (95% CI 91.62% to 100%) for unfavorable outcomes in the derivation cohort. For validation, we retrospectively collected data for 859 patients with out-of-hospital cardiac arrest from January 1, 2012, to December 31, 2014. A SWAP score of 4 was 100% specific (95% CI 99.9% to 100%) for unfavorable outcomes in the validation cohort.

Conclusion: The SWAP score is a simple and useful predictive model that may provide information for the very early estimation of prognosis for patients with out-of-hospital cardiac arrest. Further research is required to integrate ultrasonographic findings and validate the SWAP score's application in other populations. [Ann Emerg Med. 2019;73:578-588.]

Please see page 579 for the Editor's Capsule Summary of this article.

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INTRODUCTION

Background

Annually, more than 250,000 patients experience an out-of-hospital cardiac arrest worldwide.[1] Despite advances in cardiac arrest resuscitation, the rate of survival until hospital discharge ranges from 6.7% to 10.8%.[2,3] In 2 regional registry studies,[3,4] survival with good functional status ranged from 1.6% to 9.0%.

Importance

Prognostic assessment tools for patients with out-of-hospital cardiac arrest are critical to determine the termination-of-resuscitation rule, the most well known of which is the basic life support (BLS) termination-of-resuscitation rule developed by Morrison et al,[4] which is composed of 3 criteria: no return of spontaneous circulation before transportation, no shock delivered, and arrest not witnessed by emergency medical services (EMS) personnel. However, termination of resuscitation by EMS personnel remains legally and ethically controversial. In Taiwan, almost all patients with out-of-hospital cardiac arrest, including those who fully meet the BLS termination-of-resuscitation rule and have minimal potential for survival, are transferred to hospitals. In addition, some patients with out-of-hospital cardiac arrest are sent to emergency departments (EDs) through private transference. Therefore, developing an assessment tool for patients who receive ongoing cardiopulmonary resuscitation (CPR) at EDs is necessary.

Editor's Capsule Summary

What is already known on this topic

Determining when further resuscitation efforts for victims of cardiac arrest are futile in the emergency department (ED) can be challenging.

What question this study addressed

Whether the SWAP assessment tool, developed with 852 ED cardiac arrest patients and validated with another 859, could identify patients unlikely to benefit from further resuscitation.

What this study adds to our knowledge

Patients with all 4 elements of the score—initial nonshockable rhythm, unwitnessed arrest, older than 60 years, and initial ED serum pH less than or equal to 7.00—had 0 point-estimate probability of a good neurologic outcome in the validation set.

How this is relevant to clinical practice

Although the score appears to be sufficiently specific, it is unclear whether it adds anything beyond what can be gleaned from clinical judgment.

Early assessment of prognosis is critical not only to determine which patients will benefit from intensive care, such as therapeutic hypothermia and extracorporeal CPR, but also to assess the effectiveness of interventional studies.[5,6] Studies have reported several factors associated with the prognosis of out-of-hospital cardiac arrest, including age, witnessed arrest, bystander CPR, duration of no-flow or low-flow status, presence of shockable rhythm, and blood pH on admission.[2,7-11] However, current scoring models, including out-of-hospital cardiac arrest score and cardiac arrest hospital prognosis scores, were designed for patients with return of spontaneous circulation.[7,9] These scores were not meant to be applied to patients with out-of-hospital cardiac arrest who receive ongoing CPR in EDs.

Goals of This Investigation

The aim of this study was to establish a simple and useful assessment to enable physicians to rapidly estimate the prognosis of patients with out-of-hospital cardiac arrest who receive CPR in an ED. The parameters associated with neurologic outcomes during discharge that were available in the ED were analyzed. In addition, a simple point score was created to predict neurologic outcomes in patients with out-of-hospital cardiac arrest.

MATERIALS AND METHODS

Study Design and Setting

We performed a prospective observational study in the ED at China Medical University Hospital, an urban medical center in Taichung, central Taiwan. In 2016, the population of Taichung was greater than 2.7 million.[12] The general ward and ICUs of this medical center contain approximately 1,625 and 130 beds, respectively, and the ED received more than 140,000 visits in 2017.

In Taiwan, emergency service technicians mainly provide BLS for patients with out-of-hospital cardiac arrest, and most airway management is performed with bag-valve-mask and laryngeal mask airway. Patients are shocked with automated external defibrillators as required. In Taichung, advanced life support (ALS) is not performed in out-of-hospital resuscitation and almost no out-of-hospital epinephrine or sodium bicarbonate is administered. Since January 1, 2015, all patients with out-of-hospital cardiac arrest have undergone blood gas analysis within 2 minutes of arrival at the ED. Physicians consider sodium bicarbonate therapy only after the results of blood gas analysis are available. The use of bicarbonate would not influence the initial serum pH value. All patients receive standard resuscitation according to international guidelines.[13-16] More details about the EMS system in Taichung and inpatient care for patients with out-of-hospital cardiac arrest are provided in Appendix E1, available online at http://www.annemergmed.com. This study was approved by the institutional review board of China Medical University.

Selection of Participants

For the derivation cohort, all patients with out-of-hospital cardiac arrest who were sent to the ED of China Medical University Hospital from January 1, 2015, to June 30, 2017, were enrolled for the analysis. Exclusion criteria were as follows: younger than 20 years, with cardiac arrest after circumstantial causes (such as trauma, hanging, drowning, or asphyxia), return of spontaneous circulation before arriving in the ED, no initial blood gas analysis, and do-not-resuscitate orders.

For validation, we retrospectively collected data from patients with out-of-hospital cardiac arrest who were admitted to the ED from January 1, 2012, to December 31, 2014. Because the protocol of early blood gas analysis was initiated in 2015, only patients who underwent the analysis within 5 minutes of arrival at the ED were enrolled in the validation cohort. In addition, patients who met the aforementioned exclusion criteria were excluded from the

validation cohort. We ensured no period or patient overlap between the two independent cohorts. A coding system was used to ensure the anonymity of all enrolled patients.

Methods of Measurement

For the Taichung Sudden Unexpected Death Registry program, all patients with out-of-hospital cardiac arrest were prospectively registered at the China Medical University Hospital.[17] The out-of-hospital data were collected according to the Utstein-style template, which included age, sex, witnessed status, bystander CPR, and use of automated external defibrillator.[18,19] The first documented cardiac rhythms were divided into 2 groups: shockable rhythm, including out-of-hospital shock by automated external defibrillator and first monitored rhythm as ventricular fibrillation or ventricular tachycardia at the ED; and nonshockable rhythm, including asystole and pulseless electrical activity. Moreover, blood gas analyses, which yielded results within 2 minutes, and the first cycle of CPR were performed simultaneously on patient arrival at the ED.

For the derivation cohort, all of the above-mentioned data were prospectively registered by a research assistant. All the information was proofread by the ED's nurse practitioner before being enrolled in the analysis. For the validation cohort, the information of patients with out-of-hospital cardiac arrest was collected by 2 study nurses from the electronic medical record system of China Medical University and confirmed by the nurse practitioner. During the study period, the shockable rhythm–witness-age-pH (SWAP) score results were not developed and both emergency physicians and inpatient attending physicians were blinded to the study results. Inclusion and exclusion of patients were conducted by the principal investigator according to the aforementioned criteria.

Outcome Measures

The primary outcome of this study was neurologic status at hospital discharge. Based on the 5-point Cerebral Performance Category scale,[20] neurologic status was classified as follows: good recovery (Cerebral Performance Category score=1), moderate disability (score=2), severe disability (score=3), persistent vegetative state (score=4), and brain death (score=5). Favorable neurologic outcomes were defined as Cerebral Performance Category scores 1 and 2, whereas scores 3 to 5 and mortality were considered unfavorable outcomes.[21] The Cerebral Performance Category scale was determined by the inpatient attending physician at hospital discharge. At China Medical University Hospital, the neurologic status of patients is routinely recorded in daily practice. Furthermore, the neurologic status at hospital discharge for patients with out-of-hospital cardiac arrest is recorded for the Taichung Sudden Unexpected Death Registry program. The secondary outcomes comprised sustained return of spontaneous circulation after resuscitation and inhospital mortality.

PRIMARY DATA ANALYSIS

To establish a new scoring model, patients belonging to the derivation cohort were divided into 2 groups based on neurologic outcomes at hospital discharge. Differences between the two groups were analyzed with the χ^2 test for categoric variables and independent-samples t tests for continuous variables. Furthermore, to identify the variables associated with neurologic outcomes, data were initially analyzed with univariate analysis. Youden's J statistic was used to select the optimum cutoff for continuous variables.[22] Significant variables were then entered into a stepwise backward logistic regression analysis. Subsequently, we constructed a scoring system according to the variables independently associated with poor neurologic outcomes. Scores were assigned to each variable in the final model according to the regression coefficients.

To assess the performance of the scoring system, the sensitivity, specificity, and positive and negative predictive values for scores of 0, greater than 1, greater than 2, and greater than 3 were calculated. We attempted to compare the performance of SWAP scores with that of SWAP scores without the pH value. Moreover, we attempted to compare the SWAP score with the BLS termination-of-resuscitation rule in the derivation and validation cohorts.[4] However, the cohorts enrolled only patients without return of spontaneous circulation. Furthermore, we did not record the witnesses' identities in our registry system. Thus, a modified termination-of-resuscitation rule (no witness of collapse, no return of spontaneous circulation before ED arrival, and no shocking by automated external defibrillator) was used for comparison. The proportions of unfavorable neurologic outcomes, mortality, and predictive specificity for unfavorable outcomes were used to compare predictive performance.

Finally, we constructed the receiver operating characteristic (ROC) curve and calculated the corresponding area under the curve to evaluate discrimination and

concordance percentage. The Hosmer-Lemeshow goodness-of-fit test was used to evaluate the calibration.

All statistical assessments were 2 sided. $P<.05$ was considered statistically significant. All statistical analyses were performed with SAS (version 9.4; SAS Institute, Inc., Cary, NC).

RESULTS

Characteristics of Study Subjects

A total of 1,328 patients with out-of-hospital cardiac arrest were referred to China Medical University Hospital from January 1, 2015, to June 30, 2017. Among the 1,065 patients who underwent CPR attempts, 32 (2.41%) were excluded because of return of spontaneous circulation before arriving in our ED, 86 (6.64%) were excluded because of circumstantial causes, 53 (4.09%) were excluded because they were younger than 20 years, and 42 (3.24%) were excluded because they lacked an initial pH value.

Among the 852 patients enrolled in the derivation cohort, the majority were male patients (62.21%), with an average age of 67.3 years (SD 17.14 years); 101 patients (11.85%) had a shockable first documented rhythm at the ED, which is similar to epidemiologic data from Japan.[23] In addition, 300 patients (35.2%) had return of spontaneous circulation after resuscitation, 95 (11.2%) were discharged alive, and only 35 (4.1%) exhibited favorable neurologic outcomes. Figure 1 shows the enrollment data and characteristics of the derivation cohort according to an Utstein-style template.

A total of 1,484 patients with out-of-hospital cardiac arrest were admitted to the ED at China Medical University Hospital between January 1, 2012, and December 31, 2014. Among these patients, 38 (2.56%) were excluded because they were recorded as anonymous and we were unable to verify their records; 354 patients were excluded according to aforementioned criteria. A total of 1,092 out-of-hospital cardiac arrest patients met the inclusion criteria; 233 (15.70%) were excluded because blood gas analysis was not conducted within 5 minutes. The registration details of the validation cohort are shown in Figure 2 according to the Utstein-style template. For possible selection bias, patients with and without blood gas analysis within the first 5 minutes in the validation cohort were compared, as shown in Table E1, available online at http://www.annemergmed.com.

Finally, a total of 859 patients were included in the retrospective validation cohort. Baseline characteristics of the two cohorts were compared (Table 1). No significant differences in age, sex, automated external defibrillator shock, and initial rhythm were observed between the two cohorts. The number of witnessed events and bystander CPRs performed was higher in the derivation cohort than in the validation cohort; similarly, higher chances of survival at discharge and more favorable neurologic outcomes were noted in the derivation cohort than in the validation cohort.

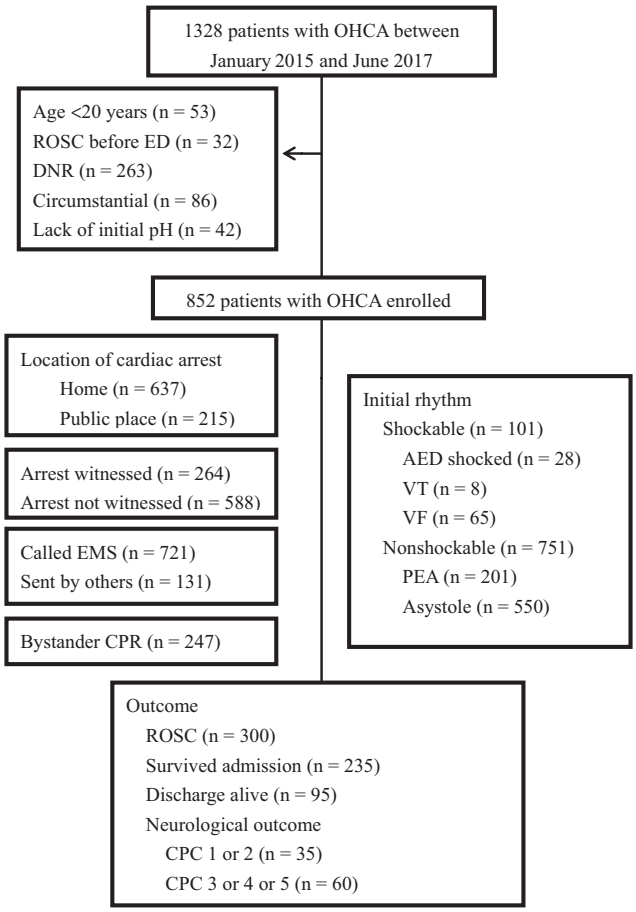

Figure 1. Patient enrollment and Utstein-Style template of the derivation cohort. *OHCA*, Out-of-hospital cardiac arrest; *ROSC*, return of spontaneous circulation; *DNR*, do not resuscitate; *AED*, automated external defibrillator; *VT*, ventricular tachycardia; *VF*, ventricular fibrillation; *PEA*, pulseless electrical activity; *CPC*, Cerebral Performance Category.

Main Results

Parameters available at the early stage of CPR at the ED were analyzed. The low-flow and no-flow durations were not used in the analysis because of the difficulty in determining the exact time that cardiac arrest occurred, especially for patients with private transference. Table 2 illustrates the predictors associated with unfavorable outcomes. According to the univariate analyses, age, sex, first documented rhythm, witnessed status, pH value of initial ED blood gas analysis, and possible cardiac cause of

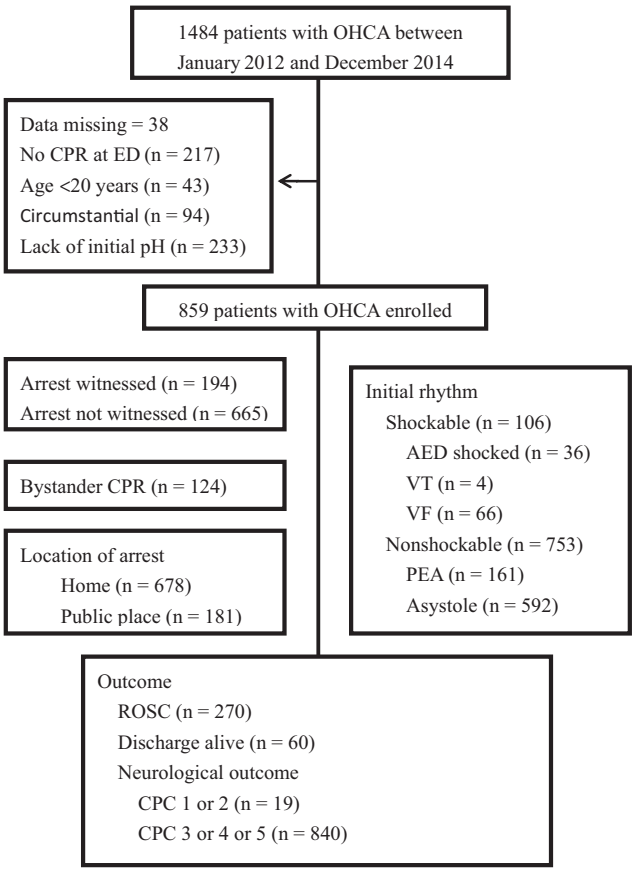

Figure 2. Patient enrollment and Utstein-Style template of the validation cohort.

Table 1. Comparison of derivation and validation cohorts.

Characteristics	Derivation Cohort (n=852)	Validation Cohort (n=859)	OR (95% CI)
Age, y (SD)	67.14 (17.14)	68.43 (16.86)	
Sex			0.99 (0.81–1.20)
Men	530 (62.21)	532 (61.93)	
Women	322 (37.79)	327 (38.07)	
First rhythm			0.96 (0.71–1.28)
Asystole/PEA	751 (88.15)	753 (91.85)	
Shockable	101 (11.85)	106 (12.34)	
Location*			0.79 (0.63–0.99)
Public	215 (25.23)	181 (21.07)	
Private	637 (74.77)	678 (78.93)	
Witnessed*			0.65 (0.52–0.81)
No	588 (69.01)	665 (77.42)	
Yes	264 (30.99)	194 (22.58)	
Bystander CPR*			0.41 (0.32–0.53)
No	605 (71.01)	735 (85.56)	
Yes	247 (28.99)	124 (14.44)	
Any ROSC			0.84 (0.69–1.03)
No	552 (64.79)	589 (68.57)	
Yes	300 (35.21)	270 (31.43)	
Survival discharge*			0.60 (0.43–0.84)
No	757 (88.85)	799 (93.02)	
Yes	95 (11.15)	60 (6.98)	
Neurologic outcome*			1.89 (1.07–3.34)
CPC scores 1 and 2	35 (4.11)	19 (2.21)	
CPC scores 3, 4, or 5, or mortality	817 (95.89)	840 (97.79)	
pH*	7.00 (0.17)	6.97 (0.16)	

OR, Odds ratio.
Categoric variables are presented as crude numbers and percentages and continuous variables are presented as mean (SD).
*Statistically significant.

death were associated with neurologic prognosis. The optimum cutoffs for age and pH were 60 years and 7.0, respectively, with Youden's J statistic. Older than 60 years, initial nonshockable rhythm, no witness of collapse, and pH less than or equal to 7 from initial ED blood gas analysis remained independent predictors of unfavorable neurologic outcomes after multivariate regression (Table 2).

The SWAP score was developed on the basis of the independent predictors. As shown in Table 2, the regression coefficients of these 4 predictors were similar. Favoring the simplicity of this score, 1 point was assigned to each predictor (as listed in Table 3), with a minimum score of 0 and maximum score of 4.

Among the 19 patients with SWAP scores of 0 in the derivation cohort, 9 (47.37%) were discharged alive and with good functional status. Only 1 of the 502 patients with SWAP scores of 4 had a favorable neurologic outcome. The predictive performances of SWAP scores for unfavorable neurologic outcomes and mortality are shown in Table 4 and Figure 3, respectively.

The predictive performances of SWAP scores, SWAP scores without the pH value, and the modified BLS termination-of-resuscitation rule were compared, using the proportion for unfavorable neurologic outcomes, mortalities, and predictive specificity for unfavorable outcomes based on the derivation and validation cohorts, as illustrated in Figure 4. With fully met criteria, the specificity for unfavorable outcomes was 97.14% (95% confidence interval [CI] 91.62% to 100%) for SWAP score, 88.57% (95% CI 78.03% to 99.11%) for SWAP score without the pH value, and 71.43% (95% CI 56.46% to 86.40%) for the modified BLS termination-of-resuscitation rule.

Figure 5 illustrates the ROC curves of the 2 cohorts in this study. The corresponding areas under the ROC curves were 0.8213 in the derivation cohort and 0.8772 in the validation cohort, which indicated the excellent predictive

Table 2. Logistic regression for parameters associated with an unfavorable outcome after cardiac arrest in the derivation cohort.

Variables	Unfavorable Outcome, N=817/852 (95.89%)	Univariate OR (95% CI)	Multivariate OR (95% CI)	Multivariate ß
Age, y (SD)	67.60 (17.14)	–*	–	–
>60 y†	–	5.33 (2.52–11.25)	3.65 (1.64–8.09)	.647
Men, No. (%)	501 (61.32)	0.33 (0.14–0.80)	0.56 (0.22–1.44)	-.290
First rhythm nonshockable (%)†	731 (89.47)	6.38 (3.15–12.91)	3.40 (1.58–7.32)	.612
pH (SD)	6.99 (0.17)	–	–	–
pH ≤7.00†	–	4.48 (2.01–9.98)	3.27 (1.42–7.54)	.593
Nonwitnessed (%)†	576 (70.50)	4.58 (2.24–9.36)	3.19 (1.51–6.75)	.580
Bystander CPR (%)	234 (28.64)	0.68 (0.34–1.37)	–	–
CPR duration, min (SD)‡	18.01 (20.85)	1.01 (0.99–1.03)	–	–

*Dashes indicate that no statistical analysis was performed.
†Statistically significant.
‡For patients with return of spontaneous circulation (N=300).

accuracy of the SWAP score. SWAP calibration was confirmed with the Hosmer-Lemeshow goodness-of-fit test, with P=.92 (>.05) in the derivation cohort and P=.68 (>.05) in the validation cohort.

LIMITATIONS

The SWAP score performed well for patients from the derivation and validation cohorts. However, it requires further prospective validation in other populations before being applied to clinical settings. A limitation of this study was that the study population consisted of only patients with out-of-hospital cardiac arrest who did not have return of spontaneous circulation before arrival to the ED. Thus, the application of SWAP score should be limited to patients with a similar clinical context. Furthermore, the incidence of shockable rhythm in this study was relatively low, possibly because we excluded patients with out-of-hospital return of spontaneous circulation, although relevant observational studies conducted in Asia have also shown a low incidence of shockable rhythm.[17,24] The reason for the relatively low incidence of shockable rhythm in the Asian population remains unclear, which might affect the application of SWAP in non-Asian populations.

Table 3. SWAP score.

Variables	Points
First rhythm	
Shockable*	0
Asystole/PEA	1
Witnessed	
Yes	0
No	1
Age, y	
≤60	0
>60	1
pH	
>7.00	0
≤7.00	1

*Shockable rhythm: out-of-hospital shock by AED or first monitored rhythm as VF or VT.

In this study, the Cerebral Performance Category score was determined by the inpatient attending physician at hospital discharge. No further review was conducted to confirm the outcomes evaluation. The intrarater and interrater reliability were uncertain, which might have led to information bias. Blood pH was easily and quickly obtained with a whole-blood analyzer; however, blood samples could be obtained from the artery or vein during CPR. Although some studies have reported minimal differences and good correlations between arterial and venous samples in regard to pH,[25,26] others have shown significant differences between the two.[27] This discrepancy could influence the accuracy of the SWAP score.

In addition, the international guidelines for CPR and EMS policies were changed during the study period. Moreover, the validation cohort excluded 233 cases (15.70%), which could reveal some bias. The survival and neurologic outcomes were superior in the derivation cohort compared with the validation cohort; however, these differences did not hinder application of the SWAP score.

No visible cardiac movement on bedside echocardiography had been highly specific for nonsuccessful termination of CPR in patients with out-

Table 4. Discrimination performance of the SWAP score.

Variables	Derivation cohort				
SWAP score	0	1	2	3	4
N	19	73	198	338	224
CPC score 3, 4, or 5, or mortality (%)	10 (52.63)	64 (87.67)	187 (94.44)	333 (98.52)	223 (99.55)
SWAP score	**0**	**>1**	**>2**	**>3**	
Sensitivity, %	98.78	90.94	68.05	27.29	
Specificity, %	25.71	51.43	82.86	97.14	
PPV, %	96.88	97.76	98.93	99.55	
NPV, %	47.37	19.57	10.00	5.41	
Variables	**Validation cohort**				
SWAP score	0	1	2	3	4
N	12	63	152	354	278
CPC score 3, 4, or 5, or mortality (%)	9 (75.00)	55 (87.30)	146 (96.05)	352 (99.44)	278 (100.00)
SWAP score	0	>1	>2	>3	
Sensitivity, %	98.93	92.38	75.00	33.10	
Specificity, %	15.79	57.89	89.47	100.00	
PPV, %	98.11	98.98	99.68	100.00	
NPV, %	25.00	14.67	7.49	3.27	

PPV, Positive predictive value; *NPV*, negative predictive value.

of-hospital cardiac arrest.[28] We did not integrate bedside ultrasonographic findings in this study. Furthermore, we lacked critical information for the criteria of the BLS and ALS termination-of-resuscitation rules of Morrison et al.[4] Moreover, the score was validated with a retrospective cohort from same institution. Therefore, further studies are required to validate the score with other populations and compare scores directly with other predictive models.

DISCUSSION

In this study, the simple SWAP score based on an analysis of prospective registry records may provide information that enables physicians to estimate the

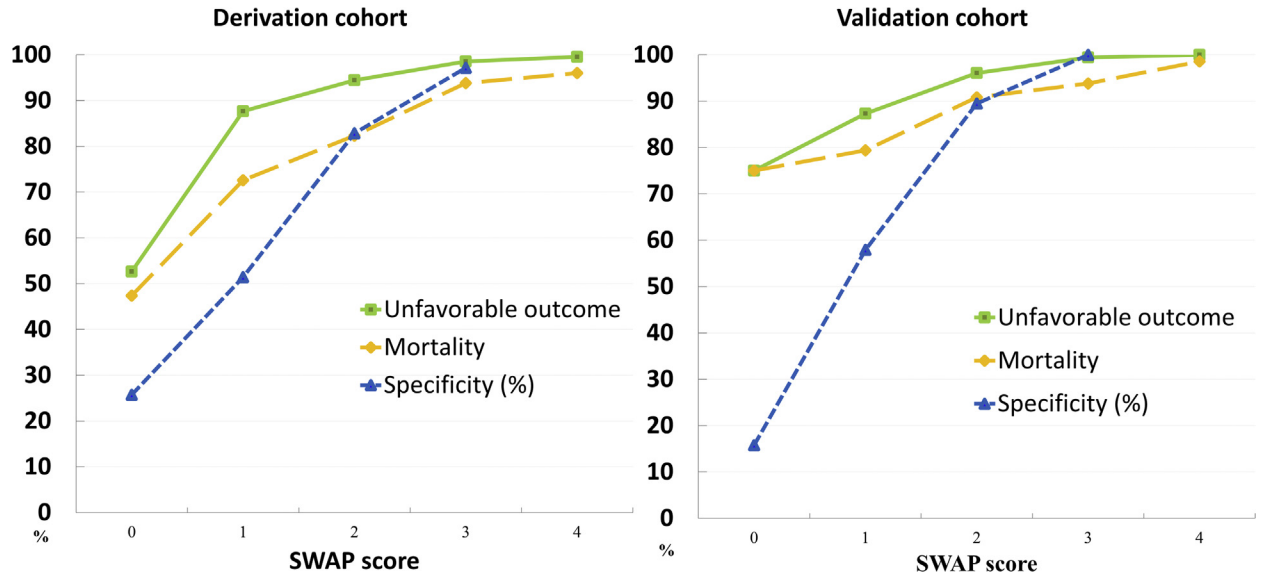

Figure 3. SWAP score performance. The proportion of unfavorable outcomes, mortality rate, and specificity for predicting unfavorable outcomes of different SWAP scores in the derivation and validation cohorts are illustrated.

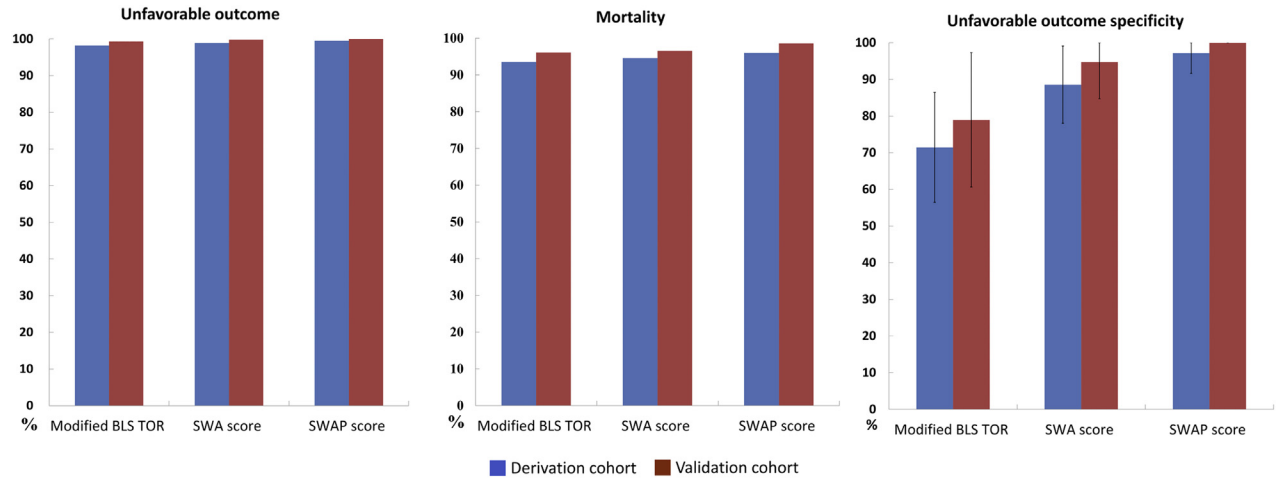

Figure 4. Proportion of unfavorable outcomes, mortality rate, and specificity for predicting unfavorable outcomes for fully meeting the criteria of the SWAP score, SWAP score without the pH value, and modified BLS termination-of-resuscitation rule. Modified BLS TOR rule: no witness of collapse, no ROSC before ED, and not shocked by AED. *TOR*, Termination of resuscitation; *SWA*, SWAP score without the pH value.

neurologic outcomes early of patients with out-of-hospital cardiac arrest during ED resuscitation. Patients with SWAP scores of 0 had a 25% to 50% chance of survival at discharge, along with favorable neurologic performance. In contrast, a SWAP score of 4 was 97.14% specific (95% CI 91.62% to 100%) in the derivation cohort and 100% specific (95% CI 99.99% to 100%) in the validation cohort for unfavorable outcomes.

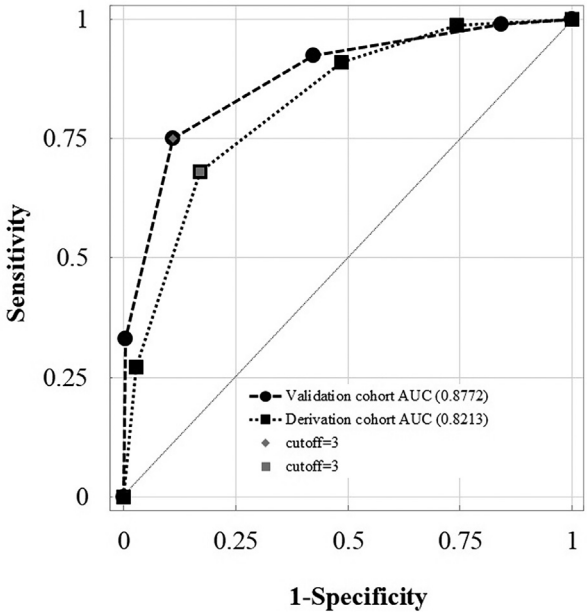

Figure 5. ROC curves of SWAP scores for predicting an unfavorable neurologic outcome or mortality after out-of-hospital cardiac arrest. The area under the curve was 0.8213 for the derivation cohort and 0.8772 for the validation cohort.

The BLS termination-of-resuscitation rule for mortality has been well established and validated.[4,29,30] However, the neurologic functional status may be a more crucial outcome than survival rate among patients with out-of-hospital cardiac arrest. Furthermore, despite meeting all BLS termination-of-resuscitation criteria, many patients were still sent to the ED and received CPR. Thus, another termination-of-resuscitation rule is required for physicians in EDs. Although we did not register the identities of witness personnel, we compared the predictive performance of the modified BLS termination-of-resuscitation rule with the SWAP score in the study population. The SWAP score showed a superior specificity of 97.14% (95% CI 91% to 100%).

Current out-of-hospital cardiac arrest prognostic scores, such as out-of-hospital cardiac arrest score, Cardiac Arrest Hospital Prognosis score, and target temperature management score, require precise estimates of no-flow and low-flow intervals and several other biomarkers;[7,9,31] however, the accuracy of out-of-hospital records may vary regionally, and most biomarkers are not readily available at EDs.[31-33] Not all patients with out-of-hospital cardiac arrest are sent to the ED by EMS personnel; in our derivation cohort, 131 patients (15.4%) did not call the EMS system. The no-flow duration is difficult to ascertain in patients lacking out-of-hospital records, and moreover, low-flow duration cannot be calculated during the early stages of CPR. Thus, those out-of-hospital cardiac arrest prognostic scores were limited when applied in the ED setting.[7,9] Also, the out-of-hospital cardiac arrest score comprised a relatively small group (n=130). With a cutoff point set at 32.5, the out-of-hospital cardiac arrest score

had a relatively low specificity of 85% for poor neurologic outcomes.[9] With a score of 4, the SWAP score had 97.14% to 100% specificity, indicating that it could be a more accurate prediction model. Both Cardiac Arrest Hospital Prognosis and target temperature management scores were developed for estimating the prognosis of patients with return of spontaneous circulation in ICUs. Both scores require much more information compared with the SWAP score. Each parameter of the Cardiac Arrest Hospital Prognosis and target temperature management scores has a different weight, making the calculation more complicated. Following the example of the quick Sequential [Sepsis-related] Organ Failure Assessment,[34] we ensured that the SWAP scoring system was simple and easy to use because it was composed of only 4 parameters with 1 weighted point for each. The SWAP scores could be calculated with a bedside blood gas analysis machine within 5 minutes of patient arrival at the ED, thereby allowing emergency physicians to quickly evaluate a patient's prognosis.

Duration of no-flow and low-flow status is crucial for neurologic deficits after out-of-hospital cardiac arrest. The presence of a witness after collapse allows early recognition of cardiac arrest with timely resuscitation, thereby shortening the no-flow and low-flow periods. Metabolic acidosis is observed in 98% of patients with out-of-hospital cardiac arrest, and the longer the no-flow or low-flow duration, the more severe the acidosis is.[35,36] Moreover, Ganga et al[37] found that severe acidemia in shockable cardiac arrest survivors was significantly associated with poor neurologic outcomes. In this study, both nonwitnessed out-of-hospital cardiac arrest and severe acidemia on arrival to the ED were independent predictors of unfavorable outcomes. Figure 4 compares the performance of SWAP score with that of SWAP score without the pH value. When criteria of the SWAP score without the pH value were fully met, the specificity for unfavorable outcomes was 88.57% (95% CI 78.03% to 99.11%), and adding the serum pH value improved the specificity to 97.14% (95% CI 91.62% to 100%).

As reported previously, aging is associated not only with an increase in the incidence of out-of-hospital cardiac arrest but also with a low chance of survival. Age has also been significantly associated with neurologic outcomes from out-of-hospital cardiac arrest.[38,39] However, a shockable rhythm enables the reversal of cardiac arrest status in a short time, and a short duration of arrest decreases ischemic cerebral injury from out-of-hospital cardiac arrest. Both age and shockable rhythm are critical prognostic factors in patients with out-of-hospital cardiac arrest.[40,41] When we were developing the SWAP scoring system, we assigned 1 point each for age and shockable rhythm because they remained independent prognostic factors for patients with out-of-hospital cardiac arrest after the multivariate analysis.

The numbers of witnessed events and bystander CPRs were higher in the derivation cohort than in the validation cohort (Table 1). Furthermore, a higher proportion of cardiac arrest events occurred at home in the validation cohort. Improving overall medical knowledge through public health education may enable people to recognize the signs of cardiac arrest. In addition, provision of BLS training will increase the number of bystander CPRs. Furthermore, dispatcher-assisted CPR, introduced in 2015 in Taichung, may help the public to recognize cardiac arrest and perform CPR before patient arrival to the ED. The above-mentioned changes may be responsible for the higher incidence of witnesses in the cohort and bystander CPR, leading to enhanced survival and neurologic outcomes after out-of-hospital cardiac arrest, as observed in relevant studies.[42,43] Survival after out-of-hospital cardiac arrest has also improved in other countries.[44,45] Despite some differences between the derivation and validation cohorts, the SWAP score demonstrated good predictive value and consistency in both cohorts.

Although the use of ultrasonography in patients with out-of-hospital cardiac arrest is still being debated, we believe that ultrasonographic findings should be an essential component of emergency physicians' care of patients with cardiac arrest. However, there is no standard for defining "no cardiac activity" in ultrasonography, and the prognostic value of minimal or agonal cardiac motion has not been thoroughly studied. In addition, ultrasonography may increase the duration of rhythm checks, which has the potential to worsen outcomes.[46] In the future, SWAP scores can be correlated with echocardiographic findings. For patients with minimal or agonal cardiac motion noted from ultrasonography, echocardiographic findings can be combined with SWAP scores to provide more information to help physicians estimate their prognosis early.

At present, the SWAP score has been verified only by a single institution, and its generalizability and reliability must still be confirmed in other populations. For patients with out-of-hospital cardiac arrest, we wish to further integrate bedside ultrasonographic findings with the SWAP score to further develop the prognosis estimating tool. After this integration, the next step would be to focus on the tool's implementation in clinical practice for early termination of resuscitation in the ED, as well as investigate the efficiency of the score and compare the predicted results with the physician's gestalt.

This study developed the SWAP score with a cohort that comprised 852 patients with out-of-hospital cardiac arrest. It is a new and simple predictive model that enables early

estimation of prognosis in these patients. Currently, the score has been validated with a retrospective cohort from the same institution. Future research is required to verify its reliability and popularity for rapidly assessing the prognosis of patients with out-of-hospital cardiac arrest during ED resuscitation.

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