Received: 20 September 2022 | Revised: 20 February 2023 | Accepted: 22 February 2023

DOI: 10.1111/aas.14229

RESEARCH ARTICLE

acta Anaesthesiologica Scandinavica

A first-level customization study of SAPS II with Norwegian Intensive Care and Pandemic Registry (NIPaR) data

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Abstract

Background: Severity scores and mortality prediction models (MPMs) are important tools for benchmarking and stratification in the intensive care unit (ICU) and need to be regularly updated using data from a local and contextual cohort. Simplified acute physiology score II (SAPS II) is widely used in European ICUs.

Methods: A first-level customization was performed on the SAPS II model using data from the Norwegian Intensive Care and Pandemic Registry (NIPaR). Two previous SAPS II models (Model A: the original SAPS II model and Model B: a SAPS II model based on NIPaR data from 2008 to 2010) were compared to the new Model C. Model C was based on patients from 2018 to 2020 (corona virus disease 2019 patients omitted; $n = 43{,}891$), and its performances (calibration, discrimination, and uniformity of fit) compared to the previous models (Model A and Model B).

Results: Model C was better calibrated than Model A with a Brier score 0.132 (95% confidence interval 0.130–0.135) versus 0.143 (95% confidence interval 0.141–0.146). The Brier score for Model B was 0.133 (95% confidence interval 0.130–0.135). In the Cox's calibration regression $\alpha \approx 0$ and $\beta \approx 1$ for both Model C and Model B but not for Model A. Uniformity of fit was similar for Model B and for Model C, both better than for Model A, across age groups, sex, length of stay, type of admission, hospital category, and days on respirator. The area under the receiver operating characteristic curve was 0.79 (95% confidence interval 0.79–0.80), showing acceptable discrimination.

Conclusions: The observed mortality and corresponding SAPS II scores have significantly changed during the last decades and an updated MPM is superior to the original SAPS II. However, proper external validation is required to confirm our findings. Prediction models need to be regularly customized using local datasets in order to optimize their performances.

KEYWORDS

first-level customization, intensive care medicine, mortality, Norwegian Intensive Care and Pandemic Registry (NIPaR), simplified acute physiology score (SAPS) II

Editorial Comment

As highlighted by this validity study of SAPS II in the Norwegian Intensive Care and Pandemic Registry, customization and external validation of prediction models are important.

1 | BACKGROUND

Severity scores and mortality prediction models (MPMs) are important tools for benchmarking and stratification in the intensive care unit (ICU).[1] Patients admitted to the ICU show a great heterogeneity and generic scores using disease severity rather independently of the primary reason for ICU admission are common. Several models have been developed including acute physiology, age, chronic health evaluation,[2] MPM,[3] and simplified acute physiology score (SAPS).[4] Although these models are not suitable for predicting individual survival, they are widely used in quality assurance, research, and performance comparison in intensive care medicine.

Discrimination, uniformity of fit, and calibration are basic properties of any MPM. Discrimination expresses the models' capability to link high mortality probabilities to patients who die, and low probabilities to survivors. The model has a good uniformity of fit if patients with similar severity scores also have similar hospital mortality, and if this covariation is found in most subgroups of patients. Calibration refers to the agreement between predicted and observed numbers of events across the range of probabilities.

The SAPS II score is widely used in European ICUs, including Norway. The original SAPS II model has previously been customized using data from the Norwegian Intensive Care and Pandemic Registry (NIPaR; the 2008–2010 cohorts) estimating a standardized mortality ratio (SMR) of 0.73.[5] However, intensive care medicine is continuously developing. Advances in medical methods and technologies have improved the individual ICU performance, including patient survival.[6,7] Moreover, during the last decades, the population of intensive care patients has changed, for example, to include a larger proportion of older patients.[8,9] Thus, there is a need to incorporate changes in patient composition and ICU performance over time in MPMs. A way of achieving this is to perform first-level customization (i.e., fitting model coefficients to new data) using data from a local and contextual cohort on a regular basis.[10]

In this study, we aimed to optimize SAPS II prediction of 30-day mortality by first-level customization in NIPaR data from 2018 to 2020. We also evaluate performance of the original SAPS II model and a previously customized model in predicting 30-day mortality in the same data set.

2 | MATERIALS AND METHODS

2.1 | Patients

NIPaR is a government funded national quality registry, which covers more than 60 ICUs across all health regions in Norway, including university hospitals, secondary hospitals, and primary hospitals. Altogether, the registry includes data from more than 90% of admissions of adult patients in Norwegian ICUs.[11] The Data S1 give additional information regarding the registration process of intensive care patients in NIPaR.

Data collected from 44,437 adult patients admitted during the period 2018–2020 make up the source population for this study. Characteristics of the study population are given in Table 1. Transfers between ICUs/hospitals and re-admittances to the ICU within 12 h of a previous discharge were considered one single ICU stay and data were aggregated accordingly. SAPS II is mandatory in NIPAR, except for bilirubin, bicarbonate, and urea values. Scoring practices dictate that any further missing data should be scored as "0" SAPS II points. This affect the proportion of truly missing data but validation studies in NIPaR indicate that the magnitude of this scoring practice is low. We excluded 156 patients from the source population due to missing SAPS II scores or other missing values. Patients with corona virus disease 2019 (COVID-19) disease were excluded ($n = 390$). This gave a study population of non-COVID-19 patients; $n = 43{,}891$. Figure 1 gives an overview of the inclusion process.

2.2 | Statistics

In this study, several models were compared. Model A, the original SAPS II model, was developed from an international, multicentre data set.[4] The other models were first-level customizations of Model A based on data from NIPaR from the time period 2008–2010 (Model B),[5] and data from NIPaR from the time period 2018–2020 (Model C). Hospital mortality is the endpoint in Model A and Model B, whereas 30-day mortality was used as the endpoint for mortality prediction in Model C because 30-day mortality is unaffected by discharge policies and hospital transfer practices. Furthermore, we give an overview of how the performances of the three models were evaluated. The predicted risk of death (PRD) was calculated using the formula

$$\mathrm{PRD} = \frac{e^{\mathrm{logit}}}{1 + e^{\mathrm{logit}}},$$

where

$$\mathrm{logit} = \beta_0 + \beta_1 \times (\mathrm{SAPS\,II}) + \beta_2 \times \ln(\mathrm{SAPS\,II} + 1) \quad (1)$$

First-level customization of a model simply means that the β-coefficients are fit to a new data set. Model A, the original SAPS II model,[1] had this equation:

TABLE 1 Characteristics of the study population.

Variable	Characteristic	Sample 2018–2020	Sample 2008–2010
n	Total number	43,891	30,712
Age (years)	Mean (SD)	65.8 (17.0)	63.2 (18.2)
	Median (IQR)	69.6 (56.9, 77.7)	66.0 (52.4, 77.3)
Sex (%)	Male	57.6	56.7
	Female	42.6	43.3
SAPS II	Mean SAPS II (SD)	38.4 (17.2)	36.8 (18.2)
	Median SAPS II (IQR)	36.0 (27.0, 48.0)	34.0 (24, 47)
Length of stay (days)	Mean (SD)	4.1 (7.3)	4.3 (6.8)
	Median (IQR)	2.0 (1.1, 4.2)	2.0 (1.1, 4.3)
Type of admission (%)	Medical	69.5	55.8
	Acute surgery	20.5	31.7
	Planned surgery	10.0	12.6
Hospital category (%)	Primary	30.6	36.7
	Secondary	36.3	39.8
	Tertiary	33.1	23.5
Survival status (30 days) (%)	Died	21.3	–
	Survived	78.7	–
Survival status (hospital) (%)	Died	–	19.4
	Survived	–	80.6

Abbreviations: IQR, interquartile range; SAPS II, simplified acute physiology score II; SD, standard deviation.

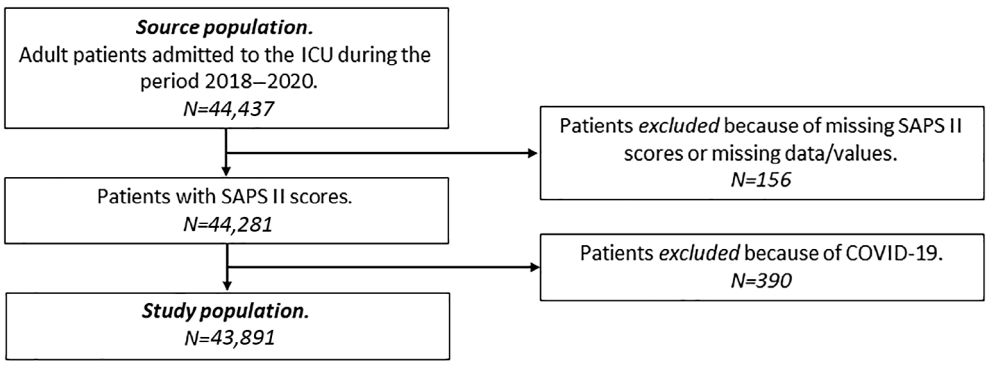

FIGURE 1 Study population. The figure shows a flow chart for the patients included in this study. The source population was adult patients admitted to Norwegian intensive care units (ICUs) in the time period 2018–2020. Patients with missing simplified acute physiology score II (SAPS II) score or other missing data were excluded. Patients with corona virus disease 2019 (COVID-19) disease were excluded.

$$\text{logit}_A = -7.7631 + 0.0737 \times (\text{SAPS II}) + 0.9971 \times \ln(\text{SAPS II} + 1)$$

Model B, the model based on NIPaR data from 2008 to 2010,[1] had this equation:

$$\text{logit}_B = -9.0917 + 0.0325 \times (\text{SAPS II}) + 1.6698 \times \ln(\text{SAPS II} + 1)$$

We evaluated the performances of the different models by splitting the NIPaR data from 2018 to 2020 in two at random, using one half as a training set and the other half as a validation set.

The area under the receiver operating characteristic curve (aROC) was used to evaluate model discrimination,[12] SMR was used to evaluate the uniformity of fit,[5] the Brier score,[13] and Cox's calibration regression[14] were used to evaluate calibration.[5] Notably, despite the fact that the Brier score is a measure of accuracy and not calibration alone, in our case the Brier score will improve if calibration improves because discrimination is the same in all models and the same data are used for comparison. We refer to Haaland et al. for a more elaborate explanation of statistical details.[5]

All analyses were conducted using R version 4.0.3 (a language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria; https://www.R-project.org/.).

2.3 | Ethics

The study was approved by the Regional Committee for Medical and Health Research Ethics for the southeastern Norway (approval number 230239). All methods were performed in accordance with the relevant guidelines and regulations, including the Declaration of Helsinki. Further, all patients were recruited from NIPaR, which is a national registry where patients are informed of their registration and have the right to withdraw their data at any time. The need for informed consent was therefore waived. Data were de-identified, and stored and analyzed on secure servers throughout the whole project (SAFE, University of Bergen, Norway).

3 | RESULTS

The equation for the model calibrated on the 2018–2020 data (Model C) were

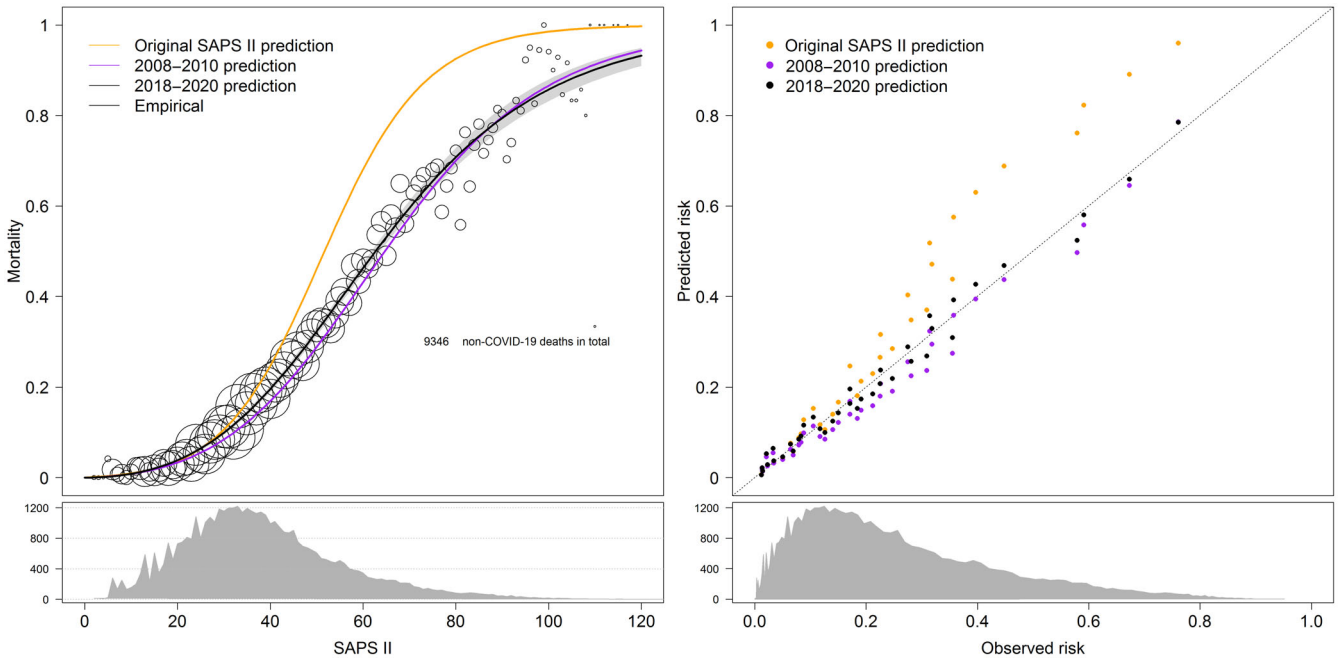

FIGURE 2 Mortality, simplified acute physiology score II (SAPS II) scores and model performances. Left, top: Predicted and empirical/observed 30-day mortality and SAPS II scores. Dark circles denote the mortality of the patients included. Circle sizes are proportional to the number of patients. The gray shadow gives the 95% confidence band. The predicted 30-day mortalities for Model A (original SAPS II score), Model B (calibrated on 2008–2010 Norwegian Intensive Care and Pandemic Registry (NIPaR) data), and Model C (calibrated on 2018–2020 NIPaR data) are given. Left, bottom: Distribution of SAPS II scores. Right, top: Calibration plot for Models A, B, and C. Right, bottom: Distribution of 30-day mortality. COVID-19, corona virus disease 2019.

TABLE 2 Performance of models on the study population.

	Model A	Model B	Model C
Brier score			
B	0.143	0.133	0.132
95% confidence interval	0.141–0.146	0.130–0.135	0.130–0.135
Cox's calibration regression			
α	−0.70	0.12	0.00
β	0.70	0.97	1.00
$\alpha \mid \beta = 0$	−0.55	0.15	0.00

Note: Model A, original simplified acute physiology score II model; Model B, model recalibrated on 2008–2010 Norwegian Intensive Care and Pandemic Registry (NIPaR) data; Model C, model calibrated on 2018–2020 NIPaR data.

TABLE 3 Comparison of the different models.

	Model A	Model B	Model C	
	SMR (95% CI)	SMR (95% CI)	SMR (95% CI)	*n*
Total non-COVID	0.76 (0.74, 0.78)	1.10 (1.06, 1.13)	1.00 (0.97, 1.03)	21,946
Age				
18–39	0.46 (0.39, 0.54)	0.66 (0.56, 0.78)	0.59 (0.50, 0.70)	2287
40–59	0.57 (0.52, 0.62)	0.81 (0.74, 0.89)	0.74 (0.67, 0.80)	4196
60–69	0.70 (0.65, 0.74)	1.00 (0.93, 1.06)	0.91 (0.85, 0.97)	4771
70–79	0.75 (0.72, 0.79)	1.09 (1.04, 1.15)	1.00 (0.95, 1.05)	6472
80+	0.99 (0.94, 1.04)	1.45 (1.38, 1.53)	1.32 (1.26, 1.39)	4220
Type of admission				
Planned surgery	0.55 (0.47, 0.64)	0.76 (0.65, 0.90)	0.68 (0.57, 0.79)	2193
Acute medical	0.80 (0.77, 0.82)	1.16 (1.12, 1.19)	1.05 (1.02, 1.09)	15,245
Acute surgery	0.65 (0.61, 0.70)	0.95 (0.88, 1.02)	0.86 (0.80, 0.92)	4508
Length of stay				
0–1	0.95 (0.90, 1.00)	1.33 (1.26, 1.41)	1.23 (1.16, 1.29)	5108
1–4	0.71 (0.68, 0.75)	1.04 (0.99, 1.08)	0.93 (0.89, 0.97)	11,141
4–30	0.71 (0.67, 0.75)	1.05 (0.99, 1.10)	0.96 (0.91, 1.01)	5419
>30	0.16 (0.09, 0.25)	0.23 (0.14, 0.37)	0.22 (0.13, 0.34)	278
Hospital category				
Primary	0.88 (0.84, 0.93)	1.28 (1.22, 1.35)	1.16 (1.10, 1.21)	6713
Secondary	0.72 (0.69, 0.76)	1.05 (1.00, 1.10)	0.95 (0.91, 1.00)	7968
Tertiary	0.69 (0.65, 0.73)	0.99 (0.94, 1.05)	0.91 (0.86, 0.95)	7265
Sex				
Male	0.73 (0.70, 0.76)	1.06 (1.02, 1.10)	0.97 (0.93, 1.00)	12,621
Female	0.79 (0.76, 0.83)	1.14 (1.09, 1.20)	1.04 (0.99, 1.09)	9325
Days on respirator				
0	0.72 (0.68, 0.76)	1.03 (0.97, 1.09)	0.92 (0.86, 0.97)	9420
0–1	0.78 (0.74, 0.82)	1.13 (1.07, 1.18)	1.02 (0.98, 1.08)	6860
1–7	0.80 (0.75, 0.84)	1.17 (1.11, 1.24)	1.08 (1.02, 1.14)	4118
>7	0.67 (0.61, 0.74)	0.99 (0.90, 1.08)	0.92 (0.83, 1.00)	1548

Note: Model A, original simplified acute physiology score II model; Model B, model recalibrated on 2008–2010 NIPaR data; Model C, model calibrated on 2018–2020 NIPaR data; Ratio vs. Model C, SMR for each model divided by the SMR of Model C.
Abbreviations: CI, confidence interval; COVID, corona virus disease; NIPaR, Norwegian Intensive Care and Pandemic Registry; SMR, standardized mortality ratio.

$$\text{logit}_C = -9.7513 + 0.0234 \times (\text{SAPS II}) + 1.9936 \times \ln(\text{SAPS II} + 1)$$

Figure 2 allows for visually inspecting the calibration of all three models evaluated in this study. As seen in Figure 2 (left, bottom), most of the ICU patients had SAPS II scores between 20 and 50. In this non-COVID-19 population, 30-day mortality increased markedly when SAPS II was higher than 40. The black circles show the mean observed 30-day mortality for each SAPS II score. Figure 2 illustrates that Model C is slightly better calibrated than the Model B, and much better calibrated than Model A. Because most of the patients had SAPS II scores below 60, Model C is particularly well calibrated for this group (Figure 2). Table 2 documents how Model C is calibrated to patients compared with the other models. As expected from Figure 2, Model C slightly outperforms Model B (Brier scores are similar, but the coefficients in Cox's calibration regression are closer to 0 and 1 for Model C). Again, we note that Model B was calibrated using hospital mortality, and not 30-day mortality, like Model C.

The aROC was 0.79 (95% CI: 0.79–0.80), which indicates an acceptable discrimination.[15,16] Table 3 shows that the SMRs were close to 1 across most categories for Model C, suggesting a good uniformity of fit. Notable exceptions were patients with very long stays, where SMR = 0.22 (95% CI: 0.13–0.34), suggesting that Model C overestimates 30-day mortality in this group.

4 | DISCUSSION

In this study, we show that an updated 30-day MPM (Model C) performs better than the original SAPS II (Model A) model among Norwegian non-COVID patients admitted to the ICU in the time period 2018–2020. The performance was similar to a model (Model B) based on the hospital mortality in a patient cohort from 2008–2010.

Development in intensive care medicine including advances in diagnostic and treatment options in several subpopulations of patients, all together affect the ICU performance and patient survival. Our results clearly illustrate that the observed mortality and corresponding SAPS II scores have significantly changed during the last decades (Figure 2). The updated 30-day MPM (Model C) is superior to the original SAPS II model (Model A). The observed SAPS II scores were similar when comparing the time period 2018–2020 and 2008–2010 (Sample 2008–2010: mean SAPS II score 36.8; Sample 2018–2020: mean SAPS II score 38.4), and the hospital mortality from 2008 to 2010 (19.4%) was similar to the 30-day mortality from 2018 to 2020 (21.3%). Thus, even though Model C and Model B exhibit similar performances in the current study population, this hints that the 30-day mortality has decreased.

Several recent studies indicate that SAPS II also has a high prognostic accuracy for 30-day mortality in ICU patients.[17,18] We used 30-day mortality as the endpoint for mortality prediction because 30-day mortality is unaffected by discharge policies and hospital transfer practices. This differs from the hospital mortality used in the original SAPS II publication,[4] and will probably challenge comparability between our model and customizations using hospital mortality. We would have expected Model C to illustrate better ICU performance and patient survival by improving calibration beyond Model B in the new data set, while performances of Model B and Model C were similar. The fact that Model B was developed in order to predict hospital mortality while used to predict 30-day mortality in the new data set may partly explain this result. Hospital mortality will usually be higher than 30-day mortality, and a model developed to predict hospital mortality would overestimate 30-day mortality in such circumstances. This is also seen in the overall SMR of Model B (Table 2). Unfortunately, hospital mortality is not available to the study group and differences between hospital and 30-day mortality predictions cannot be assessed.

There are some differences between the 2008–2010 and the 2018–2020 patient cohorts, which could potentially counteract the effects of improved diagnosis and treatment. The 2018–2020 patient cohort consists of a higher proportion of patients in tertiary hospitals (Table 1). This may indicate that patients are more severely ill, without SAPS II score picking up the full magnitude of this difference. There is also a marked increase in the proportion of medical admissions in the recent data set. However, type of admission is accounted for in the SAPS II score, and the difference would only impact predictions if the relative effects of type of admission have changed since weighting in the original SAPS II publication. In addition, COVID-19 patients were excluded from the study and we can speculate if the pandemic situation somehow also affect the current study population. Although Models B and C perform similarly, the issues discussed above still point out the importance of regularly updating first-level customization.

There are several strengths and some limitations in our study. We present national data in a large patient cohort representing a public health service with low missing data since SAPS II is mandatory in NIPaR. Given that there are no private ICU options in Norway and that NIPaR contains data from most ICU stays in the country, our patient cohort is representable on a national level. Notably, scoring practices in NIPaR dictate that missing data should be scored as "0" SAPS II points, and the proportion of missing data are therefore unknown. Any missing data scored as "0" would bias SAPS II score in the direction of underestimating mortality. However, internal validation indicates that missing data are a minor issue in NIPaR. SAPS II scoring can be difficult and differences in scoring practices between regions, hospitals, and ICUs cannot be ruled out. Conducting internal validation using bootstrap resampling could have led to more stable results. However, because of the sample size, the main results were very stable. Proper external validation is required to confirm our findings.

5 | CONCLUSION

The observed 30-day mortality and corresponding SAPS II scores have significantly changed during the last decades and an updated MPM is superior to the original SAPS II. External validation is needed to confirm our findings. Prediction models need to be regularly updated.

AUTHOR CONTRIBUTIONS

Øyvind Bruserud, Eirik Alnes Buanes, and Reidar Kvåle made available the datasets analyzed in the current study. Øystein Ariansen Haaland performed the statistical analyses. Øyvind Bruserud drafted the manuscript. All authors read and approved the final manuscript.

ACKNOWLEDGMENTS

We would like to acknowledge registrars in hospitals across Norway who diligently report data to NIPaR. Their contributions enable us to monitor ICU activity and performance in Norway.

FUNDING INFORMATION

None declared.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.

DATA AND MATERIALS AVAILABILITY STATEMENT

The datasets used/or analyzed during the current study are available from the corresponding author on reasonable request provided necessary approvals according to Norwegian legislation.

PATIENT CONSENT STATEMENT

All methods were performed in accordance with relevant guidelines and regulations including the Declaration of Helsinki. All patients were recruited from NIPaR, which is a national registry in which patients are informed of their registration and have the right to withdraw their data at any time. The need for informed consent was therefore waived. Data were de-identified, stored, and analyzed on secure servers throughout the whole project (SAFE, University of Bergen, Norway).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Bruserud Ø, Haaland ØA, Kvåle R, Buanes EA. A first-level customization study of SAPS II with Norwegian Intensive Care and Pandemic Registry (NIPaR) data. *Acta Anaesthesiol Scand*. 2023;67(6):772-778. doi:10.1111/aas.14229