Original Article

Yonsei Med J 2021 Dec;62(12):1145-1154
https://doi.org/10.3349/ymj.2021.62.12.1145

Yonsei Medical Journal
YMJ
pISSN: 0513-5796 · eISSN: 1976-2437

Modification and Validation of a Complaint-Oriented Emergency Department Triage System: A Multicenter Observational Study

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Purpose: The objective of this study was to modify and validate an emergency department (ED) triage system with improved prediction performance on hospital outcomes by modifying the Korean Triage and Acuity Scale (KTAS).

Materials and Methods: We performed a retrospective observational study at three academic universities in South Korea. The KTAS code, determined by the chief complaint and the selected modifier of a patient, was used to derive the Modified KTAS (MKTAS). We calculated the area under the receiver operating characteristics curve (AUC) and the test characteristics to evaluate the performance of MKTAS to predict hospital mortality, critical outcome, and admission.

Results: A total of 272402 and 128831 ED visits were used for the derivation and validation of MKTAS, respectively. Compared to KTAS, MKTAS had significantly higher AUC values for the prediction of hospital mortality [MKTAS 0.826 (0.818–0.835) vs. KTAS 0.794 (0.784–0.803)], critical outcome [MKTAS 0.836 (0.830–0.841) vs. 0.798 (0.792–0.804)], and admission [MKTAS 0.725 (0.723–0.728) vs. KTAS 0.685 (0.682–0.688)]. The sensitivity for predicting hospital mortality and critical outcome, as well as the specificity for predicting admission, were significantly improved.

Conclusion: MKTAS was derived by modifying the KTAS, and then validated. Compared with KTAS, MKTAS showed better discriminating ability to predict hospital outcomes. Continuous efforts to evaluate and modify widely used triage systems are required to improve their performance.

Key Words: Emergency medical services, triage, patient acuity, Korea

INTRODUCTION

The number of patients visiting the emergency department (ED) has been continuously increasing, which has led to ED crowding. In the United States, the number of ED visits increased from 128.9 million to 137.8 million between 2010 and 2014.[1] In South Korea (henceforth, Korea), the number increased from 10.2 million to 10.6 million between 2013 and 2018.[2] Studies have shown that ED crowding leads to treatment delays, which results in greater hospital mortality, ED cost, and ED length of stay.[3,4] Therefore, it is critical to prioritize patients and efficiently distribute medical resources to each individual.

ED triage is a method of prioritizing patients by their severity and urgency of illness and is performed immediately after patients' arrival at the hospital.[5] This triage process can be challenging as patients with diverse complaints visit the ED and the healthcare staff must act with limited information in a short amount of time.[6] Although it is not a simple task, ED patient

Received: July 9, 2021 **Revised:** September 16, 2021
Accepted: September 27, 2021
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•The authors have no potential conflicts of interest to disclose.

triage needs to be accurate and reliable. If urgent and severely ill patients are underestimated in the triage process (undertriage), there will be delays to time-sensitive treatments, which may lead to increases in morbidity and mortality.[7,8] On the other hand, overestimation of the urgency and severity of a patient (overtriage) will result in unnecessary use of medical resources.[9,10]

Many studies have attempted to validate triage systems and develop new triage systems with better performance results.[5,11-14] Modern triage systems, such as the Emergency Severity Index (ESI), the Manchester Triage System (MTS), the Canadian Triage and Acuity Scale (CTAS), and the Korean Triage and Acuity Scale (KTAS), use a five-level triage scale and have demonstrated better reliability compared to other scale systems.[13,15,16] KTAS, developed in 2015 and based on CTAS, has also been evaluated in several studies. Kwon, et al.[17] discovered that ED length of stay and mortality rate were reduced after KTAS implementation, but they did not validate KTAS in terms of whether each patient was assigned to an appropriate triage level. Choi, et al.[18] reported that KTAS predicted emergent patients with high sensitivity. However, the same investigators also mentioned that KTAS showed lower specificity compared to CTAS or MTS when predicting either emergency or admission. Lee, et al.[19] pointed out that the degree of pain led to overtriage of ED patients and reduced the discriminatory power of KTAS. As shown, previous studies examining the validity of KTAS had certain limitations, leaving the room for improvement of KTAS.

The objective of this study was to develop and validate a complaint-oriented triage system with improved prediction performance on hospital outcomes by modifying KTAS.

MATERIALS AND METHODS

Study design

We performed a retrospective observational study at three academic university hospitals in Korea. The hospitals were secondary or tertiary medical centers with an annual ED volume of 50000 to 90000 visits. We used the data of ED visits to Seoul National University Hospital and the Seoul Metropolitan Government-Seoul National University Boramae Center from May 2016 to April 2019 for the derivation of Modified KTAS (derivation dataset). For external geographic validation, we used the data of ED visits to Seoul National University Bundang Hospital, a tertiary hospital located in a different province (validation dataset), between May 2016 and April 2018.

Data collection

We used the National Emergency Department Information System (NEDIS) data collected from each of the hospitals, which included the demographics, baseline characteristics (chief complaint codes, vital signs, mental status), triage levels, diagnosis codes, and treatment results of patients who visited the ED. Most of the primary information regarding the baseline demographics, emergency medical services (EMS) use, ED arrival time, triage level, vital signs, and mental status were recorded by an ED triage nurse. Information such as chief complaint, diagnosis codes, and treatments administered in the ED or inpatient ward were recorded by a physician.

The NEDIS data from each hospital was merged with the National Emergency Medical Center (NEMC) server, and quality management was performed by the NEMC on a monthly basis. Under the EMS Act, the NEMC evaluates the structure requirements, processes, and outcomes of all EDs annually.[20,21] This evaluation is associated with financial support, which encourages all EDs to conduct quality control to fulfill the requirements.

Study population

We included all adult patients (aged 18 years or older) who visited the EDs of the three hospitals during the study period. We excluded patients with missing demographic information (age, sex, and EMS use) or missing information on the KTAS level or code. We also excluded patients who were dead upon ED arrival or had missing information on ED or hospital outcome, such as those who transferred to another hospital or left the hospital against medical advice. Adult patients triaged with the pediatric version of the KTAS were excluded, since our study was intended to modify and validate only the adult version of the KTAS.

KTAS and KTAS codes

KTAS is an ED triage tool developed based on CTAS after some modifications to make it more suitable for use in Korea. KTAS was developed and implemented in 2015. In 2016, the Ministry of Health and Welfare in Korea legislated all EDs to adopt the KTAS and apply it to all patients. ED triage by KTAS can be performed by qualified physicians, nurses, or paramedics who have completed a 6-hour training program and passed the pretest and posttest, which is operated by the KTAS committee. KTAS has five levels—level 1, resuscitation; level 2, emergent; level 3, urgent; level 4, less urgent; and level 5, non-urgent[15]—and two versions: adult (aged 15 years or older) KTAS and pediatric (aged less than 15 years) KTAS. This age criterion was decided by considering pediatric anatomy, physiologic development processes, and other social factors.[18]

The KTAS level was decided by the chief complaint and a chosen modifier, the same as for CTAS. Modifiers provide additional acuity information and is composed of first order modifiers and second order modifiers. First order modifiers included vital sign modifiers (respiratory distress, hemodynamic status, level of consciousness, temperature), pain score modifiers, bleeding disorder modifiers, and modifiers related to the mechanism of injury. Second order modifiers were defined for certain chief complaints and could be applied in cases where a first order modifier was not assigned beforehand.[22] An example

https://doi.org/10.3349/ymj.2021.62.12.1145

of the modifiers that can be selected for a specific chief complaint is shown in Supplementary Table 1 (only online).

KTAS code comprised five capital letters that showed the classification process of triage. The first letter of the KTAS code distinguished adults from children. The second letter classified chief complaints into 17 broad categories: substance abuse, psychiatric and social problems, neurology, eye, nose, ear, laryngopharynx, pulmonology, cardiology, gastroenterology, obstetrics and gynecology, urology, orthopedics, trauma, environmental injuries, dermatology, and general and mild illness. The third letter more specifically classified the symptoms. The last two letters were determined based on the modifier used for triage. The total number of KTAS codes was 2016, and each of the codes was matched with a KTAS level, which was predetermined when the KTAS was developed.[23] The KTAS code and level were also collected and sent to the NEDIS database with other information.

Derivation of the Modified KTAS (MKTAS)

First, to derive the Modified KTAS (MKTAS), we grouped patients according to the KTAS code, assigned at triage, in the derivation dataset. Second, for the KTAS codes assigned to patients less than 10 times or not assigned at all, the KTAS level was maintained as the MKTAS level. We considered that these codes were used too rarely to be evaluated. For the remaining 836 KTAS codes which comprised about 99% of the total ED visits in the derivation dataset, we calculated the percentage of patients who were hospitalized or had critical outcomes. Critical outcome was defined as hospital death or direct admission to the intensive care unit (ICU) from the ED. Through this method, we obtained the percentage of critical outcome, as well as the percentage of admission for each KTAS code.

In a similar manner to a previous study, we determined the cutoff thresholds to designate triage levels and assigned a triage level for each KTAS code by using the percentages of critical outcome and admission.[6] To facilitate comparisons, the cutoff values were calibrated so that the proportion of patients in each triage level would be similar for the MKTAS and KTAS. Fig. 1 shows the cutoff values that designated the triage levels. KTAS codes with the percentage of critical outcome greater than or equal to 25% were assigned to MKTAS level 1. KTAS codes with the percentage of critical outcome between 6% and 25% were assigned to MKTAS level 2. KTAS codes with the percentage of critical outcome between 1% and 6%, or KTAS codes with the percentage of admission greater than or equal to 15%, were assigned to MKTAS level 3. KTAS codes not fulfilling MKTAS levels 1–3 criteria were assigned to MKTAS level 4 if the percentage of admission was between 3% and 15%, and level 5 if the percentage was below 3%. Some examples of MKTAS level and KTAS level for each KTAS code are shown in Supplementary Table 2 (only online).

MKTAS triage algorithm for each KTAS code

Level 1	25%≤critical outcome		-
Level 2	6%≤critical outcome<25%		-
Level 3	1%≤critical outcome<6%	or	15%≤admission
Level 4	Critical outcome<1%	and	3%≤admission<15%
Level 5	Critical outcome<1%	and	Admission<3%

Fig. 1. MKTAS triage algorithm for each KTAS code. Critical outcome was defined as hospital death or direct admission to the intensive care unit from the emergency department. KTAS, Korean Triage and Acuity Scale; MKTAS, Modified KTAS.

Main outcomes

The main outcomes of this study were hospital mortality, critical outcome, and admission. Hospital mortality was defined as mortality in the ED or mortality after admission to the ward or ICU. Critical outcome was defined as hospital death or direct admission to the ICU from the ED. Admission was defined as admission to either the general ward or ICU, and patients who died in the ED were also considered an admission.

Statistical analysis

We performed descriptive analysis to examine the demographics of the study population. Continuous variables were presented using means and standard deviation (SD), and categorical variables were presented using percentages. For comparison between groups, Wilcoxon rank-sum test was used for continuous variables and chi-square test was used for categorical variables. After deriving the MKTAS, we compared the percentages of hospital outcomes by triage level with the KTAS in the derivation dataset.

We assessed the validity of the MKTAS by calculating the area under the receiver operating characteristics curve (AUC) and test characteristics (sensitivity, specificity, positive predictive value, negative predictive value) with 95% confidence intervals (CIs) from the logistic regression models. The performance of MKTAS was compared with KTAS. To calculate test characteristics for the prediction of hospital mortality and critical outcome, triage levels were grouped into high acuity (levels 1 or 2) and low or moderate acuity (levels 3 to 5). To calculate the test characteristics of predicting admission, triage levels were grouped into at least moderate acuity (levels 1 to 3) and low acuity (levels 4 or 5). For internal validation, bootstrap sampling of 1000 samples of size 272402 with replacement from the derivation dataset was performed to calculate AUC and test characteristics with 95% CIs. For external validation, AUC and test characteristic with 95% CIs were acquired in the validation dataset.

For additional analysis, we compared the MKTAS level and KTAS level for each KTAS code. We attempted to determine which KTAS codes were underestimated (the MKTAS estimated a patient to be more severe than the KTAS) or overestimated (the MKTAS estimated a patient to be less severe than the KTAS) in terms of the severity of the patient.

Bootstrap sampling and analysis of internal validation results were performed using Python version 3.8.8 (Python software foundation, Wilmington, DE, USA). All other statistical analysis was performed using SAS software, version 9.4 (SAS Institute Inc., Cary, NC, USA).

Ethics statement

The Institutional Review Board at Seoul Metropolitan Government-Seoul National University Boramae Medical Center approved this project with a waiver of informed consent (IRB no. 20-2020-2). The authors have made sure that was no violation of human rights concerning the study.

RESULTS

From May 2016 to April 2019, there was a total of 377227 ED visits to Seoul National University Hospital and Seoul Metropolitan Government-Seoul National University Boramae Center. After exclusion, 272402 visits remained for the derivation dataset. There were 181031 ED visits to Seoul National University Bundang Hospital from May 2016 to April 2018; and after exclusion, 128831 remained for analysis in the validation dataset (Fig. 2).

The demographics and outcomes of the study population had some differences between the derivation and validation datasets (Table 1). In the derivation dataset, the median age was 55.0 years, and females constituted 51.5% of the total population. The percentages of patients triaged to KTAS levels 1, 2, 3, 4, and 5 were 1.4%, 11.2%, 46.1%, 34.9%, and 6.3%, respectively. In the validation dataset, the median age was slightly younger (54.4 years) and females constituted a higher portion (53.0%) of the total population, compared to the derivation dataset. The proportion of patients triaged to KTAS levels 1, 2, 3, 4, and 5 were 0.8%, 9.8%, 54.4%, 29.2%, and 5.8%, respectively. In the validation dataset, the proportions of hospital mortality and admission were 1.6% and 24.0%, respectively, which were greater than the proportions of hospital mortality (1.4%) and admission (23.1%) in the derivation dataset. The percentages of patients triaged to each MKTAS level in the derivation dataset were 2.0% for level 1, 12.3% for level 2, 41.0% for level 3, 35.9% for level 4, and 8.8% for level 5. Additionally, the percentages of hospital outcomes by the triage level of MKTAS and KTAS

Table 1. Demographics and Outcomes of the Study Population

Characteristic	Derivation dataset (n=272402)	Validation dataset (n=128831)	*p* value
Age (yr)	55.0±19.4	54.4±19.1	<0.001
Sex			<0.001
Female	140386 (51.5)	68226 (53.0)	
Male	132016 (48.5)	60605 (47.0)	
Ambulance use			<0.001
Non-use	202736 (74.4)	100500 (78.0)	
Prehospital use	57901 (21.3)	22109 (17.2)	
Interhospital use	11765 (4.3)	6222 (4.8)	
KTAS level			<0.001
1	3881 (1.4)	1083 (0.8)	
2	30401 (11.2)	12569 (9.8)	
3	125688 (46.1)	70060 (54.4)	
4	95153 (34.9)	37642 (29.2)	
5	17279 (6.3)	7477 (5.8)	
Outcomes			
Hospital mortality	3736 (1.4)	2014 (1.6)	<0.001
Critical outcome*	11075 (4.1)	5192 (4.0)	0.594
Admission	62983 (23.1)	30964 (24.0)	<0.001

KTAS, Korean Triage and Acuity Scale.
Data are presented as mean±standard deviation or n (%).
*Critical outcome was defined as hospital death or direct admission to the intensive care unit from the emergency department.

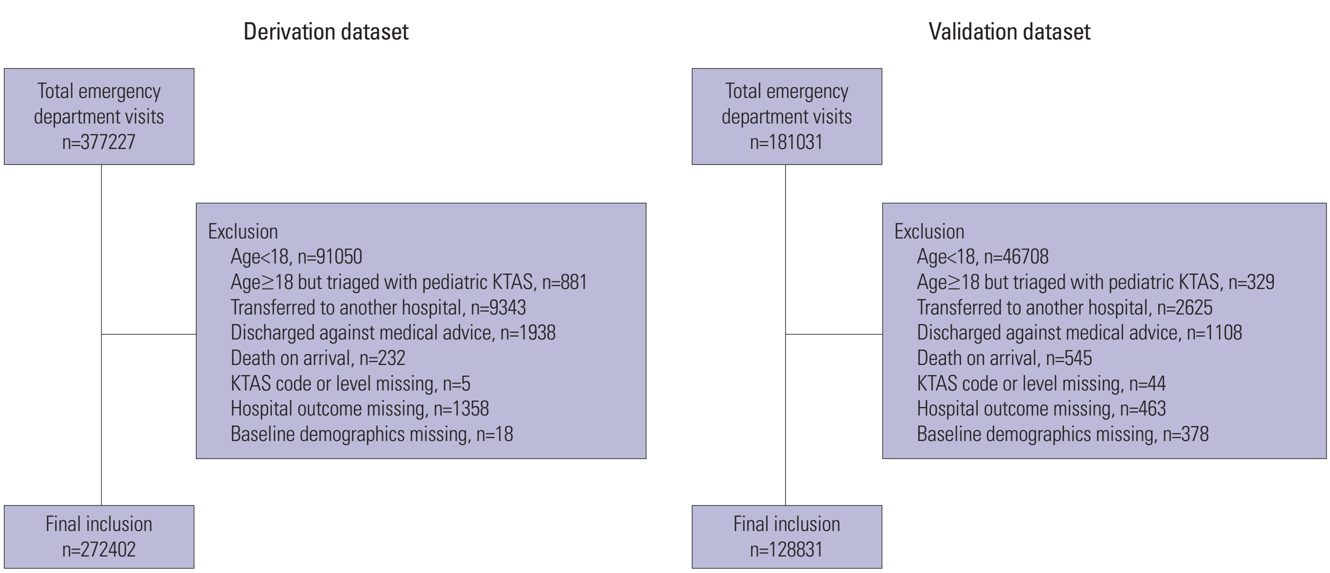

Fig. 2. Study flowchart. KTAS, Korean Triage and Acuity Scale.

https://doi.org/10.3349/ymj.2021.62.12.1145

in the derivation dataset are presented in Fig. 3.

The AUCs of MKTAS for the prediction of hospital mortality (AUC, 0.872; 95% CI, 0.866–0.878), critical outcome (AUC, 0.876; 95% CI, 0.873–0.880), and admission (AUC, 0.750; 95% CI, 0.748–0.752) were significantly higher than the AUCs of KTAS (AUC, 95% CI; hospital mortality: 0.856, 0.850–0.862; critical outcome: 0.857, 0.854–0.860; admission: 0.727, 0.725–0.729) in the derivation dataset. The p-values for the difference of AUCs between MKTAS and KTAS for the prediction of hospital mortality, critical outcome, and admission were all <0.001.

Fig. 4 shows the receiver operating characteristics curves for the prediction of hospital outcomes in the validation dataset. The AUCs of MKTAS for the prediction of hospital mortality (AUC, 0.826; 95% CI, 0.818–0.835), critical outcome (AUC, 0.836; 95% CI 0.830–0.841), and admission (AUC, 0.725; 95% CI, 0.723–0.728) were significantly higher than the AUCs for KTAS (AUC, 95% CI; hospital mortality: 0.794, 0.784–0.803; critical outcome: 0.798, 0.792–0.804; admission: 0.685, 0.682–0.688). The *p*-values for the difference of AUCs between MKTAS and KTAS for the prediction of hospital mortality, critical outcome, and admission were all <0.001.

The results of the test characteristics for prediction of hospital outcomes in the derivation (Table 2) and validation dataset (Table 3) are presented. The trends of the results were generally consistent between the derivation and validation datasets. Compared to KTAS, the MKTAS had a significantly higher sensitivity (MKTAS 0.610; 95% CI, 0.588–0.631 vs. KTAS 0.550; 95% CI, 0.528–0.571) but a lower specificity (MKTAS 0.888; 95% CI, 0.886–0.889 vs. KTAS 0.901; 95% CI, 0.899–0.903) in the validation dataset to predict hospital mortality. The sensitivity for pre-

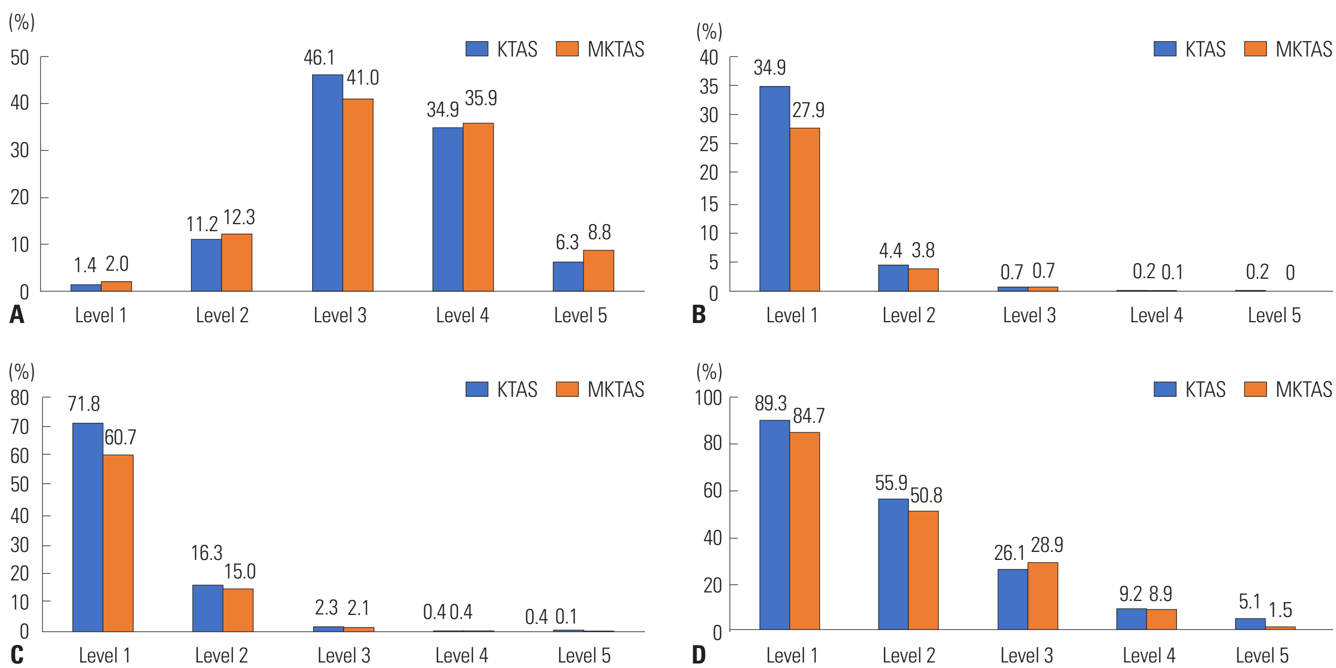

Fig. 3. Percentages of patients in the derivation dataset by triage level. (A) Patient distribution, (B) hospital mortality, (C) critical outcome, and (D) admission rate by triage level in KTAS and MKTAS in the derivation dataset. KTAS, Korean Triage and Acuity Scale; MKTAS, Modified KTAS.

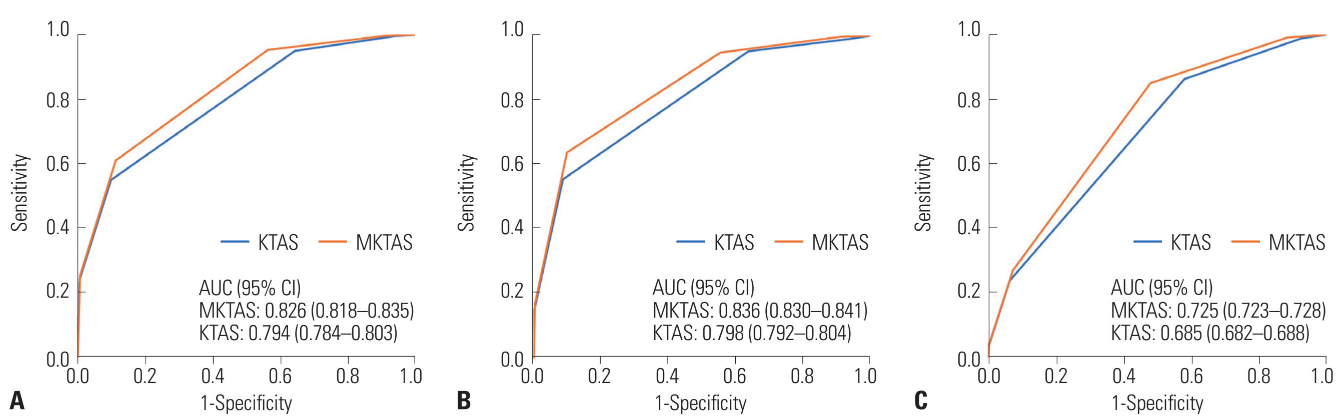

Fig. 4. Receiver operating characteristics curve for prediction of (A) hospital mortality, (B) critical outcome, and (C) admission in the validation dataset. KTAS, Korean Triage and Acuity Scale; MKTAS, Modified KTAS; CI, confidence interval; AUC, area under the receiver operating characteristics curve.

Table 2. Test Characteristics of MKTAS and KTAS in the Derivation Cohort

Outcome and triage model	Sensitivity (95% CI)	*p* value	Specificity (95% CI)	*p* value	PPV (95% CI)	*p* value	NPV (95% CI)	*p* value
Hospital mortality								
KTAS level 1–2 vs. 3–5	0.720 (0.706–0.734)	Reference	0.882 (0.881–0.884)	Reference	0.078 (0.076–0.081)	Reference	0.996 (0.995–0.996)	Reference
MKTAS level 1–2 vs. 3–5	0.750 (0.736–0.764)	0.003	0.866 (0.864–0.867)	<0.001	0.072 (0.069–0.075)	0.003	0.996 (0.996–0.996)	0.030
Critical outcome*								
KTAS level 1–2 vs. 3–5	0.698 (0.689–0.707)	Reference	0.898 (0.897–0.900)	Reference	0.226 (0.221–0.230)	Reference	0.986 (0.985–0.986)	Reference
MKTAS level 1–2 vs. 3–5	0.753 (0.745–0.761)	<0.001	0.883 (0.882–0.884)	<0.001	0.214 (0.210–0.218)	<0.001	0.988 (0.988–0.989)	<0.001
Admission								
KTAS level 1–3 vs. 4–5	0.846 (0.844–0.849)	Reference	0.491 (0.489–0.493)	Reference	0.333 (0.331–0.336)	Reference	0.914 (0.912–0.916)	Reference
MKTAS level 1–3 vs. 4–5	0.856 (0.854–0.859)	<0.001	0.538 (0.536–0.540)	<0.001	0.358 (0.356–0.360)	<0.001	0.926 (0.924–0.927)	<0.001

KTAS, Korean Triage and Acuity Scale; MKTAS, Modified KTAS; CI, confidence interval, PPV, positive predictive value; NPV, negative predictive value.
*Critical outcome was defined as hospital death or direct admission to the intensive care unit from the emergency department.

Table 3. Test Characteristics of MKTAS and KTAS in the Validation Cohort

Outcome and triage model	Sensitivity (95% CI)	*p* value	Specificity (95% CI)	*p* value	PPV (95% CI)	*p* value	NPV (95% CI)	*p* value
Hospital mortality								
KTAS level 1–2 vs. 3–5	0.550 (0.528–0.571)	Reference	0.901 (0.899–0.903)	Reference	0.081 (0.077–0.086)	Reference	0.992 (0.992–0.993)	Reference
MKTAS level 1–2 vs. 3–5	0.610 (0.588–0.631)	<0.001	0.888 (0.886–0.889)	<0.001	0.079 (0.075–0.084)	0.539	0.993 (0.993–0.994)	<0.001
Critical outcome*								
KTAS level 1–2 vs. 3–5	0.554 (0.540–0.568)	Reference	0.913 (0.911–0.914)	Reference	0.211 (0.204–0.218)	Reference	0.980 (0.979–0.981)	Reference
MKTAS level 1–2 vs. 3–5	0.637 (0.624–0.650)	<0.001	0.901 (0.900–0.903)	<0.001	0.214 (0.207–0.220)	0.539	0.983 (0.983–0.984)	<0.001
Admission								
KTAS level 1–3 vs. 4–5	0.863 (0.859–0.867)	Reference	0.418 (0.415–0.421)	Reference	0.319 (0.316–0.322)	Reference	0.906 (0.903–0.909)	Reference
MKTAS level 1–3 vs. 4–5	0.850 (0.846–0.854)	<0.001	0.519 (0.516–0.522)	<0.001	0.359 (0.355–0.362)	<0.001	0.916 (0.914–0.919)	<0.001

KTAS, Korean Triage and Acuity Scale; MKTAS, Modified KTAS; CI, confidence interval, PPV, positive predictive value; NPV, negative predictive value.
*Critical outcome was defined as hospital death or direct admission to the intensive care unit from the emergency department.

dicting critical outcome was greatly increased (MKTAS, 0.637; 95% CI, 0.624–0.650 vs. KTAS, 0.554; 95% CI, 0.540–0.568), with a small decrease in specificity (MKTAS, 0.901; 95% CI, 0.900–0.903 vs. KTAS, 0.913; 95% CI, 0.911–0.914). To predict admission, the specificity was greatly increased (MKTAS, 0.519; 95% CI, 0.516–0.522 vs. KTAS, 0.418; 95% CI, 0.415–0.421), with a small decrease in sensitivity (MKTAS, 0.850; 95% CI, 0.846–0.854 vs. KTAS, 0.863; 95% CI, 0.859–0.867).

The proportions of underestimated or overestimated KTAS codes by chief complaint category (Fig. 5) and by the type of modifier (Fig. 6) were analyzed. Among a total of 2016 KTAS codes, 189 (9.4%) were overestimated and 157 (7.8%) were underestimated. KTAS codes for chief complaints in the categories of "neurologic," "cardiovascular," "gastrointestinal," and "orthopedic" were more likely to underestimate than overestimate the severity of patients. On the other hand, KTAS codes for chief complaints in the categories of "ophthalmology," "nose," "ears," "mouth, throat, neck," and "obstetrics and gynecology" were more likely to overestimate than underestimate the severity of patients. KTAS codes that used the level of consciousness, respiratory distress, and temperature modifiers were more likely to underestimate than overestimate the severity of patients, whereas the KTAS codes that used bleeding disorder and mechanism of injury modifiers were more likely to overestimate than underestimate the severity of patients.

DISCUSSION

In this retrospective multicenter study, we used the data from 272402 ED visits to derive the MKTAS, a modified version of a complaint-oriented triage system. Next, using the data from 128831 ED visits, we validated the ability of MKTAS to predict hospital outcomes. The discriminating ability of the MKTAS to predict hospital mortality, critical outcome, and admission was significantly improved compared to the KTAS. The sensitivity for predicting hospital mortality and critical outcome greatly increased with only a small decrease in specificity. For the prediction of admission, the specificity was greatly increased with a small decrease in sensitivity.

The CTAS, introduced in 1999, has been updated every 4 years, but the triage level for each chief complaint and modifier has not been revised.[22] The KTAS level for each KTAS code was determined by expert opinion when the KTAS was developed. After its implementation, whether the KTAS level appropriately reflected the severity and urgency of the KTAS code

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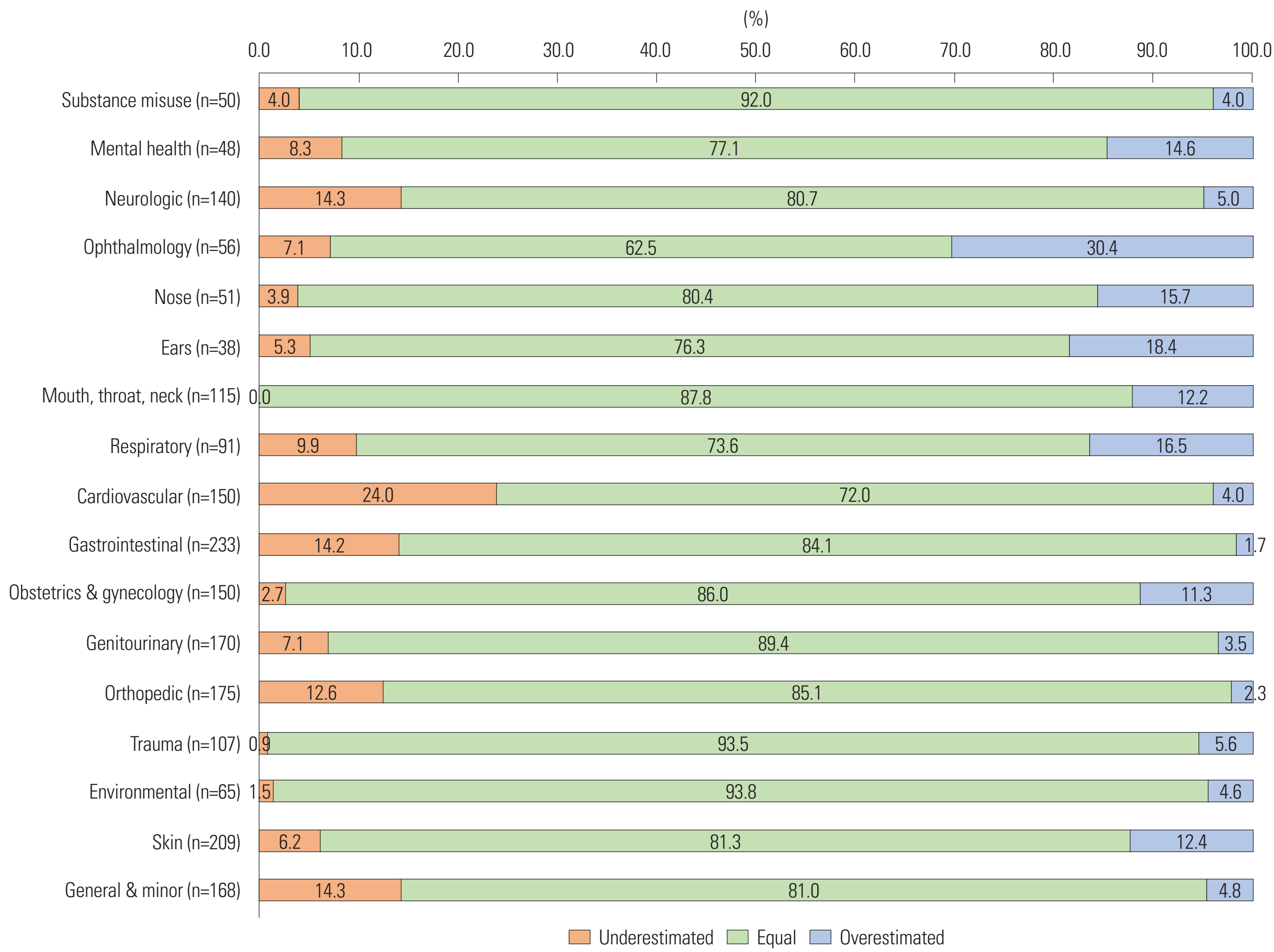

Fig. 5. Underestimated* or overestimated** KTAS codes by chief complaint category. *Underestimated KTAS code: MKTAS estimated a patient to be more severe than KTAS; **Overestimated KTAS code: MKTAS estimated a patient to be less severe than KTAS in terms of the severity of the patient. The *p*-value for the chi-square test of underestimated, overestimated, and equal KTAS codes by chief complaint category was <0.001. KTAS, Korean Triage and Acuity Scale; MKTAS, Modified KTAS.

was not validated. The goal of ED triage is to optimize ED resource allocation to provide critically ill patients with timely care, and alleviate ED crowding.[24] Therefore, it is critical to accurately predict the severity and acuity of patients visiting the ED. In studies that have assessed triage system validity, clinical outcomes were often evaluated with measures of mortality, critical illness, and hospitalization.[24-26] We also evaluated MKTAS with these outcomes and obtained an improved discriminating ability to predict hospital mortality, critical care, and admission. A previous study evaluated the performance of ESI before the CTAS was implemented in Korea. The AUCs for predicting hospital mortality and admission were 0.641 and 0.633, respectively. Although direct comparison was impossible as the study population was different, the performance of the MKTAS for predicting hospital mortality and admission seemed to be superior to the ESI as well.

In this study, we used a binary classification of levels 1–2 vs. 3–5 for hospital mortality and critical outcome, and a binary classification of levels 1–3 vs. 4–5 for admission. We divided the groups based on a published review to facilitate comparison with other studies and triage systems.[26] Considering the fact that almost 50% of patients are triaged to KTAS level 3, predicting severe outcomes using binary class of levels 1–2 vs. 3–5 would have more clinical meaning than using class of levels 1–3 and 4–5. On the other hand, when predicting admission, there is more meaning in identifying low-acuity patients who do not require much ED resources and can be discharged early.

Specifically, compared to KTAS, MKTAS achieved a higher sensitivity for the prediction of high-severity outcomes (hospital mortality, critical outcome). This finding shows that MKTAS reduces the number of severely ill patients who are undertriaged to levels 3–5. By contrast, compared with KTAS, MKTAS achieved a higher specificity for prediction of admission. This finding implies that patients with no need for hospitalization are less overtriaged to levels 1–3 when they are triaged with MKTAS. Although the sensitivity to predict hospitalization was

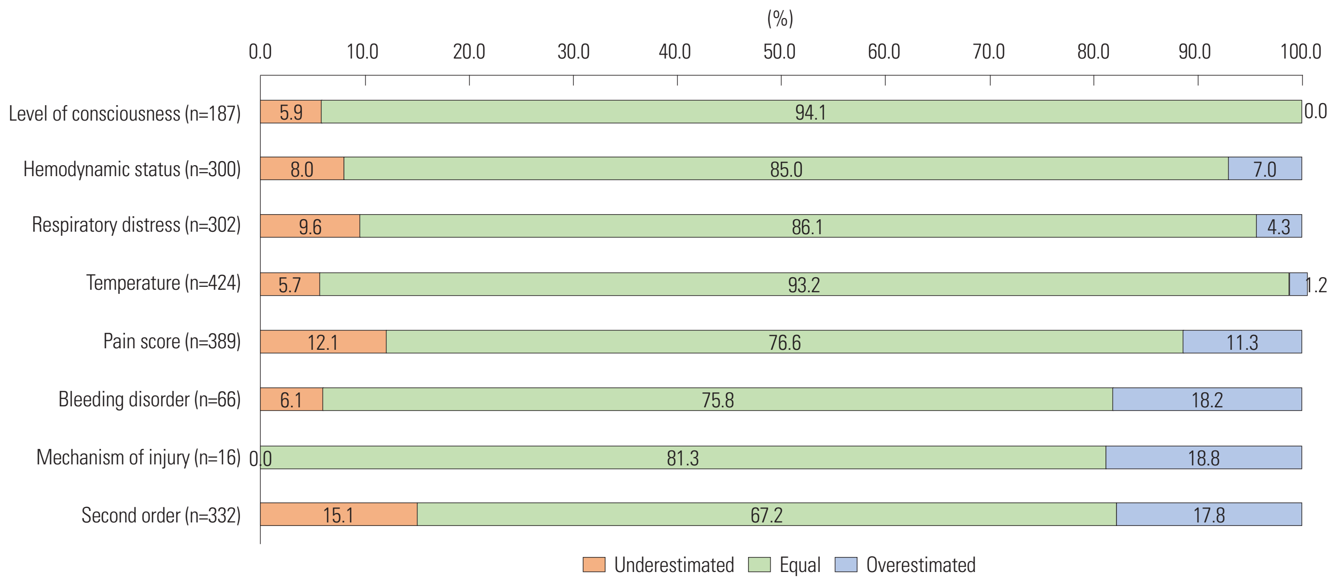

Fig. 6. Underestimated* or overestimated** KTAS codes by the type of modifier. *Underestimated KTAS code: MKTAS estimated a patient to be more severe than KTAS; **Overestimated KTAS code: MKTAS estimated a patient to be less severe than KTAS in terms of the severity of the patient. The *p*-value for the chi-square test of underestimated, overestimated, and equal KTAS codes by the type of modifier was <0.001. KTAS, Korean Triage and Acuity Scale; MKTAS, Modified KTAS.

slightly decreased, this finding seems to be an allowable trade-off. Patients going to be hospitalized do not always require abundant ED resources. Therefore, high sensitivity models for the prediction of hospitalization are not always preferable, as they can cause excessive resource utilization and overcrowding.[24,25]

In the current KTAS, the percentage of hospital mortality for KTAS level 5 patients (0.2%) was not that small compared to that of KTAS level 3 patients (0.7%), and had no difference compared to that of KTAS level 4 patients (0.2%). Similarly, the percentages of critical outcome for level 4 and level 5 patients also had no difference. Compared to KTAS, MKTAS more effectively differentiated level 5 patients from level 4 and level 3 patients (Fig. 3). Once a patient was triaged to level 5, the time from ED arrival to appropriate care could be greatly delayed, since ED clinicians anticipate the severity of the patient's complaint to be "non-urgent." The MKTAS has a certain advantage in preventing treatment delays in severe patients who could have been triaged to level 5 in the KTAS system. Raita, et al.[25] reported that the percentages of critical outcome for ESI levels 1, 2, 3, 4, and 5 were 11.1%, 6.4%, 1.7%, 0.5%, and 0.7%, respectively. The percentages of admission for the ESI levels were 41.5%, 35.9%, 18.4%, 5.8%, and 6.2% respectively. Compared to these results, MKTAS and KTAS have a higher proportion of both critical care outcome and admission for triage patients at levels 1–3. As shown, the proportion of hospital outcomes for each triage level can differ by different triage systems, countries, and hospitals, which makes it difficult to compare the study results directly.

Another important finding from our study was that patients with chief complaints in the categories of "neurologic," "cardiovascular," "gastrointestinal," and "orthopedic" were more likely to be underestimated in terms of severity using KTAS. Chief complaints related to ophthalmology, otorhinolaryngology, and obstetrics and gynecology were frequently overestimated. Some experts might consider this an acceptable overtriage to prevent physicians from not being able to recognize the few urgent patients. Patients with retinal detachment, epiglottitis, and pregnant patients are some examples of these cases.

Also, the outcomes of patients who were triaged with level of consciousness, respiratory distress, or temperature modifiers were more severe than the KTAS had predicted. Patients with sepsis, stroke, cerebral hemorrhage, or acute respiratory failure are examples of patients who would be triaged with the aforementioned modifiers. The results of our study suggest that the KTAS system has not been considering these patients to be as severe as they actually were. In contrast, patients triaged with bleeding disorder and mechanism of injury modifiers were less severe than the predicted KTAS level. However, considering that patients with hemorrhage or injury from a high-risk mechanism can deteriorate rapidly, this can be regarded as an acceptable overtriage.

This study had several limitations that must be addressed. First, we used data from three urban teaching hospitals; therefore, our data did not represent the entire ED population. The characteristics of patients who visit the study hospitals may differ from those who visit other hospitals that serve a different population. However, we were not able to perform the study on a national level due to our lack of national data. As an alternative, we externally validated the MKTAS in a different province, and found that the performance of the MKTAS was acceptable in a hospital different from where the new system was devel-

https://doi.org/10.3349/ymj.2021.62.12.1145

oped. For different populations, different cutoff thresholds for triage may be more suitable to efficiently distribute the patients. No guidelines are available that present absolute values for the cutoff thresholds to designate triage levels. We chose these cutoff values to effectively distribute the patients in this study based on our data. Therefore, a nationwide study is required before the MKTAS can be applied to all of the EDs across the country. Second, we were not able to prospectively validate the performance of the MKTAS in this study. Third, we could not evaluate the inter-rater agreement of triage levels among the triage nurses of our ED. Although the triage process was performed by trained, qualified nurses, the judgment of severity and urgency can differ. However, unlike the ESI, which relies heavily on a triage-provider intuition, the KTAS and CTAS use the chief complaint and detailed clinical discriminators and vital sign combinations to designate triage levels of the patients.[26] One prospective study observed that the inter-rater agreement for KTAS levels showed substantial agreement between two triage nurses.[27] Fourth, we assessed the construct validity using hospital mortality, critical outcome, and admission for our outcome measure. However, in some disease entities, such as anaphylaxis or retinal detachment, these outcomes are insufficient to evaluate the acuity. These patients need immediate intervention; however, after they are stabilized, most of them are discharged. One way to overcome this limitation is to measure the rate of critical interventions, such as epinephrine injection or emergent operation. Although we were unable to apply such methods due to insufficient data, they could be applied in further research. Fifth, patients who left the ED without notice were not excluded from the study population. However, patients in the "other discharges" category, which included patients who left the ED without notice, comprised only 0.07% of the total study population and are unlikely to have affected the study results in a significant manner.

In conclusion, by modifying a complaint-oriented ED triage system, we derived the MKTAS and validated its performance. Compared to the KTAS, the MKTAS showed better discriminating ability to predict hospital outcomes. The sensitivity for predicting hospital mortality and critical outcome, as well as the specificity for predicting admission, were significantly improved. Continuous efforts to evaluate and modify widely used triage systems are needed to improve their performance.

AUTHOR CONTRIBUTIONS

Conceptualization: Sang Do Shin, Kyoung Jun Song, and Ki Jeong Hong. Data curation: Jeong Ho Park, Tae Han Kim, and Joo Jeong. Formal analysis: Jeong Ho Park, Won Pyo Hong, and Dong Hyun Choi. Investigation: Sang Do Shin. Methodology: Kyoung Jun Song. Project administration: Sang Do Shin. Resources: Jeong Ho Park, Tae Han Kim, and Joo Jeong. Software: Ki Jeong Hong. Supervision: Sang Do Shin. Validation: Jeong Ho Park. Visualization: Won Pyo Hong. Writing—original draft: Dong Hyun Choi. Writing—review & editing: Won Pyo Hong. Approval of final manuscript: all authors.

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https://doi.org/10.3349/ymj.2021.62.12.1145