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Derivation and validation of a prediction model to establish nursing-sensitive quality benchmarks in medical inpatients: a secondary data analysis of a prospective cohort study

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Summary

BACKG ROUND: Hospitals are using nursing-sensitive outcomes (NSOs) based on administrative data to measure and benchmark quality of nursing care in acute care wards. In order to facilitate comparisons between different hospitals and wards with heterogeneous patient populations, proper adjustment procedures are required. In this article, we first identify predictors for common NSOs in acute medical care of adult patients based on administrative data. We then develop and cross-validate an NSO-oriented prediction model.

METHODS: We used administrative data from seven hospitals in Switzerland to derive prediction models for each of the following NSO: hospital-acquired pressure ulcer (≥ stage II), hospital-acquired urinary tract infection, non-ventilator hospital-acquired pneumonia and in-hospital mortality. We used a split dataset approach by performing a random 80:20 split of the data into a training set and a test set. We assessed discrimination of the models by area under the receiver operating characteristic curves. Finally, we used the validated models to establish a benchmark between the participating hospitals.

RESULTS: We considered 36,149 hospitalisations, of which 51.9% were male patients with a median age of 73 years (with an interquartile range of 59–82). Age and length of hospital stay were independently associated with all four NSOs. The derivation and validation models showed a good discrimination in the training (AUC range: 0.75–0.84) and in the test dataset (AUC range: 0.77–0.81), respectively. Variation among different hospitals was relevant considering the risk for hospital-acquired pressure ulcer (≥ stage II) (adjusted Odds ratio [aOR] range: 0.51 [95% CI: 0.38–0.69] – 1.65 [95% CI: 1.33–2.04]), the risk for hospital-acquired urinary tract infection (aOR range: 0.46 [95% CI: 0.36–0.58] – 1.45 [95% CI: 1.31–1.62]), the risk for non-ventilator hospital-acquired pneumonia (aOR range: 0.28 [95% CI: 0.09–0.89] – 2.87 [95% CI: 2.27–3.64]), and the risk for in-hospital mortality (aOR range: 0.45 [95% CI: 0.36–0.56] – 1.39 [95% CI: 1.23–1.60]).

CONCLUSION: The application of risk adjustment when comparing nursing care quality is crucial and enables a more objective assessment across hospitals or wards with heterogeneous patient populations. This approach has potential to establish a set of benchmarks that could allow comparison of outcomes and quality of nursing care between different hospitals and wards.

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Background

The relationship between higher levels of qualified nursing staff (registered nurses vs. non-registered nurses) and patient outcomes has been established.The relationship between higher levels of qualified nursing staff (registered nurses vs. non-registered nurses) and patient outcomes has been established [1–5]. Higher nurse staffing is, for example, associated with a lower incidence of hospital-acquired pressure ulcers, hospital-acquired pneumonia, and in-hospital mortality in medical inpatients [6, 7]. These outcomes, which are influenced by nursing care, are generally understood as nursing-sensitive outcomes (NSO). NSOs have been defined as outcomes "that are relevant, based on nurses' scope and domain of practice, and for which there is empirical evidence linking nursing inputs and interventions to the outcomes" [8, 9].

NSOs may help to establish an outcome-related measure of quality of care [10–13]. In some countries, there are mandatory sets of NSOs already established in clinical routines that help to measure and compare the quality of nursing care [11, 12, 14–16]. However, there is no international

Table 1:
Nursing-sensitive outcomes of interest.

Nursing-sensitive outcome	ICD-10 codes or definition	References	Adjustment variables*
Hospital-acquired pressure ulcer (≥ stage II)	L89	[12, 20, 24–29]	In-hospital death [57]; presence of diabetes / peripheral vascular disease [58]; presence of a stage I pressure ulcer / urinary tract infection [59]
Hospital-acquired urinary tract infection	T83.5	[1, 20, 27, 30–33]	Presence of diabetes [60, 61]
Non-ventilator hospital-acquired pneumonia	U69.0	[1, 2, 20, 27, 34–38]	Living situation before hospital admission; Readmission [62, 63]
In-hospital mortality	Variable 1.5.V03: discharge location: death [64]	[3, 5, 27, 39–42]	MDC "Myeloproliferative Diseases & Disorders" [65]

*In addition to the basic set of adjustment variables for all models (age; gender; Charlson Comorbidity Index; length of hospital stay; Major Diagnostic Category according to DRG; type of hospital)

consensus on NSO sets for quality of care assessment. Definitions and measurement methods vary considerably within international healthcare systems, and thus do not allow comparison of NSOs. In general, administrative coding data is used to measure NOSs because of its availability and standardized definition within a healthcare system. Yet not all countries have standardized reporting of NSOs. In Switzerland, for example, only the 'Swiss National Association for Quality Development in Hospitals and Clinics' (ANQ) reports annually on aspects of quality of acute care by means of a cross-sectional survey. The ANQ methodology has important weaknesses. First, the yearly data acquisition for ANQ analyses requires large staff resources. Second, data are collected on one day per year for point prevalence, which results in low incidence rates. This does not allow trends to be assessed in order to analyse the power of NSO.

Here, the frequency of NSOs from uniformly defined administrative data could be a useful and cost-effective complement. In addition to the availability of data and a clear definition, a suitable adjustment procedure is needed to facilitate comparisons between different hospitals or wards with heterogeneous patient populations.

The primary aim of this study was to identify predictors for four common NSOs of acute medical care of adult patients based on administrative data for the development and cross-validation of an NSO-related prediction model. The secondary aim of this study was to establish a set of benchmarksbetween seven Swiss hospitals using the four pre-specified NSOs. There is broad consensus that analyses and comparisons of NSO should occur at the ward level so that specific quality improvement actions can be taken [17]. Therefore, in addition to the overall hospital view presented here, which provides an impression of the overall comparison between medical departments, the proposed procedure will also be applicable at the ward level. This may allow comparisons within a department.

Methods

Design

This was a secondary data analysis of a prospective cohort study (In-HospiTOOL study) [18]. The "In-HospiTOOL" study was a quasi-experimental investigator-initiated, multicenter comparative effectiveness trial investigating the impact of an interprofessional discharge planning tool on length of hospital stay and other outcomes. The study established a representative benchmarking database to promote the measurement of quality of care across different sized Swiss hospitals.

Study population and setting

We included all consecutively admitted adult (≥18 years) emergency patients from July 2017 to January 2019. Patients had to be hospitalized on a medical ward in one of the following seven secondary and tertiary care hospitals: Cantonal Hospital Aarau, Cantonal Hospital Baden, Cantonal Hospital Muensterlingen, Hospital Muri, Hospital Zofingen, Hospital Interlaken, and University Hospital Basel. We excluded patients with a length of hospital stay shorter than 24 hours or longer than 90 days and patients who have been treated in the intensive care unit (ICU) as part of their hospitalisation because the NSOs under study have not been developed for use in these patient populations.

Covariates of interest

We conducted a literature review to identify covariates that may affect the occurrence of an NSO. Based on previous studies, we used a basic set of adjustment variables for all models: age, gender, Charlson Comorbidity Index [19], length of hospital stay, Major Diagnostic Category (MDC) according to Diagnosis Related Groups (DRG), and type of hospital [20, 21]. Further covariates related to individual NSOs are described in table 1. Data availability was a limiting factor in the selection of covariates.

Outcome of interest

An NSO was defined as "a variable patient or family caregiver state, behavior, or perception responsive to nursing intervention… [that] can be measured and compared to a baseline over time" [22]. They are deemed scientifically acceptable if there is sufficient evidence of the link between process measures and patient outcomes and if they are attributable to nursing [23]. Therefore, we have included NSOs for which the relationship between patient outcomes and nursing staff variables was found to be statistically significant in the literature and for which a data basis is available in the administrative data. Based on these criteria we analysed four NSOs:

– hospital-acquired pressure ulcer (≥ stage II) [12, 20, 24–29];
– hospital-acquired urinary tract infection [1, 20, 27, 30–33];

– non-ventilator hospital-acquired pneumonia [1, 2, 20, 27, 34–38];
– in-hospital mortality [3, 5, 27, 39–42] (table 1).

Data collection

We used administrative data provided by the coding department as well as data from the electronic patient record of each of the participating hospitals between July 1, 2017, and January 31, 2019, as part of the In-HospiTOOL study. The datasets were linked at the case number level and data consistency between the different datasets was checked to ensure data quality. The administrative data comprises a set of uniform, clearly defined variables created by the Swiss Federal Statistical Office, that are therefore comparable among hospitals [43]. The diagnosis coding takes place after the hospitalisation has been completed, based on the discharge reports and the electronic patient record. To enable the coding of an outcome, the prerequisite had to be fulfilled that the outcome had been correctly recorded by a nurse or physician in the electronic patient chart or diagnosis list as part of the routine processes during hospitalisation. A single patient may have more than one hospital admission within the study period. Information on status of readmission to the same hospital according to the definition of Swiss-DRG, i.e. within 18 days after hospital discharge, was available for each hospitalisation. Length of hospital stay was calculated based on Swiss-DRG definition by day of admission and each subsequent day without the day of discharge.

Statistical analysis

We stratified sociodemographic characteristics and covariates by the four NSOs. Discrete variables were expressed as frequency (percentage) and continuous variables as medians and interquartile ranges (IQR). We used International Classification of Diseases (ICD) 10 codes to create variables to indicate whether patients experienced a NSO during their hospital stay using algorithms previously developed by Needleman, Buerhaus [44] and used in similar research projects [20, 27]. For example, a hospital-acquired pressure ulcer (≥ stage II) was identified for any patient who had a secondary diagnosis code of L89 (inclusion criteria – see table 1) unless they had a length of stay <4 days, a major diagnostic category of 9 or a diagnosis code between G80-G83. These exclusion criteria are described in figure 1 (second level). The Charlson Comorbidity Index was calculated using the Stata command "charlson" [45].

To assess associations between predictors, covariates and NSOs, we performed logistic regression models. The area under the receiver operating characteristic curve (AUC) was used as a measure of discrimination. To ensure higher generalisability of the results and to avoid overfitting, we used a split dataset approach by performing a random 80:20 split of the data into a training set and a test set, respectively, while maintaining the proportion of outcomes within each of the two samples. The model fit by decile (estimated and observed probabilities) was plotted for each model (see figures A-1–A-4 in the appendix). We used likelihood-ratio tests (LR) to compare models with all predefined covariates with restricted models. For the benchmark comparison, data from a single hospital were compared with those of the remaining six hospitals. For this purpose, we used logistic regression models and reported the crude and adjusted odds ratios as measures of association. We considered a two-tailed *P*-value at a 5% alpha level for statistical significance. Statistical analyses were performed using Stata 15.1 (StataCorp, College Station, TX, USA). All results are presented in an anonymous form to avoid identification of an individual hospital.

Ethics approval and consent to participate

All patients were informed by a flyer about their study participation after admission. As a quality improvement and control study, the institutional review board (IRB) of Northwestern Switzerland approved the study and waived the need for individual informed consent by formulating a declaration of no objection (AG/SO 2009/074 and EKNZ BASEC PB_2017–00449).

Results

Study population

Of 45,146 hospitalisations, we excluded 8,997 with a length of hospital stay <24 h or >90 days, age <18 years, ICU stay or due to missing ICD-10 diagnosis resulting in 36,149 hospitalisations for the final analysis (see figure 1). There were no other missing data besides the ones mentioned. The median age of the overall population was 73 years (IQR 59–82); 51.9% were male and 80.3% were Swiss residents. The most common reasons for hospital admission regarding MDC were diseases of the circulatory system (n = 8873, 24.5%) and diseases of the respiratory system (n = 5008, 13.9%). Within this sample, 436 patients experienced a hospital-acquired pressure ulcer (≥ stage 2), 2,412 experienced a hospital-acquired urinary tract infection, 339 had a non-ventilator hospital-acquired pneumonia, and 1,525 died in the hospital. Further baseline characteristics are shown in table 2.

Prediction model derivation and validation

Most predefined covariates showed a significant association with the corresponding NSO (Table 3). In-hospital death (OR 3.75 [95% CI: 2.80–5.00]), peripheral vascular disease present (OR 1.59 [95% CI: 1.22–2.07]), and present pressure ulcer stage I (OR 7.00 [95% CI: 4.90–9.90]) were strongest associated with the NSO hospital-acquired pressure ulcer (≥ stage II). Gender, MDC and type of hospital did not show any significant association with hospital-acquired pressure ulcer (≥ stage II) and have been removed from the model, based on an LR test (p = 0.17). The development of a hospital-acquired urinary tract infection was most strongly associated with gender (OR for male gender 0.41 [95% CI: 0.37–0.45]) and paraplegia presence (OR 3.10 [95% CI: 2.08–4.62]). Change in Charlson Comorbidity Index, and type of hospital did not show any significant association with hospital-acquired urinary tract infections and have been removed from the model, based on an LR test (p = 0.09). With regards to the NSO of hospital-acquired pneumonia (for non-ventilator patients), we found the strongest association with gender (OR for male gender 1.53 [95% CI: 1.22–1.92]), the living situation be-

Table 2:
Baseline characteristics of the study sample.

	Overall n = 36'149	**Hospital-acquired pressure ulcer (≥ stage II)** n = 436	**Hospital-acquired urinary tract infection** n = 2412	**Non-ventilator hospital-acquired pneumonia** n = 339	**In-hospital mortality** n = 1525
Incidence rate (%)	12.4%	1.9%	7.1%	1.1%	4.2%
Socio-demographics					
Age, median (IQR)	73.0 (59.0, 82.0)	80.0 (71.0, 87.0)	80.0 (72.0, 86.0)	78.0 (68.0, 85.0)	80.0 (69.0, 87.0)
Male gender (%)	18'764 (51.9%)	211 (48.4%)	762 (31.6%)	207 (61.1%)	827 (54.2%)
Swiss resident (%)	29'039 (80.3%)	380 (87.2%)	2072 (86.0%)	290 (85.5%)	1309 (85.8%)
Private insurance (%)	7690 (21.3%)	114 (26.2%)	549 (22.8%)	62 (18.3%)	319 (20.6%)
Year of admission					
2017	10'531 (29.1%)	140 (32.1%)	743 (30.8%)	99 (29.2%)	461 (30.2%)
2018	23'933 (66.2%)	277 (63.5%)	1572 (65.2%)	224 (66.1%)	974 (63.9%)
2019	1685 (4.7%)	19 (4.4%)	97 (4.0%)	16 (4.7%)	90 (5.9%)
Morbidity					
Major diagnostic category (ICD-10)					
I – Certain infectious and parasitic diseases	2694 (7.5%)	46 (10.6%)	232 (9.6%)	29 (8.6%)	143 (9.4%)
II –Neoplasms	3255 (9.0%)	72 (16.5%)	282 (11.7%)	89 (26.3%)	593 (38.9%)
VI –Diseases of the nervous system	2848 (7.9%)	26 (6.0%)	212 (8.8%)	21 (6.2%)	22 (1.4%)
IX – Diseases of the circulatory system	8873 (24.5%)	74 (17.0%)	630 (26.1%)	97 (28.6%)	383 (25.1%)
X – Diseases of the respiratory system	5008 (13.9%)	70 (16.1%)	279 (11.6%)	–	156 (10.2%)
XI – Diseases of the digestive system	3175 (8.8%)	26 (6.0%)	189 (7.8%)	24 (7.1%)	70 (4.6%)
XVIII – Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified	2142 (5.9%)	9 (2.1%)	99 (4.1%)	9 (2.7%)	32 (2.1%)
Others	8151 (22.5%)	113 (25.9%)	489 (20.3%)	70 (20.7%)	126 (8.3%)
Comorbidities					
Hypertension	18241 (50.5%)	242 (55.5%)	1481 (61.4%)	202 (59.6%)	623 (40.9%)
Obesity	1213 (3.4%)	11 (2.5%)	100 (4.1%)	4 (1.2%)	22 (1.4%)
Type 2 diabetes mellitus	6212 (17.2%)	119 (27.3%)	510 (21.1%)	64 (18.9%)	234 (15.3%)
Type 1 diabetes mellitus	155 (0.4%)	3 (0.7%)	11 (0.5%)	1 (0.3%)	2 (0.1%)
Dyslipidaemia	6138 (17.0%)	49 (11.2%)	360 (14.9%)	29 (8.6%)	101 (6.6%)
Coronary artery disease	7386 (20.4%)	92 (21.1%)	481 (19.9%)	81 (23.9%)	251 (16.5%)
Myocardial infarction	400 (1.1%)	9 (2.1%)	40 (1.7%)	7 (2.1%)	49 (3.2%)
Congestive heart failure	4458 (12.3%)	81 (18.6%)	446 (18.5%)	87 (25.7%)	349 (22.9%)
Atrial fibrillation	6722 (18.6%)	125 (28.7%)	638 (26.5%)	99 (29.2%)	361 (23.7%)
Peripheral arterial disease	1736 (4.8%)	55 (12.6%)	149 (6.2%)	17 (5.0%)	77 (5.0%)
Obstructive sleep apnoea syndrome	948 (2.6%)	8 (1.8%)	59 (2.4%)	7 (2.1%)	21 (1.4%)
Cerebrovascular diseases	2501 (6.9%)	22 (5.0%)	234 (9.7%)	37 (10.9%)	107 (7.0%)
Stroke	220 (0.6%)	2 (0.5%)	32 (1.3%)	7 (2.1%)	24 (1.6%)
Chronic obstructive pulmonary disease	2208 (6.1%)	32 (7.3%)	135 (5.6%)	47 (13.9%)	113 (7.4%)
Gastrointestinal disorder	7550 (20.9%)	119 (27.3%)	594 (24.6%)	98 (28.9%)	385 (25.2%)
Solid tumours	3642 (10.1%)	80 (18.3%)	293 (12.1%)	75 (22.1%)	542 (35.5%)
Haematological malignancies	563 (1.6%)	12 (2.8%)	30 (1.2%)	7 (2.1%)	25 (1.6%)
Musculoskeletal disorder	7046 (19.5%)	116 (26.6%)	631 (26.2%)	95 (28.0%)	196 (12.9%)
Mental disorder	9154 (25.3%)	166 (38.1%)	850 (35.2%)	121 (35.7%)	309 (20.3%)
Alcohol addiction	1887 (5.2%)	21 (4.8%)	98 (4.1%)	26 (7.7%)	44 (2.9%)
Charlson Comorbidity Index, mean (SD)	2.3 (2.6)	3.6 (3.0)	3.0 (2.7)	3.6 (3.1)	4.7 (3.5)
Living situation					
Before admission					
At home (%)	29874 (82.6%)	229 (52.5%)	1605 (66.5%)	279 (62.4%)	1067 (70.0%)
After discharge					
At home (%)	25294 (70.0%)	119 (27.3%)	1136 (47.1%)	137 (30.6%)	0 (0%)
Clinical outcomes					
Length of hospital stay, median (IQR)	5.0 (3.0, 9.0)	11.0 (7.0, 17.0)	9.0 (5.0, 13.0)	12.0 (8.0, 19.0)	5.0 (2.0, 10.0)
In-hospital mortality	1525 (4.2%)	74 (17.0%)	148 (6.1%)	67 (15.0%)	1525 (100.0%)
Readmission*	962 (2.7%)	18 (4.1%)	92 (3.8%)	36 (8.1%)	0 (0%)

*as defined by SwissDRG (within 18 days after discharge)

fore hospital admission (OR 0.43 [95% CI: 0.34–0.55]) and rehospitalisation (OR 2.34 [95% CI: 1.44–3.82]). MDC did not show any significant association with the NSO and has been removed from the model, based on an LR test (p = 0.11). Concerning the NSO of in-hospital mortality, we found the strongest association with the MDC "myeloproliferative Disease & Disorders" (OR 3.90 [95% CI: 3.26–4.67]) and the living situation before hospital admission (OR 0.58 [95% CI: 0.51–0.67]). Gender did not show any significant association with the NSO and has

been removed from the model, based on an LR test (p = 0.05).

All final models showed a good AUC in both the training set (AUC range: 0.75–0.84) and the test set (AUC range: 0.77–0.81), respectively. We did not observe a decrease in discrimination between the training and test sets (p >0.05) (table 3).

Benchmarking between different hospitals

While the prevalence of hospital-acquired pressure ulcer (≥ stage II) was lower in hospital A and higher in hospital F, there were no differences among the remaining hospitals. Hospitals C and D showed a higher prevalence of hospital-acquired urinary tract infection, while hospitals B, F, and G showed a lower prevalence and two hospitals (A and E) showed no difference compared to the other hospitals included. When comparing with the six remaining hospitals,

Figure 1: Flow chart of study patients.

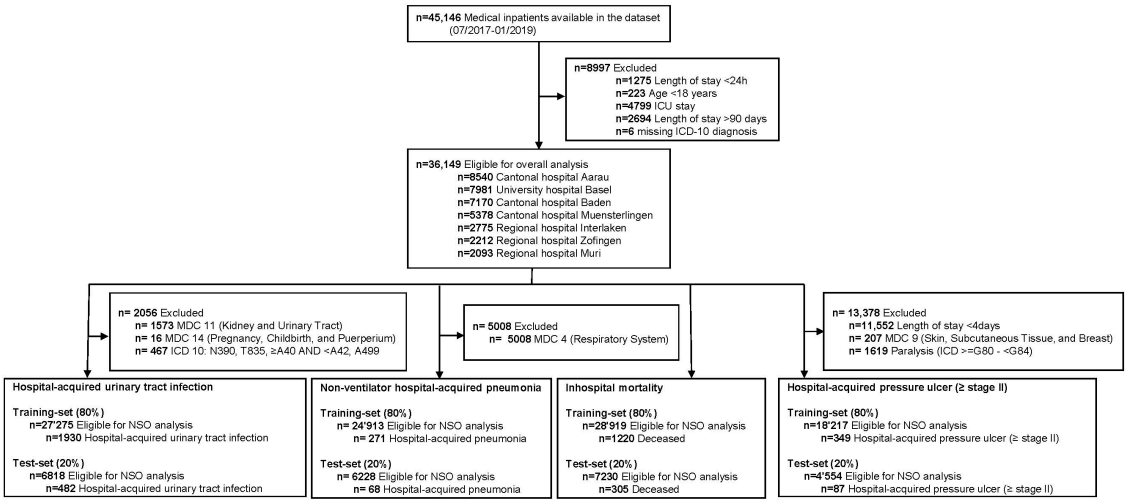

Figure 2: Crude and adjusted association of the nursing-sensitive outcomes between the participating hospitals. Marked green: significantly lower odds compared to all other hospitals Marked red: significantly higher odds compared to all other hospitals

		Hospital-acquired pressure ulcer (≥ stage II)	Hospital-acquired urinary tract infection	In-hospital mortality	(Non-ventilator) hospital-acquired pneumonia
Overall					
	Mean	1.92%	7.07%	4.22%	1.08%
	Percentile 10%	1.03%	4.41%	1.95%	0.22%
	Percentile 25%	1.70%	5.57%	3.50%	0.42%
	Percentile 50%	2.25%	6.58%	4.81%	1.20%
	Percentile 75%	2.45%	9.42%	5.33%	1.29%
	Percentile 90%	2.45%	9.89%	5.56%	2.29%
Hospital					
A	Crude Prevalence, n (%; 95%CI)	49 (1.03%; 0.7-1.37)	531 (6.58%; 6.04-7.13)	411 (4.81%; 4.37-5.29)	32 (0.42%; 0.28-0.59)
	Adj. Prevalence (95%CI)	1.12% (0.81-1.43)	7.61% (7.02-8.21)	4.96% (4.51-5.40)	0.44% (0.29-0.59)
	Crude OR (95% CI)	0.48 (0.35-0.64)	0.90 (0.82-1.00)	1.20 (1.07-1.35)	0.32 (0.22-0.45)
	Adj. OR (95% CI)	0.51 (0.38-0.69)	1.09 (0.98-1.55)	1.28 (1.12-1.44)	0.32 (0.21-0.47)
B	Crude Prevalence, n (%; 95%CI)	26 (1.65%; 1.08-2.40)	115 (4.44%; 3.67-5.31)	97 (3.49%; 2.84-4.25)	22 (0.92%; 0.58-1.39)
	Adj. Prevalence (%) (95%CI)	1.66% (1.04-2.23)	4.40% (3.37-5.26)	3.38% (2.75-4.02)	1.03% (0.61-1.44)
	Crude OR (95% CI)	0.85 (0.57-1.27)	0.59 (0.48-0.71)	0.81 (0.66-1.00)	0.84 (0.54-1.29)
	Adj. OR (95% CI)	0.76 (0.51-1.13)	0.55 (0.46-0.67)	0.77 (0.61-0.95)	0.98 (0.63-1.53)
C	Crude Prevalence, n (%; 95%CI)	114 (2.25%; 1.90-2.69)	668 (9.89%; 9.19-10.63)	399 (5.56%; 5.05-6.12)	140 (2.28%; 1.92-2.69)
	Adj. Prevalence (%) (95%CI)	1.93% (1.59-2.28)	8.41% (7.48-9.00)	5.22% (4.75-5.70)	2.21% (1.78-2.51)
	Crude OR (95% CI)	1.24 (0.99-1.54)	1.61 (1.47-1.78)	1.46 (1.30-1.64)	2.91 (2.34-3.62)
	Adj. OR (95% CI)	1.04 (0.83-1.30)	1.34 (1.22-1.48)	1.39 (1.23-1.60)	2.87 (2.27-3.64)
D	Crude Prevalence, n (%; 95%CI)	60 (1.72%; 1.31-2.21)	483 (9.42%; 8.63-10.25)	269 (5.00%; 4.43-5.62)	59 (1.29%; 0.98-1.70)
	Adj. Prevalence (%) (95%CI)	1.63% (1.23-2.04)	9.20% (8.45-9.95)	4.50% (4.00-5.02)	1.38% (1.03-1.71)
	Crude OR (95% CI)	0.89 (0.67-1.16)	1.46 (1.31-1.62)	1.24 (1.08-1.42)	1.22 (0.92-1.62)
	Adj. OR (95% CI)	0.82 (0.62-1.09)	1.45 (1.31-1.62)	1.10 (0.96-1.28)	1.25 (0.94-1.68)
E	Crude Prevalence, n (%; 95%CI)	19 (1.74%; 1.11-2.70)	119 (6.19%; 5.16-7.37)	75 (3.58%; 2.82-4.47)	1 (0.06%; 0.001-0.03)
	Adj. Prevalence (%) (95%CI)	1.83% (1.03-2.63)	7.03% (5.86-8.19)	2.79% (2.16-3.42)	0.01% (0.00-0.03)
	Crude OR (95% CI)	0.90 (0.57-1.44)	0.86 (0.71-1.04)	0.84 (0.66-1.06)	0.05 (0.00-0.35)
	Adj. OR (95% CI)	0.95 (0.59-1.53)	0.99 (0.81-1.20)	0.62 (0.48-0.80)	0.09 (0.01-0.69)
F	Crude Prevalence, n (%; 95%CI)	134 (2.45%; 2.05-2.89)	421 (5.57%; 5.06-6.11)	156 (1.95%; 1.66-2.28)	81 (1.20%; 0.95-1.48)
	Adj. Prevalence (%) (95%CI)	2.73% (2.28-3.18)	5.58% (5.08-6.10)	2.32% (1.90-2.74)	0.44% (0.25-0.63
	Crude OR (95% CI)	1.29 (1.04-1.61)	0.73 (0.65-0.81)	0.39 (0.33-0.46)	1.13 (0.88-1.46)
	Adj. OR (95% CI)	1.65 (1.33-2.04)	0.72 (0.64-0.80)	0.45 (0.36-0.56)	0.30 (0.16-0.56)
G	Crude Prevalence, n (%; 95%CI)	34 (2.57%; 1.79-3.57)	75 (3.65%; 2.88-4.56)	118 (5.33%; 4.43-6.35)	4 (0.22%; 0.06-0.57)
	Adj. Prevalence (%) (95%CI)	2.60% (2.23-3.10)	3.61% (2.82-4.40)	2.57% (1.90-3.10)	0.34% (0.03-0.70)
	Crude OR (95% CI)	1.38 (0.97-1.97)	0.48 (0.38-0.60)	1.30 (1.07-1.58)	0.19 (0.07-0.52)
	Adj. OR (95% CI)	1.42 (0.98-2.05)	0.46 (0.36-0.58)	0.57 (0.41-0.77)	0.28 (0.09-0.89)

Table 3:
Adjustment model per nursing-sensitive outcome.

Outcome	Covariates	Odds ratio (95% CI)***	AUC (95% CI) training set***	AUC (95% CI) test set***	P value**	% Correctly classified
Hospital-acquired pressure ulcer (stage II or greater)	Age	1.02 (1.02–1.03)	0.78 (0.76–0.81)	0.77 (0.72–0.82)	0.82	98%
	Charlson Comorbidity Index	1.04 (1.00–1.08)				
	Diabetes present	1.40 (1.12–1.75)				
	Gender*	0.87 (0.71–1.06)				
	In-hospital death	3.75 (2.80–5.00)				
	Length of stay	1.06 (1.05–1.07)				
	Major Diagnostic Category*	1.01 (0.99–1.04)				
	Peripheral vascular disease present	1.59 (1.22–2.07)				
	Pressure ulcer stage I present	7.00 (4.90–9.90)				
	Urinary tract infection	1.50 (1.15–1.96)				
	Type of hospital*	1.12 (0.97–1.29)				
Hospital-acquired urinary tract infection	Age	1.04 (1.04–1.05)	0.76 (0.75–0.77)	0.75 (0.72–0.77)	0.63	93%
	Charlson Comorbidity Index*	1.01 (0.99–1.03)				
	Diabetes present	1.18 (1.06–1.33)				
	Gender	0.41 (0.37–0.45)				
	Length of stay	1.07 (1.06–1.07)				
	Major Diagnostic Category	0.96 (0.95–0.97)				
	Paraplegia present	3.10 (2.08–4.62)				
	Type of hospital*	1.06 (0.99–1.13)				
In-hospital mortality	Age	1.05 (1.04-1.05)	0.81 (0.80–0.83)	0.81 (0.78–0.83)	0.58	99%
	Charlson Comorbidity Index	1.14 (1.11–1.16)				
	Gender*	1.08 (0.97–1.20)				
	Length of stay	0.97 (0.97–0.98)				
	Major Diagnostic Category "Myeloproliferative Diseases & Disorders"	3.90 (3.26–4.67)				
	Major Diagnostic Category	0.95 (0.93–0.97)				
	Living situation before hospital admission	0.58 (0.51–0.67)				
	Type of hospital	0.76 (0.71–0.82)				
(Non-ventilator)hospital-acquired pneumonia	Age	1.03 (1.02–1.04)	0.84 (0.82–0.87)	0.81 (0.76–0.86)	0.18	99%
	Charlson Comorbidity Index	1.09 (1.05–1.12)				
	Gender	1.53 (1.22–1.92)				
	Length of stay	1.09 (1.08–1.10)				
	Living situation before hospital admission	0.43 (0.34–0.55)				
	Major Diagnostic Category*	0.98 (0.95–1.01)				
	Rehospitalisation	2.34 (1.44–3.82)				
	Type of hospital	1.36 (1.13–1.62)				

*Removed from the final training & test sets based on the results of a LR test

** Association between training and test sets

*** Excluding the variables that have been removed after the LR test

in-hospital mortality was lower in hospitals B, E, F and G and higher in hospitals A and C, respectively. Prevalence of hospital-acquired pneumonia was lower in hospitals A, E, F and G, but higher in hospital C (figure 2).

Discussion

The key findings of this study are two-fold: first, the derived and validated prediction models showed a good discrimination ability for four well-studied NSOs (hospital-acquired pressure ulcer (≥ stage II), hospital-acquired urinary tract infection, non-ventilator hospital-acquired pneumonia, and in-hospital mortality). Second, we found relevant variation in risk of achieving an adverse NSO, suggesting that the outcome-related quality of nursing care differs among the investigated hospitals.

The indicators presented in this study may help to compare quality of care between NSOs of different hospitals using uniformly defined administrative data. This approach allows a timely evaluation of the results without additional effort for data generation. Internationally, mainly administrative data is used in the development of NSO-sets. A recent example is the nursing-sensitive outcome indicator suite for monitoring public patient safety in Western Australia, which was shown to be methodologically robust [46]. These results are largely consistent with the C-statistics in our study, confirming the external validity of our results.

Regarding hospital-acquired pressure ulcer (≥ stage II), we found little variance between the hospitals. On the one hand, the reason may be missing data due to underreporting [47]. Although, cross-sectional surveys by the ANQ showed similar but even lower prevalence rates (1.8%) compared to our study data (1.92%). It has been reported that administrative data do not provide valid data for this NSO due to several reasons [48–50]. This fact seems to

be confirmed in our data, as we would expect prevalence rates of five percent or higher [51, 52]. Therefore, before using administrative data to calculate the frequency of this NSO, we recommend reviewing the guideline-compliant documentation of the NSO in the electronic documentations as well as the coding procedure. On the other hand, it is important that the selected outcomes also have a clinically relevant frequency and variability. Otherwise, they offer no benefit in terms of quality development. Regarding hospital-acquired urinary tract infection the measured prevalence in our cohort (6.78%) is consistent with the expected prevalence (between 5.1 and 9.4% [53]), so we do not expect relevant under- or over-recording in the administrative data used.

With regards to the application of the developed method as a benchmark comparison by means of real-world data, two hospitals (B and E) showed a tendency towards lower risks in all NSOs, with some being statistically significant. Other hospitals, however, had higher risks of all (C) or almost all (D) NSOs, again with some reaching statistical significance. While our results should not be used for judging on a hospital's quality *per se*, it may provide an overview nevertheless which is notably more comprehensive than reporting individual outcomes based on cross-sectional surveys. For future studies, evaluations at the ward level are needed so that it can be investigated whether the prevalence and variation of the outcomes show relevant differences between the wards. Results on this level may support decision makers to reevaluate their pathways in providing care and thus to improve quality of nursing care. Nursing-related reasons for the differing frequency of negative outcomes could be, for example, an inadequate skill and grade mix, staffing ratios, or insufficiently planned or standardisednursing processes [54].

The strength of this study is the large sample size. While this study covers hospitals from different regions in Switzerland, results might be generalisedat a larger level. However, the results of this study must be interpreted in the context of the study design. First, the use of administrative data is prone to information bias as hospitalisations will be selected according to the ICD-10 codes with the risk of misclassification and underreporting of diagnoses. Thus, frequency of NSO is usually underestimated, especially due to its low financial relevance [55, 56]. Second, we did not have severity estimates of the hospitalised cases. Third, the non-experimental, observational design of our study limits the ability to draw a firm causal link. Fourth, since we do not have information about clinical parameters, we will be unable to account for unmeasured residual confounding and we were limited in selecting all appropriate covariates for the models. Fifth, we did not have data on nurse staffing in the study period. Sixth, external validation of our models is needed in follow-up studies.

Conclusion

The application of risk adjustment when comparing quality of nursing care enables a more objective assessment across hospitals or wards with heterogeneous patient populations. This approach has potential to establish a set of benchmarks allowing comparison of quality of nursing care between different hospitals or wards with manageable effort.

Data sharing statement

The data that support the findings of this study are available from the corresponding author, [DK], upon reasonable request.

Acknowledgements
Authors' contributions: PS and BM were the initiators and scientific project leaders. DK, AK contributed to the data collection. DK, AK, TV, CG, AC, MK, PS and BM participated in the conception and design of the study, contributed methodical expertise, and performed statistical analysis. DK wrote the manuscript, which was revised and approved by all authors.

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Potential competing interests
All authors have completed and submitted the International Committee of Medical Journal Editors form for disclosure of potential conflicts of interest. No potential conflict of interest was disclosed.

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Appendix

Figure S1: Model fit by decile (hospital-acquired pressure ulcer (≥ stage II).

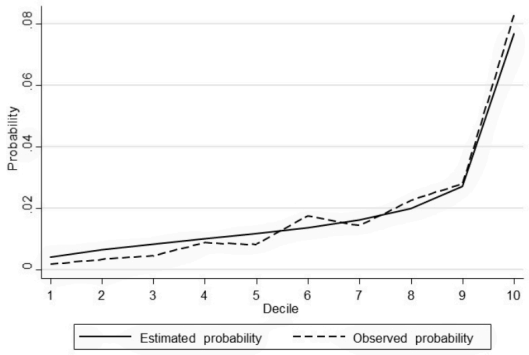

Figure S2: Model fit by decile (hospital-acquired urinary tract infection).

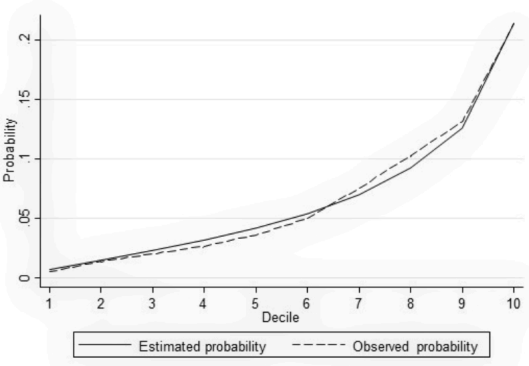

Figure S3: Model fit by decile (in-hospital mortality).

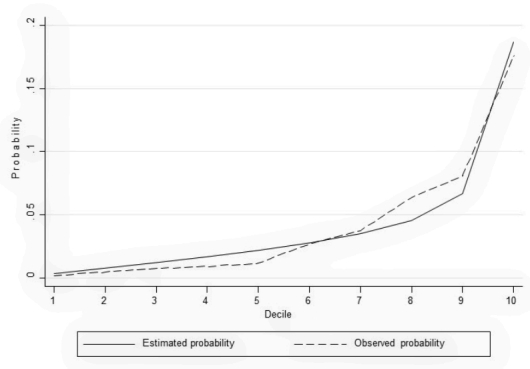

Figure S4: Model fit by decile (non-ventilator hospital-acquired pneumonia).

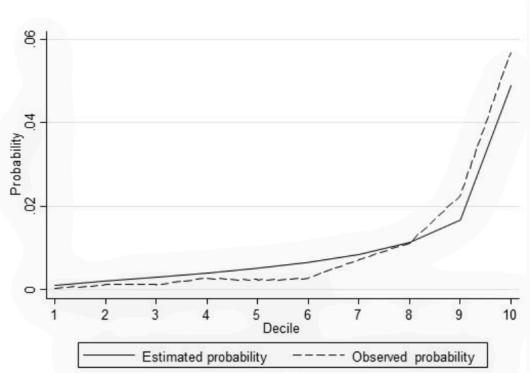

Table S1:
Covariates

Variable	Description
Age	Age at hospital admission (full years)
Gender	1 if male; 0 if female
Charlson Comorbidity Index (CCI)	Integer between 0 and 29: The CCI is a method of categorising comorbidities of patients based on the International Classification of Diseases (ICD) diagnosis codes. Each comorbidity category has an associated weight (from 1 to 6), based on the adjusted risk of mortality or resource use, and the sum of all the weights results in a single comorbidity score for a patient. A score of zero indicates that no comorbidities were found. The higher the score, the more likely the predicted outcome will result in mortality or higher resource use (19).
Length of hospital stay	Integer between 1 and 90 (see exclusion criteria); Length of stay of one patient = date of discharge - date of admission
Major Diagnostic Category according to DRG	Refers to the chapter structure of the Swiss DRG catalog; Coded as integer between 1 and 20. (*Example: Main Diagnostic Category "Certain infectious and parasitic diseases" (Chapter 1) = 1.*)
Type of hospital	According to hospital typology (Swiss Federal Statistical Office); Coded as integer between 1 and 4:
	K122 = 1
	K121 = 2
	K112 = 3
	K111 = 4
In-hospital death	0 = not deceased during hospitalisation
	1 = deceased during hospitalisation
Presence of diabetes	0 = diabetes not present (according to CCI)
	1 = diabetes present (according to CCI)
Peripheral vascular disease present	0 = Peripheral vascular disease not present (according to CCI)
	1 = Peripheral vascular disease present (according to CCI)
Presence of a stage I pressure ulcer	1 = Stage I pressure ulcer present (DRG-codes: L8900; L8901; L8902; L8903; L8904; L8905; L8906; L8907; L8908; L8909)
	0 = Stage I pressure ulcer not present
Presence of urinary tract infection	1 = urinary tract infection present (DRG-codes: T835; N390)
	0 = urinary tract infection not present
Living situation before hospital admission	1 = Lived in own home before hospitalisation (no institution)
	0 = Has lived in an institution before admission to hospital (e.g., retirement home, nursing home)
Readmission	1 = case is readmitted to the same hospital within 18 calendar days of discharge and both cases fall into the same MDC
	0 = no readmission that meets the above criteria
MDC "Myeloproliferative Disease & Disorder" present	1 = Disease from the main Diagnostic category "Myeloproliferative Diseases & Disorders" present.
	0 = No disease from the main Diagnostic category "Myeloproliferative Diseases & Disorders" present.