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30-day mortality in patients after hip fracture surgery: A comparison of the Charlson Comorbidity Index score and ASA score used in two prediction models

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ABSTRACT

Objective: To compare the Charlson Comorbidity Index (CCI) and American Society of Anesthesiologists (ASA) Physical Status Classification used in two prediction models for 30-day mortality after hip fracture surgery.

Study Design and Setting: Data from 3651 patients (mean age: 83 years) from a Norwegian University Hospital were retrospectively obtained and randomly divided into two cohorts: a model cohort ($n = 1825$) to develop two prediction models with CCI and ASA as the main predictors, and a validation cohort ($n = 1826$) to assess the predictive ability of both models. A receiver operating characteristic (ROC) curve determined the best model to predict mortality.

Results: Area under the ROC curve at 30 days was 0.726 ($p = 0.988$) for both the CCI- and ASA-model. The chosen cut-off-points on the ROC curve for CCI- and ASA-model corresponded to similar model sensitivities of 0.657 and specificities of 0.680 and 0.679, respectively. Hence, each model predicts correctly 66% ($n = 96$) of the mortalities and 68% ($n = 1132$ and $n = 1131$) of the survivals. 23% ($n = 33$) of the mortalities were predicted by neither model.

Conclusion: The CCI- and ASA-model had equal predictive ability of 30-day mortality after hip fracture. Considering the effort involved in calculating Charlson Comorbidity Index score, the ASA score may be the preferred tool to predict the 30-day mortality after hip fracture.

Introduction

Hip fracture in frail older patients is associated with high postoperative mortality, up to 10% mortality is reported within 30 days and more than 30% within one year. 30-day mortality is used as a quality indicator for hospital treatment after hip fracture [1-3].

Continuous improvements are made to optimize treatment for these patients. Changes have been made in surgical techniques, surgical implants and care systems in order to reduce mortality rates [4-6]. Guidelines recommend early surgery, early postoperative mobilization and use of standardized and orthogeriatric care [7].

For further improvements in care statistical prediction models are developed to be used in the follow-up of the most frail patients to allow for an adapted, individual care so medical complications and comorbidity can be addressed in time [8-16]. Patients with a hip fracture often have significant comorbidity [7], which is associated with worse health outcomes and increased mortality. Comorbidity can be assessed by comorbidity indices [17].

The Charlson Comorbidity Index (CCI), based on International Classification of Diseases (ICD), operationalizes the seriousness of the patient's diseases into a Charlson Comorbidity Index score (CCI-score), from 0 to 24 [18]. CCI was originally developed in 1987 to predict the one-year survival in women with breast cancer [19], and was later used for patients with hip fracture [8-11,20]. The calculation of the CCI-score requires a thorough review of medi-

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cal records to be accurate, which can involve data collected over years prior to the current hospital admission.

The American Society of Anesthesiologists (ASA) Physical Status Classification is a numeric scale (from 1 to 5) used to describe the patient's health status and peri–operative risk [21]. The ASA-score was originally developed to obtain standardized categories for physical status for a uniform interpretation and for use in statistical studies (Owens 1978). The ASA-score is routinely set by the anesthesiologist before an anesthetic procedure, based on a subjective assessment [22], and is easily available in medical records. Both CCI and ASA-scores are used to predict other outcomes than originally intended, such as readmissions [23] and complications [24] after hip fracture.

A comparison of the predictive power of CCI and ASA is interesting considering the difference in accessibility of the two scores. The ASA-score is considerably easier to obtain than a CCI-score requiring extensive calculation. A simple procedure is preferred in a busy clinical practice.

The aim of this study was to compare the ability of CCI-score and ASA-score to predict 30-day mortality after hip fracture surgery in patients 65 years or older. The prediction of one-year mortality will also be reported.

Material and methods

All patients underwent hip fracture surgery between April 18, 2008 and April 29, 2019 at St. Olavs Hospital, Trondheim University Hospital (Trondheim, Norway). St. Olavs Hospital is the local hospital for approximately 300,000 inhabitants. We collected data from 3651 patients aged ≥65 years, with a low-energy hip fracture identified in the hospital administrative databases by Surgical Procedure Terminology, NOMESCO Classification of Surgical Procedures (NCPS) and by the International Classification of Diseases (ICD-10), S72.0–S72.2. We retrospectively obtained data spanning 3 years prior to the hip fracture and a one-year follow-up (ranging from April 18, 2005 to April 29, 2020). In patients with multiple hip fractures, only the first hip fracture was included. The calculation of CCI-score was based on all registered main and secondary ICD-10 codes in the last 3 years prior to current admission, based on standards from the Norwegian Knowledge centre for the Health Services [25]. Additionally, we included diagnoses from the current episode. The CCI-score was calculated for each patient by assigning values modified by Quan [26].

The CCI- and ASA-scores were used in two statistical prediction models. The CCI-score was modelled as a continuous variable and the ASA-score as a categorical variable. Age, sex and type of fracture were initially considered as explanatory covariates, based on previously published research considered important for survival after hip fracture [27].

The total data material was randomly divided into two cohorts – a model cohort for development and one validation cohort for evaluation of the models. The steps are described in detail in the statistical analysis section. The data set was complete except for 38 missing ASA-scores: 23 in the model cohort and 15 in the validation cohort.

Statistical analysis

The included patients were randomized by Random Number Generator into two groups; a model cohort ($n = 1825$) to develop two prediction models (CCI and ASA), and a validation cohort ($n = 1826$) to assess the predictive ability of the models. The selection of covariates in the final prediction models was based on multiple logistic regression analysis; covariates holding a p-value of <0.10 were included [12].

Table 1
Patient characteristics in model and validation cohort.

	Model cohort $N = 1825$	Validation cohort $N = 1826$
Sex		
M/F	547 (30%)	566 (31%)
	1278 (70%)	1260 (69%)
Age		
Mean (SD)	82.5 (8.0)	83.0 (7.7)
Median (min–max)	83 (65–103)	84 (65–104)
Fracture type		
S72.0	1120 (61.4%)	1160 (63.5%)
S72.1	591 (32.4%)	572 (31.3%)
S72.2	114 (6.2%)	94 (5.1%)
CCI-score		
Mean (SD)	1.17 (1.63)	1.17 (1.59)
Median (min–max)	0 (0–10)	0 (0–10)
ASA 1	27 (1.5%)	18 (1.0%)
ASA 2	501 (27.5%)	506 (27.7%)
ASA 3	1078 (59.1%)	1101 (60.3%)
ASA 4	196 (10.7%)	186 (10.2%)
30-day mortality	128 (7.0%)	146 (8.0%)
12-month mortality	461 (25.3%)	473 (25.9%)

The performance of the models was validated by calibration and discrimination. Calibration is related to goodness-of-fit and reflects the consistency between predictions and outcomes. The calibration of the final CCI- and ASA-prediction models was accomplished on the model cohort, assessed by the Hosmer - Lemeshow test. A statistically significant outcome ($p \leq 0.05$) indicates lack of fit [12,28].

Discrimination was accomplished on the validation cohort by receiver operating characteristic (ROC) curve analysis. The two models were applied on the validation cohort to calculate individual patient mortality risks. The discriminative power of each model is related to the corresponding AUC. The larger the area, the better the discriminative ability. An AUC of 0.70–0.79, 0.80–0.89, and >0.90 represents acceptable, excellent, and outstanding discrimination ability, respectively [29]. The ROC curve shows the relation between sensitivity and specificity for every mortality risk. To exemplify the discriminative power of the models in our validation cohort, a single point (cut-off-point) on the ROC curve had to be chosen. By considering sensitivity and specificity as equally important, the point nearest to the top left-hand corner was chosen as cut-off-point [30]. All statistical analyses were carried out using SPSS (IBM© SPSS© Statistics version 26, Armonk, NY, USA).

Results

Total cohort

The mean and median age at admission of the 3651 patients were 83 and 84 years, respectively, and 69.5% of the cohort were women. The distribution of fractures was as follows: 62% intracapsular fracture (S72.0), 32% pertrochanteric fractures (S72.1), and 6% subtrochanteric fractures (S72.2). Mean and median CCI were 1.17 and 0, respectively, and the mean and median ASA were 2.80 and 3, respectively. The mortality was as follows: 1.6% of the patients died during hospital stay, 7.5% died within the first 30 days, and 25.6% died within one year.

The patient characteristics for the two randomized cohorts are presented in Table 1.

Model cohort

Higher CCI-score as well as higher ASA-score was associated with increased 30-day mortality (Fig. 1).

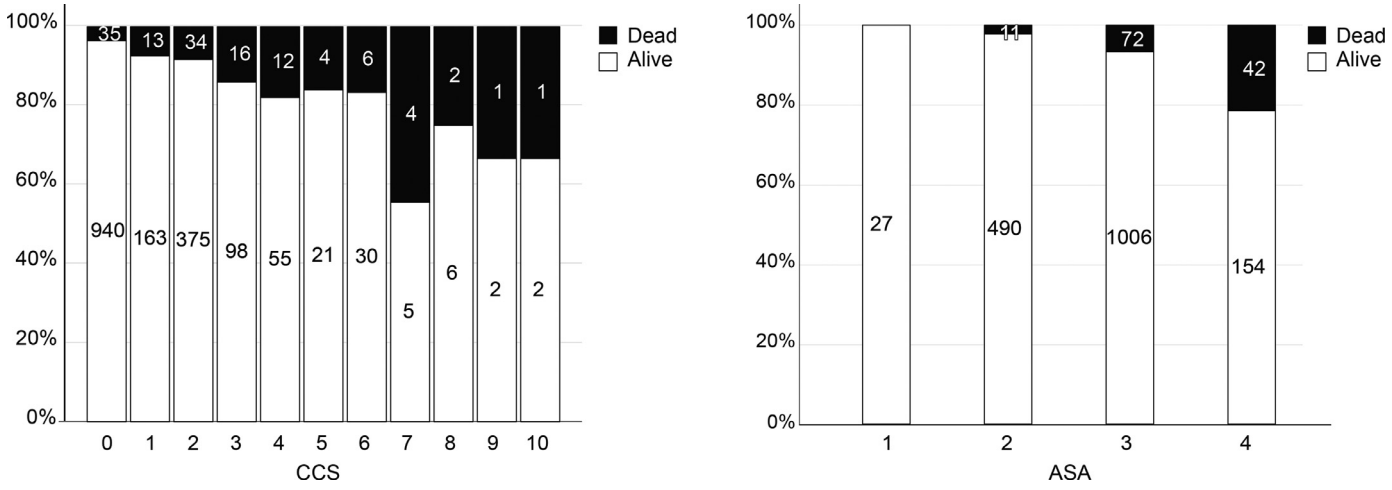

Fig. 1. Proportion of survival and mortality within 30-days after hip fracture according to CCI-score and ASA-score. 23 patients with missing ASA-score were excluded.

Table 2
Model parameters for the CCI-model.

	30-day follow-up Coefficient B	p-value	OR	95% CI Lower	Upper
Sex*	0.756	<0.001	2.672	1.441	3.151
Age	0.104	<0.001	1.110	1.078	1.142
CCI-score	0.347	<0.001	1.414	1.291	1.549
Constant	−12.248	<0.001			

* Female sex is the reference category.

Table 3
Model parameters for ASA-model.

	30-day follow-up Coefficient B	p-value	OR	95% CI Lower	Upper
Sex*	0.814	<0.001	2.257	1.522	3.346
Age	0.084	<0.001	1.087	1.057	1.119
ASA 1	−18.717	0.998	0.000	0.000	0.000
ASA 2	−2.207	<0.001	0.110	0.055	0.221
ASA 3	−1.264	<0.001	0.283	0.184	0.433
ASA 4*		<0.001			
Constant	−8.781	<0.001			

* Female sex and ASA 4 are reference categories.

In the initial logistic regression analyses, age and sex satisfied the threshold for inclusion holding a p-value of < 0.001 and a p-value of < 0.001 respectively, for both the CCI-model and the ASA-model. Type of hip fracture did not satisfy the threshold for inclusion and was excluded from the final prediction model ($p \geq 0.519$ in the CCI-model and $p \geq 0.720$ in the ASA-model). In the final prediction models, age and sex were included as covariates together with CCI-score and ASA-score, respectively. The Hosmer - Lemeshow tests for the CCI- and ASA-models at 30-days did not indicate lack of fit ($p = 0.683$ and $p = 0.711$, respectively). The model parameters are presented in Tables 2 and 3.

Validation cohort

The discriminative power of the CCI- and ASA-model at 30-day and one-year follow-up are presented as AUC (Fig. 2). The AUC of 0.726 was similar for the CCI- and the ASA-model at 30 days ($p = 0.988$). The chosen cut-off point holds a sensitivity of 0.657 in both the CCI- and ASA-models. The specificities were 0.680 and 0.679 for the two models. The AUC for the CCI- and the ASA-model at one year were 0.751 and 0.732 ($p = 0.069$), respectively.

The association of CCI-scores and ASA-scores is presented in Fig. 3.

Quantification of the discriminative power when using our chosen cut-off points is presented in Fig. 4. Each model predicts correctly 66% ($n = 96$) of the mortalities and 68% ($n = 1132$ and $n = 1131$) of the survivals. 23% ($n = 33$) of the mortalities were predicted by neither model.

Discussion

We developed and validated a CCI- and an ASA- statistical model to predict 30-day mortality in patients undergoing hip fracture surgery and found the CCI- and ASA-model to have similar predictive ability with an acceptable discrimination of 0.726.

Other studies have compared mortality prediction models. Karres et al. [14] compared six models for prediction of 30-day mortality after hip fracture. Among these six, three were relevant regarding our study, one model used the CCI-score [14] and two

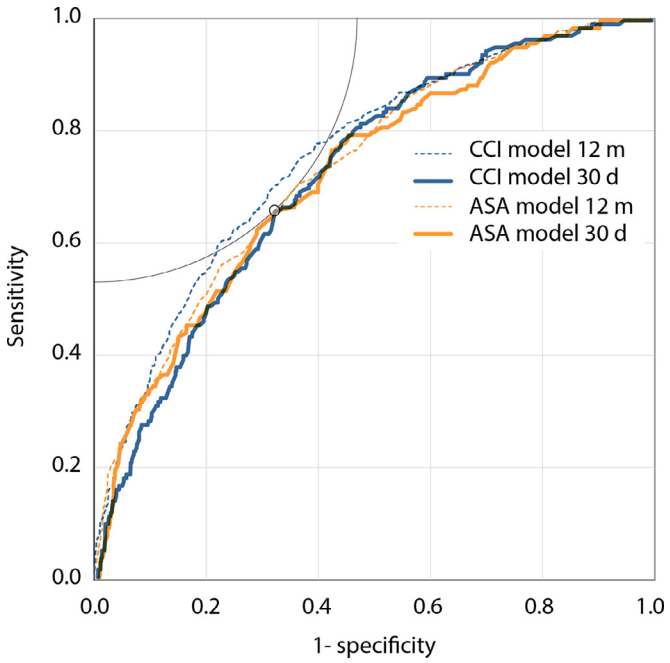

Fig. 2. ROC curves of CCI- and ASA-model at 30-day and one-year follow-up with the one chosen cut-off point marked as a circle.

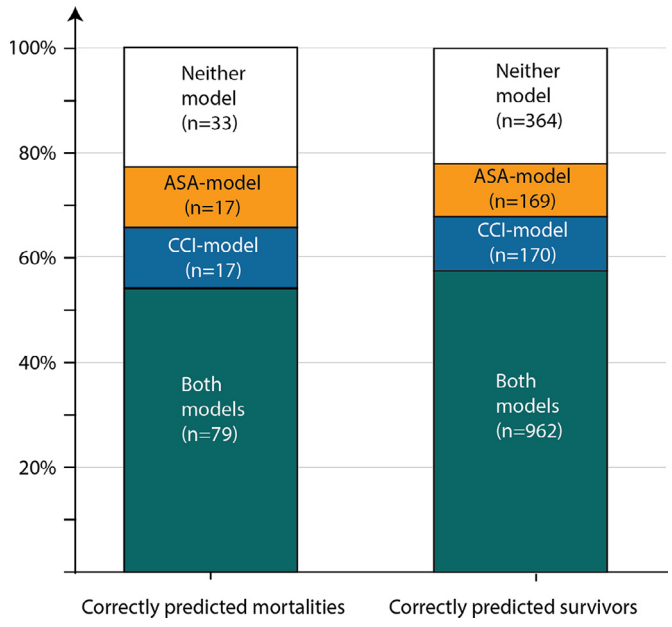

Fig. 4. Quantification of the discriminative power at 30-days follow-up. 15 patients with missing ASA-scores were excluded.

models used ASA-score as one of several predictors [31,32]. Karres reported AUCs ranging from 0.71 to 0.76.

The Hip Fracture Estimator of Mortality Amsterdam (HEMA) aimed to identify patients with a higher mortality risk. Nine predictors were finally included to quantify the comorbidity. The HEMA calculated individual risk of mortality and ranged the patients into three severity groups for risk of mortality within 30-day mortality. The predicted 30-day mortality, showed an AUC of 0.79 [12].

Maxwell et al. [9] compared Nottingham Hip Fracture Score (NHFS) and ASA-score in predicting the 30-day mortality. The aim was to improve in-hospital care. NHFS-AUC was 0.719 and the ASA-AUC was 0.718. Mortality rates at 30 days were similar as in the present study. The population were somewhat younger than in the present study, including patients irrespective of age.

To summarize these 30-day results, AUC were ranging from 0.71 for CCI [14] to 0.79 for the HEMA [12]. Our 30 days AUC results

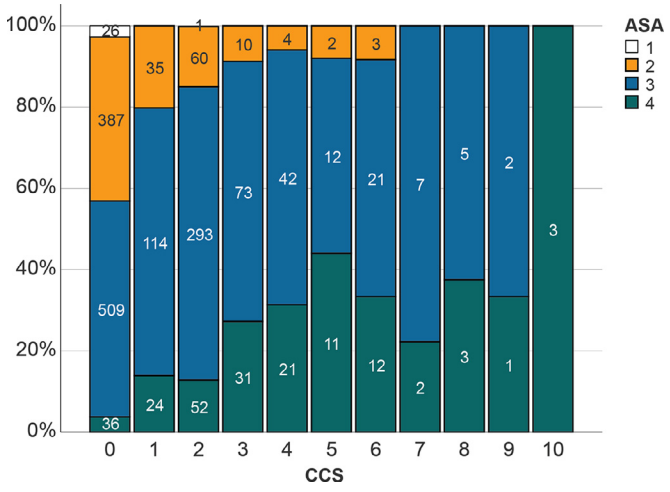

Fig. 3. Association of CCI-scores and ASA-scores. 15 patients with missing ASA-scores were excluded.

were similar for the CCI- and ASA-models with an AUC of 0.726, somewhat higher than reported by Maxwell and lower than the HEMA.

Both the CCI- and ASA-model in the present study showed an acceptable discrimination ability but failed to reach a level of excellence.

Quach et al. [8] evaluated the effect of comorbidity on 12-month mortality after hip fracture surgery, comparing the following; CCI based on the original CCI-score, an age-adjusted CCI-score and ASA-score. The AUCs were 0.61, 0.61, and 0.67, respectively [8]. The inclusion criteria, the study population and the morbidity were quite similar to the present study. Our 12-months results with an AUC of 0.751 for the CCI-score and AUC of 0.732 for the ASA-score were higher when compared to Quach.

We found higher CCI-scores was associated with higher ASA-scores (Fig. 3). Still, 36 patients with an ASA-score of 4 had corresponding CCI-score of 0. The CCI-score ranging from 0 to 24 holds a higher resolution than the ASA five-grade classification. However, health condition and lifestyle factors such as cigarette smoking and obesity may be relevant for mortality. These lifestyle aspects are accounted for when registering the ASA-score [21] but not considered in the CCI.

We found that each model predicted correctly 66% of the mortalities and 68% of the survivals. The discriminative power is rated satisfactory, but the clinical usefulness is limited. In our validation cohort, 96 of the 146 mortalities in each model were correctly predicted at 30-day follow up (Fig. 4). However, for 533 (CCI) and 534 (ASA) patients the models failed to predict survival. 23% of the mortalities were predicted by neither model.

Prediction models including multiple predictors may increase the performance at the cost of applicability in a clinical setting. Obtaining data and calculating CCI-score is time consuming while ASA-score is easy to apply.

The strength of the study is the randomization of patients into two different cohorts, one for developing the model and one for validating the results, and the relatively high number of patients and high level of data completeness. The study has limitations, the retrospective design and that all data is from a single hospital. The included patients were 65 years or older, the CCI-score ranged

from 0 to 10. Hence, the results are not generalizable to patients younger than 65 years or to those with a higher CCI-score than 10.

Conclusion

Our results show that the CCI- and ASA-model had equal prediction ability of mortality after hip fracture at 30-days follow-up in patients 65 years or older. Hence, the models are interchangeable. Considering the effort involved in calculating CCI-score, ASA-score may be the preferred tool to predict mortality within 30-days after a hip fracture.

Declarations of Competing Interest

None

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