

Comparative predictive performance of the CORN and culturally adapted Munro scales for intraoperatively acquired pressure injury: a retrospective cohort study

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Article

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Abstract

Background

Intraoperatively acquired pressure injury (IAP) is a common perioperative complication, yet no risk-assessment scale is universally accepted for surgical patients. The CORN scale, developed for Chinese patients, and the culturally adapted Munro scale have rarely been compared directly. We compared their predictive performance for IAP in a multispecialty inpatient surgical cohort.

Methods

Retrospective cohort study at a tertiary hospital in Shenzhen, China (February–April 2024). Of 300 records drawn by random number table from 2332 eligible records (expected operative duration ≥ 1 h), 296 were analysed. Both scales were scored retrospectively from each medical record by two trained nurses blinded to the outcome. The outcome was IAP, ascertained from routine records and staged using the 2016 National Pressure Ulcer Advisory Panel system. Discrimination was compared with paired DeLong tests; accuracy indices are reported with exact confidence intervals, and observed incidence is reported by risk grade. Reporting followed TRIPOD + AI and STROBE.

Results

IAP occurred in 25/296 patients (8.4%; 95% CI 5.8–12.2), most commonly stage 1. The preoperative area under the curve (AUC) was 0.862 (95% CI 0.816–0.908) for CORN versus 0.667 (0.573–0.761) for Munro (difference 0.195, 95% CI 0.112–0.277; $P < 0.001$); the intraoperative AUC was 0.948 (0.914–0.982) versus 0.838 (0.773–0.903) (difference 0.110, 95% CI 0.046–0.173; $P < 0.001$). The Munro preoperative grade did not differ between outcome groups ($P = 0.097$). In sensitivity analyses, expected operative time alone reached an AUC of 0.893; removing this single item abolished the preoperative difference (0.712 vs 0.667; $P = 0.279$), and neither the stage-matched ($P = 0.062$) nor the duration-matched ($P = 0.196$) intraoperative comparison was significant.

Conclusions

CORN showed higher apparent discrimination in this single-centre cohort, but the advantage was largely attributable to operative-duration items and was not robust in like-for-like sensitivity analyses. Munro classified more participants as moderate or high risk, with lower specificity at the evaluated thresholds. Prospective multicentre validation is required before recommending one scale over the other.

Background

Intraoperatively acquired pressure injury (IAP) is a localised injury of the skin and underlying soft tissue that develops in dependent areas during a surgical procedure [1]. Injuries arising in the operating room have been reported to account for approximately 45% of all hospital-acquired pressure injuries [2, 3]. Surgical patients are a high-risk population because they are exposed to sustained local tissue pressure that cannot be relieved by repositioning, prolonged anaesthesia, positioning and support devices, and preoperative fasting, often against a background of comorbidity [4].

IAP increases patient suffering, prolongs hospital stay, raises health-care costs and adds to nursing workload [5]. Among critically ill patients, the development of pressure injury has been associated with a several-fold increase in the risk of death [6], and pressure injury has been reported to be among the most costly health conditions to treat [7]. Early, systematic and objective risk identification is therefore the first step in prevention. International and national guidance—including the fourth edition of the international guideline on the prevention and treatment of pressure ulcers/injuries and Chinese perioperative nursing standards—recommends a structured approach to risk assessment, in which a standardised risk-assessment scale is one component, as the foundation of preventive care [8–11]. It should be noted, however, that a Cochrane review found the available evidence insufficient to establish that using a structured risk-assessment tool reduces pressure injury incidence, so the recommendation rests largely on consensus rather than on demonstrated effect on patient outcomes [12, 13].

For surgical patients specifically, however, no adult IAP risk-assessment instrument is universally accepted [14]. Generic scales such as the Braden, Norton and Waterlow scales lack surgery-specific factors (position, operative time, anaesthesia) and provide only a single preoperative assessment point; several studies have concluded that the scores they generate have limited value in the operative setting [15, 16]. Among surgery-specific tools, the Munro scale, developed in 2010, was the first scale designed specifically for surgical patients and is recommended by the Association of periOperative Registered Nurses; it has good predictive ability but has been criticised for being lengthy, time-consuming and insufficiently predictive preoperatively [17, 18]. The CORN scale, a surgery-specific tool for intraoperatively acquired pressure injury risk assessment developed by the Operating Room Nursing Committee of the Chinese Nursing Association and released in 2021, has fewer, more objective items, was designed for the Chinese population, and is included in current Chinese perioperative nursing practice guidance [11, 19, 20]. Because it is comparatively new, evidence comparing CORN with other surgery-specific scales is scarce.

To date, only one study has compared the CORN and Munro scales directly, and it enrolled only patients undergoing hepatobiliary, gastrointestinal or cardiac surgery with an operative time of ≥ 3 h [21]; it reported that CORN discriminated less well than Munro but with a more balanced sensitivity and specificity. An ideal risk-assessment scale should accurately stratify a broad range of at-risk patients rather than a narrow high-risk subset. We therefore compared the CORN and Munro scales in a multispecialty inpatient surgical cohort spanning 14 specialties, with an expected operative duration of at least 1 h, evaluating discrimination and predictive performance, in order to identify the scale better suited to IAP risk assessment in Chinese operating-room practice.

Methods

Design

This was a retrospective, single-centre cohort study comparing the predictive performance of two perioperative risk scales (CORN and Munro) for the subsequent occurrence of IAPI. Because the scales are used to anticipate an event that has not yet occurred, the analysis is one of prognostic rather than diagnostic accuracy. Both scales were scored retrospectively from the medical record by two trained nurses who were blinded to the outcome. Reporting followed the TRIPOD + AI statement for studies of prediction-model performance and the STROBE statement for observational cohort studies [22, 23]. The two scales are applied at different points with different intended uses: the preoperative subscales are completed before induction and are intended to guide preventive planning for the whole operation, whereas the intraoperative subscales include actual operative time and blood loss and can only be completed towards the end of surgery, so their prediction window is short and their practical role is closer to identifying patients needing intensified postoperative surveillance than to guiding intraoperative prevention.

Setting and participants

Adult inpatients who underwent surgery at The University of Hong Kong–Shenzhen Hospital between February and April 2024 were eligible. Inclusion criteria were: age ≥ 18 years; inpatient surgery; and the first surgery of the current admission. Exclusion criteria were: outpatient surgery; day surgery (admission and discharge within 24 h); and an expected operative time of < 1 h. From all records meeting these criteria during the study period, 300 were drawn using a random number table.

The sample size was estimated from the formula for a single-proportion survey, using an expected IAPI incidence (π) of 12.2% derived from a Chinese meta-analysis [24], a two-sided significance level ($Z_{\alpha/2} = 1.96$) and an allowable error (δ) of 0.05, giving a minimum of 165 patients. To ensure an adequate number of events and precision, the sample was expanded to 300 patients.

Risk-assessment instruments

The CORN scale comprises preoperative, intraoperative and postoperative subscales. The preoperative subscale contains six risk factors (American Society of Anesthesiologists [ASA] grade, body mass index, skin condition of the pressure area, preoperative limb mobility, expected operative time, and diabetes); diabetes is scored 4 points and each remaining item 1–4 points, giving a total classified as low (< 9), moderate (9–14) or high (> 14) risk. The intraoperative subscale contains four risk factors (temperature-loss factors, intraoperative blood loss, change in pressure/shear force, and actual operative time), each scored 1–4 points, with totals classified as low (< 8), moderate (8–12) or high (> 12) risk. The postoperative component records skin assessment of the pressure area only and does not generate a

risk grade; it was therefore not included in the predictive analysis. The scale is published as the normative annex to the Chinese Nursing Association group standard on prevention of intraoperatively acquired pressure injury [20]. That standard defines a separate total score and risk grade for each of the two assessment stages and defines no single combined preoperative-plus-intraoperative total; the summed score used in the sensitivity analyses is therefore an index constructed for this study rather than a scale-defined score.

The Munro scale used was the culturally adapted version validated by Li et al. for Chinese surgical patients [25] (a separate modified Munro version has been developed by Liao et al. [26]). It comprises preoperative, intraoperative and postoperative subscales covering patient mobility, fasting time, body mass index, recent weight loss, age and health-related adverse factors preoperatively; ASA grade, anaesthesia type, temperature, blood-pressure fluctuation, moisture, intraoperative surface movement and patient position intraoperatively; and operative time and blood loss postoperatively. Cumulative totals are classified as low, moderate or high risk at each stage. Preoperative and intraoperative grades were used for the comparison with CORN.

Outcome definition and ascertainment

The outcome was the occurrence of IAPI. When a skin abnormality was identified, the circulating nurse reported it to the hospital adverse-event system, and the hospital adverse-event group inspected the skin, confirmed whether IAPI had occurred, and staged it according to the 2016 National Pressure Ulcer Advisory Panel (NPUAP) staging system (stage 1–4, deep-tissue injury, or unstageable) [27]. Skin integrity was documented for every patient at three points – the preoperative handover form, the intraoperative nursing record and the postoperative handover form – and a pressure injury already documented before surgery rendered a record ineligible. Skin was assessed jointly by two nurses on transfer to the recovery room, on return to the ward, and during subsequent ward handovers until discharge. This surveillance followed the same routine procedure and was carried out by comparable staff for every patient irrespective of risk, so the intensity of assessment did not differ between those who did and did not develop an injury. Attribution of an injury to the intraoperative period was decided case by case by the hospital adverse-event group; no protocol-defined time window was applied. Outcome ascertainment was part of routine care and was completed before the study scores existed, so it could not have been influenced by them; conversely, the nurses who assigned the scale scores were blinded to the outcome (see Data collection). The two determinations were therefore made independently of one another. A further consequence of the retrospective design is that the study scores could not have triggered any preventive measure during the episode of care, so no treatment paradox can arise from the scores analysed here; preventive decisions taken at the time on other grounds are considered separately below.

Preventive care during the study period

Throughout the study period every patient received the department's standard pressure-injury prevention measures. In addition, patients judged to be at high risk received targeted pressure-relieving measures, the decision being based on the attending nurses' clinical experience together with the risk grade recorded in routine practice. Because the scores analysed here were generated retrospectively, they played no part in these decisions; routine risk assessment, however, may have done so, and the implications are considered in the Limitations.

Data collection

Scale scores were generated for this study rather than taken from routine documentation. Two nurses drawn from the group that had completed the standardised training programme in both instruments assigned all CORN and Munro item scores from the information available in the anaesthetic record, the operative record and the perioperative nursing notes. The 300 sampled records were divided between them, one nurse scoring 163 records and the other 137; both scales were scored by the same nurse for a given record. Every record was then checked against the source documents by the other nurse, and any disagreement was resolved by discussion until consensus was reached, so every record passed through both nurses.

Before scoring, the postoperative skin assessments and the hospital adverse-event reports were withheld, so that the nurses did not know whether the patient had developed IAPI. Patient and operative characteristics and the skin outcome were extracted separately from the scoring.

Where an item had not been documented in the record and could therefore not be scored, it was assigned its lowest value; this affected the Munro items for intraoperative temperature, blood-pressure fluctuation and recent weight loss most often. Items describing conditions observed during surgery were scored from defined fields of the record rather than from direct observation, using composite rules agreed before scoring began and applied by both nurses. Moisture was scored from the recorded volume of irrigation fluid, the irrigation site and the free-text notes of the nursing record. Change in pressure/shear force and intraoperative surface movement were scored from the recorded surgical position, the positioning devices used and the free-text notes of the intraoperative nursing record, together with the descriptions of patient position in the anaesthetic and operative records.

Separately, and before the study period, 29 circulating nurses received standardised training in both instruments, covering the purpose, completion rules and scoring criteria of each item, and consensus was reached on potential scoring discrepancies; five of them then independently scored the same 13 patients to examine inter-rater reliability. This preliminary exercise is the source of the Kendall's W values reported below. It was conducted independently of the present analysis and contributed no records to it, so those coefficients describe agreement among trained nurses in general rather than agreement between the two nurses who produced the study data.

Statistical analysis

Analyses were performed in R version 4.5.1 (R Foundation for Statistical Computing, Vienna, Austria). Continuous variables are described as mean $\pm$ standard deviation and categorical variables as frequency (percentage). Scale scores were compared between patients who did and did not develop IAPI using the independent-samples t test with Welch's correction (not assuming equal variances), and ordinal risk grades using the Mann–Whitney U (rank-sum) test. Inter-rater reliability was assessed with Kendall's coefficient of concordance (W), which measures concordance of rankings rather than absolute agreement, and internal consistency with Cronbach's α , computed across the nine ordinally scored CORN items (the dichotomously scored diabetes item, 0 or 4 points, was excluded because it is not measured on the same 1–4 scale) and across all 15 items of the Munro scale. Discrimination was assessed from receiver operating characteristic (ROC) curves using the AUC, the unweighted Youden index (sensitivity + specificity – 1) [28], sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV); paired AUCs of the two scales were compared with the DeLong test [29]. Optimal cut-offs were determined in-sample as the score maximising the Youden index; because they were not pre-specified or externally validated, the corresponding accuracy estimates should be regarded as optimistic. Neither scale publishes a mapping from total score to predicted probability, so probability calibration could not be evaluated; instead we report the observed incidence of IAPI within each scale's predefined risk grades, with exact binomial confidence intervals. Item-level and sensitivity analyses were exploratory, and no adjustment for multiple testing was applied. A two-sided $P < 0.05$ was considered statistically significant.

Ethics

The study was approved by the Medical Ethics Committee of The University of Hong Kong–Shenzhen Hospital under its expedited review procedure (protocol no. hkuszh2024103; approval dated 26 April 2024). The need for individual informed consent was waived by the same committee, the Medical Ethics Committee of The University of Hong Kong–Shenzhen Hospital, because the study analysed anonymised data recorded as part of routine care and involved no additional intervention or contact with patients. All procedures were carried out in accordance with the Declaration of Helsinki. Records were sampled and scored retrospectively after that approval, and all records were anonymised before analysis.

Results

Participants

During the study period 5366 surgical procedures were performed. A total of 3034 did not meet the eligibility criteria (155 aged < 18 years; 859 outpatient surgery; 105 day surgery; 1894 expected operative time < 1 h; 21 not the first surgery of the admission), leaving 2332 eligible records, from which 300 (12.9%) were drawn using a random number table (Fig. 1). On review, four of the sampled records proved to be of patients aged under 18 years and therefore did not meet the eligibility criteria; they were excluded, leaving 296 records for analysis. No further record had to be replaced, in the sense that every

remaining record yielded a complete set of scored items; whether an individual item had been left blank in the source record and therefore scored at its lowest value (see Methods) could not be recovered retrospectively.

Two hundred and ninety-six patients from 14 surgical specialties were analysed. IAPI occurred in 25 patients (8.4%; 95% CI 5.8–12.2), of whom 19 (6.4%) had stage 1 injury, 5 (1.7%) stage 2 and 1 (0.3%) deep-tissue injury; the remaining 271 patients formed the non-occurrence group. Participant and operative characteristics by outcome are shown in Table 1. Patients who developed IAPI were more often male, more often in a prone or lateral position, of higher ASA grade and much more often had an actual operative time of at least 4 h (80.0% vs 7.0%), whereas age, body mass index, elective versus emergency status and comorbidity count did not differ significantly. Events were concentrated in orthopaedic (8/70) and neurosurgical (7/19) procedures, and none occurred in the 47 obstetric and gynaecological cases. Table 2 describes the 29 nurses who received pre-implementation training in the two instruments; five of them took part in the reliability pretest, and the two nurses who scored the study records were drawn from this trained group. No harms were associated with administering the scales or performing the skin assessments.

Table 1
Participant and operative characteristics by IAPI occurrence.

Characteristic	Category	IAPI (n = 25)	No IAPI (n = 271)	P
Age (years)	Mean $\pm$ SD	52.72 $\pm$ 20.89	49.57 $\pm$ 15.81	0.469
Sex	Male	21 (84.0)	103 (38.0)	< 0.001
	Female	4 (16.0)	168 (62.0)	
BMI (kg/m ²)	< 18.5	3 (12.0)	12 (4.4)	0.162
	18.5–23.9	10 (40.0)	155 (57.2)	
	24.0–27.9	9 (36.0)	79 (29.2)	
	$\geq$ 28	3 (12.0)	25 (9.2)	
Surgical position	Supine	9 (36.0)	168 (62.0)	< 0.001
	Lithotomy	1 (4.0)	61 (22.5)	
	Prone	9 (36.0)	26 (9.6)	
	Lateral	6 (24.0)	16 (5.9)	
Surgery type	Elective	21 (84.0)	230 (84.9)	1.000
	Emergency	4 (16.0)	41 (15.1)	
ASA grade	I	1 (4.0)	64 (23.6)	< 0.001
	II	11 (44.0)	162 (59.8)	
	III	9 (36.0)	40 (14.8)	
	IV or above	4 (16.0)	5 (1.8)	
Anaesthesia	General	24 (96.0)	200 (73.8)	0.045
	Neuraxial / nerve block	1 (4.0)	43 (15.9)	
	Monitored / local	0 (0)	28 (10.3)	
Actual operative time (h)	< 3	4 (16.0)	233 (86.0)	< 0.001
	$\geq$ 3 to < 3.5	1 (4.0)	11 (4.1)	
	$\geq$ 3.5 to < 4	0 (0)	8 (3.0)	
	$\geq$ 4	20 (80.0)	19 (7.0)	
Comorbidities (n)	0	12 (48.0)	173 (63.8)	0.080
	1	12 (48.0)	64 (23.6)	
	2	1 (4.0)	23 (8.5)	

Characteristic	Category	IAPI (n = 25)	No IAPI (n = 271)	P
	3	0 (0)	11 (4.1)	

ASA, American Society of Anesthesiologists; BMI, body mass index; IAPI, intraoperatively acquired pressure injury; SD, standard deviation. Values are n (%) within each outcome group unless stated. Age was compared with Welch’s t test and all categorical variables with Fisher’s exact test (Freeman–Halton extension for tables larger than 2 × 2), which is exact irrespective of expected cell counts. These comparisons are descriptive; no adjustment for multiple testing was applied. ASA grade and actual operative time are also scored items of the CORN scale, so their association with the outcome is not independent of the scale comparisons reported below. Surgical specialty, shown as total (IAPI), was orthopaedics 70 (8), obstetrics and gynaecology 47 (0), gastrointestinal 31 (1), urology 29 (3), head and neck 22 (3), neurosurgery 19 (7), breast 16 (0), thyroid 15 (0), hepatobiliary 11 (0), vascular 10 (0), cardiac and great-vessel 9 (3), thoracic 8 (0), ophthalmology 5 (0) and plastic 4 (0); no test was performed because 14 categories share 25 events. Percentages may not sum to 100% because of rounding.

Table 2
Characteristics of nurses receiving pre-implementation training (n = 29).

Characteristic	Category	n (%) or mean ± SD
Sex	Female	23 (79.3)
	Male	6 (20.7)
Age (years)	Mean ± SD	33.93 ± 3.85
Highest education	Associate degree	3 (10.3)
	Bachelor	25 (86.2)
	Postgraduate	1 (3.4)
Professional title	Nurse practitioner	6 (20.7)
	Nurse-in-charge	22 (75.9)
	Associate chief nurse	1 (3.4)
Work experience (years)	Mean ± SD	12.21 ± 4.59

Percentages may not sum to 100% because of rounding. This table describes all 29 nurses who received pre-implementation training. The five who took part in the reliability pretest and the two who scored the study records were drawn from this group; their characteristics were not recorded separately.

Reliability

These indices are reported descriptively. Both scales are formative risk indices assembled from heterogeneous factors (operative duration, diabetes, position, blood loss, temperature) rather than

reflective instruments measuring a single latent construct, so a higher Cronbach's α does not by itself indicate a better scale, and no formal comparison of the two α values or of the two W values was made. In the pre-implementation pretest (five nurses independently scoring the same 13 patients), Kendall's W for the preoperative and intraoperative assessments was 0.941 and 0.918 for CORN and 0.918 and 0.896 for Munro, respectively (all $P < 0.05$). In the 296 analysed records, Cronbach's α was 0.738 for CORN across its nine ordinal items (0.685 when the dichotomous diabetes item is also included) and 0.676 for Munro across all 15 of its items.

Scale scores and risk grades

Scores were higher in the IAPI group than in the non-occurrence group for both scales at both time points, and all score differences were statistically significant (Table 3), indicating that both scales can identify patients at higher risk. For risk grades (Table 4), the CORN preoperative and intraoperative grades and the Munro intraoperative grade differed significantly between groups (all $P < 0.001$), whereas the Munro preoperative grade did not ($Z = -1.662$, $P = 0.097$). Among patients who did not develop IAPI, the CORN grade was most often low risk (70.8% preoperatively and 90.8% intraoperatively), whereas the Munro grade was most often moderate risk or above (83.4% preoperatively and 100% intraoperatively); Munro therefore classified a larger proportion of participants as moderate or high risk in this cohort.

Table 3
Scale scores in relation to IAPI occurrence.

Scale	Time point	IAPI group (n = 25)	Non-IAPI group (n = 271)	t (P)
CORN	Preoperative	11.04 $\pm$ 1.70	7.69 $\pm$ 2.45	9.049 (< 0.001)
	Intraoperative	10.68 $\pm$ 2.55	5.31 $\pm$ 1.82	10.316 (< 0.001)
Munro	Preoperative	9.16 $\pm$ 1.60	8.21 $\pm$ 1.72	2.833 (0.008)
	Intraoperative	25.16 $\pm$ 2.41	21.27 $\pm$ 3.08	7.520 (< 0.001)

Values are mean $\pm$ standard deviation. IAPI, intraoperatively acquired pressure injury. P values from independent-samples t tests with Welch's correction.

Table 4
Risk grades in relation to IAPI occurrence.

Scale	Time point	Risk grade	IAPI (n = 25)	Non-IAPI (n = 271)	Z (P)
CORN	Preoperative	Low	1 (4.0)	192 (70.8)	-6.609 (< 0.001)
		Moderate	23 (92.0)	74 (27.3)	
		High	1 (4.0)	5 (1.8)	
	Intraoperative	Low	3 (12.0)	246 (90.8)	-10.521 (< 0.001)
		Moderate	16 (64.0)	24 (8.9)	
		High	6 (24.0)	1 (0.4)	
Munro	Preoperative	Low	1 (4.0)	45 (16.6)	-1.662 (0.097)
		Moderate	24 (96.0)	226 (83.4)	
		High	0 (0.0)	0 (0.0)	
	Intraoperative	Low	0 (0.0)	0 (0.0)	-4.861 (< 0.001)
		Moderate	11 (44.0)	228 (84.1)	
		High	14 (56.0)	43 (15.9)	

Values are n (%). IAPI, intraoperatively acquired pressure injury. P values from Mann–Whitney U (rank-sum) tests. Percentages may not sum to 100% because of rounding.

Discrimination

The preoperative AUC was 0.862 (95% CI 0.816–0.908) for CORN and 0.667 (95% CI 0.573–0.761) for Munro, and the intraoperative AUC was 0.948 (95% CI 0.914–0.982) for CORN and 0.838 (95% CI 0.773–0.903) for Munro (Fig. 2, Fig. 3; Table 5). The between-scale AUC difference favoured CORN both preoperatively (0.195, 95% CI 0.112–0.277; DeLong Z = 4.628, P < 0.001) and intraoperatively (0.110, 95% CI 0.046–0.173; Z = 3.394, P < 0.001). The optimal preoperative and intraoperative cut-offs for CORN (8.5 and 7.5) matched the scale's published thresholds [19]; those for Munro (7.5 and 22.5) differed from the original thresholds but agreed with the validation of the adapted Munro scale [25].

At the optimal cut-off (Table 6), CORN combined high sensitivity with substantially higher specificity than Munro. Preoperatively, CORN reached a Youden index of 0.668 (sensitivity 96.0%, specificity 70.8%) versus 0.311 for Munro (sensitivity 92.0%, specificity 39.1%); intraoperatively, CORN reached 0.788 (sensitivity 88.0%, specificity 90.8%) versus 0.595 for Munro (sensitivity 92.0%, specificity 67.5%). Both scales showed low PPV and high NPV, as expected at the low observed IAPI prevalence (8.4%); routine universal preventive care, which further lowers the event rate, is a likely additional contributor.

Table 5
Comparison of the ROC curves of the CORN and Munro scales.

Time point	Scale	AUC	95% CI	AUC difference (95% CI)	Z (P)
Preoperative	CORN	0.862	0.816–0.908	0.195 (0.112–0.277)	4.628 (< 0.001)
	Munro	0.667	0.573–0.761		
Intraoperative	CORN	0.948	0.914–0.982	0.110 (0.046–0.173)	3.394 (< 0.001)
	Munro	0.838	0.773–0.903		

AUC, area under the receiver operating characteristic curve; CI, confidence interval. Individual AUC confidence intervals and the between-scale comparison were both derived from the DeLong variance estimator [29]. AUC differences and their confidence intervals are computed from unrounded AUCs and may differ slightly from the subtraction of the rounded values shown.

Table 6
Accuracy of the CORN and Munro scales at the optimal cut-off.

Time point	Scale	Cut-off	Sensitivity % (95% CI)	Specificity % (95% CI)	Youden	PPV % (95% CI)	NPV % (95% CI)
Preoperative	CORN	8.5	96.0 (79.6–99.9)	70.8 (65.0–76.2)	0.668	23.3 (15.5–32.7)	99.5 (97.1–100)
	Munro	7.5	92.0 (74.0–99.0)	39.1 (33.3–45.2)	0.311	12.2 (7.9–17.8)	98.1 (93.5–99.8)
Intraoperative	CORN	7.5	88.0 (68.8–97.5)	90.8 (86.7–93.9)	0.788	46.8 (32.1–61.9)	98.8 (96.5–99.8)
	Munro	22.5	92.0 (74.0–99.0)	67.5 (61.6–73.1)	0.595	20.7 (13.6–29.5)	98.9 (96.1–99.9)

CI, confidence interval; NPV, negative predictive value; PPV, positive predictive value. Confidence intervals are exact (Clopper–Pearson) binomial intervals. The wide sensitivity intervals reflect the small number of events ($n = 25$).

Observed IAPI incidence by risk grade

Because neither scale publishes a mapping from total score to predicted probability, formal calibration in the probabilistic sense could not be assessed. We therefore report the observed incidence of IAPI within each predefined risk grade (Table 7); this describes how the grades behaved in this cohort but is not a test of probability calibration.

For CORN, incidence rose steeply from the low to the moderate grade at both time points (preoperative 0.5% vs 23.7%; intraoperative 1.2% vs 40.0%), and reached 85.7% in the seven patients graded high risk intraoperatively. The preoperative high-risk grade contained only six patients, of whom one developed IAPI (16.7%), so the preoperative gradient was not monotonic at the top grade. For Munro, no patient was graded high risk preoperatively and none was graded low risk intraoperatively, so only two grades were populated at each time point; incidence was 2.2% versus 9.6% preoperatively and 4.6% versus 24.6% intraoperatively.

Table 7
Observed IAPI incidence within each predefined risk grade.

Scale	Time point	Risk grade	n	IAPI	Incidence % (95% CI)
CORN	Preoperative	Low	193	1	0.5 (0.0–2.9)
		Moderate	97	23	23.7 (15.7–33.4)
		High	6	1	16.7 (0.4–64.1)
	Intraoperative	Low	249	3	1.2 (0.2–3.5)
		Moderate	40	16	40.0 (24.9–56.7)
		High	7	6	85.7 (42.1–99.6)
Munro	Preoperative	Low	46	1	2.2 (0.1–11.5)
		Moderate	250	24	9.6 (6.2–13.9)
		High	0	—	—
	Intraoperative	Low	0	—	—
		Moderate	239	11	4.6 (2.3–8.1)
		High	57	14	24.6 (14.1–37.8)

CI, confidence interval; IAPI, intraoperatively acquired pressure injury. Confidence intervals are exact (Clopper–Pearson) binomial intervals. Grades are those defined by each scale; this table describes observed incidence and is not an assessment of probability calibration.

Sensitivity analyses

Because the two scales differ in which risk factors they place at each assessment point, we examined how far the headline comparisons depended on that structure (Table 8). At item level, CORN's preoperative advantage was concentrated in a single item: expected operative time alone reached an AUC of 0.893 (95% CI 0.831–0.955), higher than the complete preoperative subscale, whereas the skin, mobility and diabetes items were close to chance (0.536, 0.537 and 0.479). Munro contains no operative-time item in either its preoperative or its intraoperative subscale, placing operative time in its postoperative subscale instead.

When the expected-operative-time item was removed, the preoperative advantage of CORN was no longer significant (AUC 0.712 vs 0.667; difference 0.045, 95% CI – 0.036 to 0.125; P = 0.279). The intraoperative comparison was likewise sensitive to how the two scales were matched. Against the Munro intraoperative subtotal (stage-matched rather than cumulative) the difference was 0.057 (95% CI – 0.003 to 0.117; P = 0.062), and against the Munro intraoperative subtotal plus its postoperative operative-time and blood-loss items (duration-matched) it was 0.031 (95% CI – 0.016 to 0.077; P = 0.196); neither reached significance.

In an exploratory comparison using a study-constructed summed CORN score (the standard defines no combined total), the advantage of CORN persisted: the summed preoperative and intraoperative score reached an AUC of 0.941 compared with 0.838 for the Munro cumulative score (difference 0.103, 95% CI 0.040–0.165; P = 0.001) and 0.892 for the complete Munro scale including its postoperative items (difference 0.049, 95% CI 0.011–0.086; P = 0.012). Finally, applied at its own published high-risk boundary (cumulative score ≥ 25) rather than at the data-derived cut-off, the Munro intraoperative grade had a sensitivity of 56.0% (95% CI 34.9–75.6) and a specificity of 84.1% (95% CI 79.2–88.3).

Table 8
Discriminative ability of individual scale items.

Item	Stage	AUC (95% CI)	Scale
Expected operative time	Preoperative	0.893 (0.831–0.955)	CORN
ASA grade	Preoperative	0.725 (0.629–0.822)	CORN
Body mass index	Preoperative	0.599 (0.487–0.711)	CORN
Limb mobility	Preoperative	0.537 (0.453–0.621)	CORN
Skin condition	Preoperative	0.536 (0.482–0.591)	CORN
Diabetes	Preoperative	0.479 (0.421–0.537)	CORN
Actual operative time	Intraoperative	0.876 (0.796–0.956)	CORN
Blood loss	Intraoperative	0.825 (0.729–0.922)	CORN
Pressure/shear change	Intraoperative	0.797 (0.709–0.884)	CORN
Temperature loss	Intraoperative	0.780 (0.709–0.850)	CORN
Recent weight loss	Preoperative	0.623 (0.533–0.714)	Munro
Mobility	Preoperative	0.621 (0.522–0.720)	Munro
Body mass index	Preoperative	0.595 (0.483–0.706)	Munro
Health-related factors	Preoperative	0.553 (0.456–0.650)	Munro
Age	Preoperative	0.533 (0.418–0.648)	Munro
Fasting time	Preoperative	0.517 (0.506–0.527)	Munro
Temperature	Intraoperative	0.802 (0.721–0.882)	Munro
Support surface	Intraoperative	0.799 (0.733–0.865)	Munro
Blood-pressure fluctuation	Intraoperative	0.720 (0.671–0.769)	Munro
ASA grade	Intraoperative	0.650 (0.576–0.725)	Munro
Anaesthesia type	Intraoperative	0.613 (0.569–0.657)	Munro
Moisture	Intraoperative	0.599 (0.514–0.684)	Munro
Patient position	Intraoperative	0.507 (0.420–0.593)	Munro
Operative time	Postoperative	0.840 (0.770–0.911)	Munro
Blood loss	Postoperative	0.755 (0.651–0.859)	Munro

ASA, American Society of Anesthesiologists; AUC, area under the receiver operating characteristic curve; CI, confidence interval. Items are ordered by stage and descending AUC within each scale.

Discussion

In a multispecialty inpatient surgical cohort spanning 14 specialties, with an expected operative duration of at least 1 h, the the CORN scale showed higher apparent AUCs than the culturally adapted Munro scale at the nominal preoperative and intraoperative assessment points. However, sensitivity analyses indicated that these differences largely reflected where operative-duration items were positioned within the two instruments. The observed IAPI incidence of 8.4%, most commonly stage 1, is lower than pooled estimates of 12.2–19.0% [24, 30]; this is consistent with our deliberately broad eligibility, which—unlike populations enriched for older age or non-supine positioning—included a large proportion of patients aged under 40 (30.7%) and in the supine position (59.8%), both associated with lower IAPI risk [31, 32]. As noted below, the routine application of preventive care to all patients further lowered the observed event rate.

Both scales are formative indices rather than reflective scales, so internal-consistency and rank-concordance coefficients should not be read as evidence that one instrument is inherently more reliable or easier to apply; we collected no timing, usability or user-experience data that could support such a claim, and any impression of greater ease of use remains a hypothesis for separate study. The lower Cronbach's α for Munro relative to earlier validation work [25] is in any case largely explained by restricted score variance in this largely low-risk cohort.

The discrimination findings are the core result. CORN achieved a preoperative AUC of 0.862 and an intraoperative AUC of 0.948, both significantly higher than the corresponding Munro values (0.667 and 0.838). The preoperative Munro AUC below 0.70 indicates limited preoperative discrimination, in agreement with previous reports [21], and implies that Munro is less able to identify at-risk patients early, when targeted preventive measures can be planned and resources allocated efficiently. Notably, our overall ranking differs from the only prior CORN-versus-Munro comparison, which found Munro superior [21]; that study was restricted to high-risk patients undergoing long operations, whereas our broader case mix exposed Munro's weaker ability to exclude patients who did not develop IAPI. This underlines that a scale's apparent performance depends heavily on the case mix in which it is tested. Conversely, our largely low-risk, predominantly short-operation single-centre case mix may itself favour CORN; whether its advantage persists in high-risk, long-operation populations—where the prior comparison favoured Munro and where CORN's lower intraoperative sensitivity would matter most—requires further study.

CORN also combined high sensitivity with markedly better specificity (preoperative 70.8% vs 39.1%; intraoperative 90.8% vs 67.5%) and a higher Youden index at both time points, indicating a better overall balance between detecting true cases and correctly excluding non-cases. The Munro preoperative risk grade did not differ between patients who did and did not develop IAPI, and no patient was ever graded low risk intraoperatively by Munro: Munro classified a larger proportion of participants as moderate or high risk in this cohort. This upward grade shift partly reflects that Munro's native cut-points, applied to our largely low-risk population, differed from the study-derived optimal thresholds, whereas CORN's

matched. Because probability calibration could not be evaluated, we cannot say whether this represents overestimation of risk; either way, grading a larger share of patients as at risk may prompt greater use of preventive resources. Both scales had low PPV and high NPV, an expected consequence of the low event rate under universal preventive care, which does not undermine the comparative findings.

The observed incidence within each risk grade shows how the grades behaved in practice rather than how well either scale is calibrated, since neither publishes a score-to-probability mapping. For CORN the gradient from the low to the moderate grade was steep at both time points, which is what a grading system is intended to achieve. Two features temper this. The CORN preoperative high-risk grade contained only six patients and its observed incidence was lower than that of the moderate grade, so the top of the preoperative gradient is unstable. For Munro, two of the six grade-by-time-point cells were empty – no patient was graded high risk preoperatively and none low risk intraoperatively – so at each time point the scale effectively operated as a two-level rather than a three-level classification in this cohort.

The sensitivity analyses locate the source of CORN's advantage more precisely than the headline comparison does. Preoperatively, the difference is driven largely by one item: CORN scores anticipated operative duration before surgery, whereas Munro defers operative time to its postoperative subscale, and once that item is removed the two scales no longer differ significantly. The same structural difference underlies the intraoperative comparison, which loses significance when the scales are matched by stage or by duration. The practical message is therefore narrower, but also more actionable, than "CORN performs better": for preoperative stratification, anticipated operative duration carries most of the available signal, and an instrument that captures it at the preoperative time point will out-perform one that does not. That said, an exploratory comparison using a study-constructed summed CORN score, which the CORN standard itself does not define, also favoured CORN, and CORN additionally has fewer items and more objective scoring criteria, which matters for routine documentation. The prominence of a single item also raises the question of whether a structured scale adds anything beyond anticipated operative duration. Three considerations suggest that it does. Intraoperatively, the combined CORN subscale reached an AUC of 0.948, appreciably higher than its strongest single item (actual operative time, 0.876), so the combination of items does carry additional information. A scale also yields a graded risk category that can be tied to a defined package of preventive measures, whereas a single continuous variable has no validated threshold and no corresponding care protocol. Finally, a structured record supports documentation and handover in a way that an isolated estimate of duration does not. This reading is consistent with current international guidance, which frames a standardised risk-assessment scale as one component of a structured assessment that should be supplemented by risk factors relevant to the population and setting and interpreted with clinical judgement [9]. Nonetheless, CORN is limited by its brief comorbidity assessment (diabetes only) and its lack of a postoperative risk grade, and our data indicate a slightly lower intraoperative sensitivity than Munro (88.0% vs 92.0%); refinement—such as adding age and position items and a postoperative grade—merits evaluation in future work.

Limitations

This study has several limitations. First, it was conducted at a single tertiary hospital in Shenzhen over a short period (February–April 2024), which may limit generalisability; multicentre validation across different populations and care settings is needed. Second, the preoperative advantage of CORN rests substantially on its expected-operative-time item and is not significant once that item is removed (see Sensitivity analyses), so this finding is better read as evidence about where each instrument places operative duration than as evidence about overall scale quality. Third, the design was retrospective: the scores were generated for this study from the existing record rather than at the bedside, so the completeness and accuracy of individual items depended on what routine practice had documented. In particular, items that require direct intraoperative observation—CORN's change in pressure/shear force and Munro's moisture and intraoperative surface movement—are less amenable to verification from the record than objective items such as operative time or blood loss. Fourth, we did not restrict by specialty in order to include all at-risk patients, which increases case-mix heterogeneity; random sampling was used to reduce selection bias, but residual confounding by case-mix (specialty, position, operative time) cannot be excluded because no adjustment was performed. Fifth, the sample size was powered for estimating IAPI incidence rather than for comparing scales; with only 25 events the study is underpowered for the AUC and sensitivity/specificity comparisons, and the confidence intervals around sensitivity and the predictive values are correspondingly wide. Sixth, the optimal cut-offs were derived in-sample by maximising the Youden index and were neither pre-specified nor internally validated, so the reported accuracy is optimistically biased; Munro's data-derived intraoperative cut-off (22.5) also differs from its published high-risk boundary, so Munro was not evaluated exactly as clinically graded. Seventh, the reported inter-rater reliability comes from a separate 13-patient pretest involving five other nurses, not from the two nurses who scored the study records. The analysed scores are consensus values, because every record was checked by the second nurse and disagreements were resolved by discussion, but the frequency and direction of those disagreements were not recorded, so agreement between the two nurses before consensus could not be quantified. Eighth, although the nurses were blinded to the outcome, both scales were scored by the same nurse for a given record, so the two sets of scores were not generated independently and an impression formed while scoring one instrument could have carried over to the other; records are also clustered within two nurses and we did not adjust for this clustering. Because most events were the subjective stage 1 category, the outcome determination is itself open to observer variation. Separately, the eligibility filter applied to the theatre register was not perfect: four of the 300 sampled records were found on review to be of patients under 18 years and were excluded, so the eligible pool of 2332 records may contain a small number of similarly misclassified records and the sampling frame is only approximate. Excluding these four records changed the preoperative AUC difference from 0.193 to 0.195 and the intraoperative difference from 0.109 to 0.110, with no change to any conclusion. Ninth, the Munro intraoperative grade is a cumulative preoperative-plus-intraoperative construct whereas the CORN intraoperative subscale is stage-specific, so the intraoperative comparison is not strictly like-for-like, and some Munro items (e.g. intraoperative temperature, blood-pressure fluctuation and recent weight loss) can be difficult to obtain. Floor scores were in fact very common in

this dataset — 94.6% for recent weight loss, 85.8% for mobility and 69.9% for intraoperative temperature — and because records that were genuinely low risk cannot be distinguished from records that were simply not documented, these items contributed little information. The number of records so assigned was not tabulated and the shared dataset retains only the final scores, so neither complete-case nor multiple-imputation analyses were possible. Because scoring was retrospective, these values reflect what the record contained rather than the patient's state, and the problem affected Munro more than CORN; it reduces item variance and may therefore have depressed both Munro's Cronbach's α and its AUC. The direction and magnitude of its effect on the between-scale comparison cannot be determined from the available data. Tenth, the predictive probabilities of neither scale are published, so we could not assess probability calibration and report only observed incidence by grade; a scale may separate risk groups well yet still be poorly calibrated, and this study cannot distinguish the two. Eleventh, the attribution of an injury to the intraoperative period was made case by case by the hospital adverse-event group rather than against a protocol-defined time window, and the interval between scoring and the final skin assessment was not systematically recorded. Attribution therefore rested on clinical judgement and may have varied between cases, and late-appearing deep-tissue injury may have been missed. Finally, all patients received standard preventive care and those judged to be at high risk received additional targeted pressure-relieving measures, decided on clinical experience and the risk grade in routine use. The scores analysed here were generated retrospectively and so could not have influenced that care, but the routine assessment that did inform it is correlated with the study scores; to the extent that extra prevention prevented injuries in patients who would otherwise have been classified correctly, the apparent performance of both scales is attenuated, and the effect need not be equal for the two instruments. Universal preventive care also lowered the observed event rate and hence the positive predictive value of both scales. Quantifying these effects would require a comparative interventional design.

Conclusions

In this multispecialty inpatient surgical cohort, the CORN scale showed higher apparent discrimination than the culturally adapted Munro scale before and during surgery, and its sensitivity and specificity were more balanced at the evaluated cut-offs. The advantage was, however, largely attributable to the operative-duration items and was not robust in like-for-like sensitivity analyses: it disappeared when the expected-operative-time item was removed and when the scales were matched by stage or by duration. Munro classified a larger proportion of participants as moderate or high risk and had lower specificity at the evaluated thresholds. Prospective multicentre validation, with a sample sized for the comparison of predictive performance, is required before one scale can be recommended over the other for routine use.

Abbreviations

ASA

American Society of Anesthesiologists

AUC

area under the receiver operating characteristic curve

BMI

body mass index

CI

confidence interval

CORN

the intraoperatively acquired pressure injury risk assessment scale of the Chinese Nursing Association
Operating Room Nursing Committee

IAP

intraoperatively acquired pressure injury

NPUAP

National Pressure Ulcer Advisory Panel

NPV

negative predictive value

PPV

positive predictive value

ROC

receiver operating characteristic

SD

standard deviation

STROBE

Strengthening the Reporting of Observational Studies in Epidemiology

TRIPOD

Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis.

Declarations

Clinical trial number. Not applicable.

Authors' contributions. Y.H. conceived and designed the study, collected and analysed the data and drafted the manuscript. J.D. carried out data cleaning and curation. C.T. contributed to the study design, data collection and analysis and critically revised the manuscript. All authors read and approved the final manuscript.

Use of generative artificial intelligence. A large language model (Claude, Anthropic) was used to assist with drafting and language editing of the manuscript, with reformatting of the analysis into R and with preparation of the figures. The study design, data collection, interpretation of the results and all scientific content are the responsibility of the authors, who reviewed and verified the statistical output and take full responsibility for the integrity of the work. The tool is not listed as an author.

Ethics approval and consent to participate.

The study was approved by the Medical Ethics Committee of The University of Hong Kong–Shenzhen Hospital under its expedited review procedure (protocol no. hkuszh2024103; approval dated 26 April 2024) and was conducted in accordance with the Declaration of Helsinki. A waiver of informed consent was submitted with the application and was among the documents approved by the committee.

Consent for publication.

Not applicable.

Competing interests.

The authors declare that they have no competing interests.

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Not applicable.

Data Availability

All data supporting the findings of this study are available within the paper and its Supplementary Information. The de-identified patient-level analysis dataset (analysis_dataset.csv), the de-identified participant and operative characteristics (baseline_dataset.csv), the complete analysis script with its output log (analysis.zip), and the figure-generation scripts (figures.zip) are provided as Supplementary Information. Together these reproduce the incidence estimate, the score and risk-grade comparisons, all receiver operating characteristic analyses including the paired DeLong comparisons and the sensitivity analyses, the internal-consistency coefficients, the observed incidence by risk grade, Table 1 and Figs. 1–3. The raw ratings from the separate 13-patient inter-rater reliability pretest, and the nurse characteristics in Table 2, were extracted from source records and are not included; these are available from the corresponding author on reasonable request.

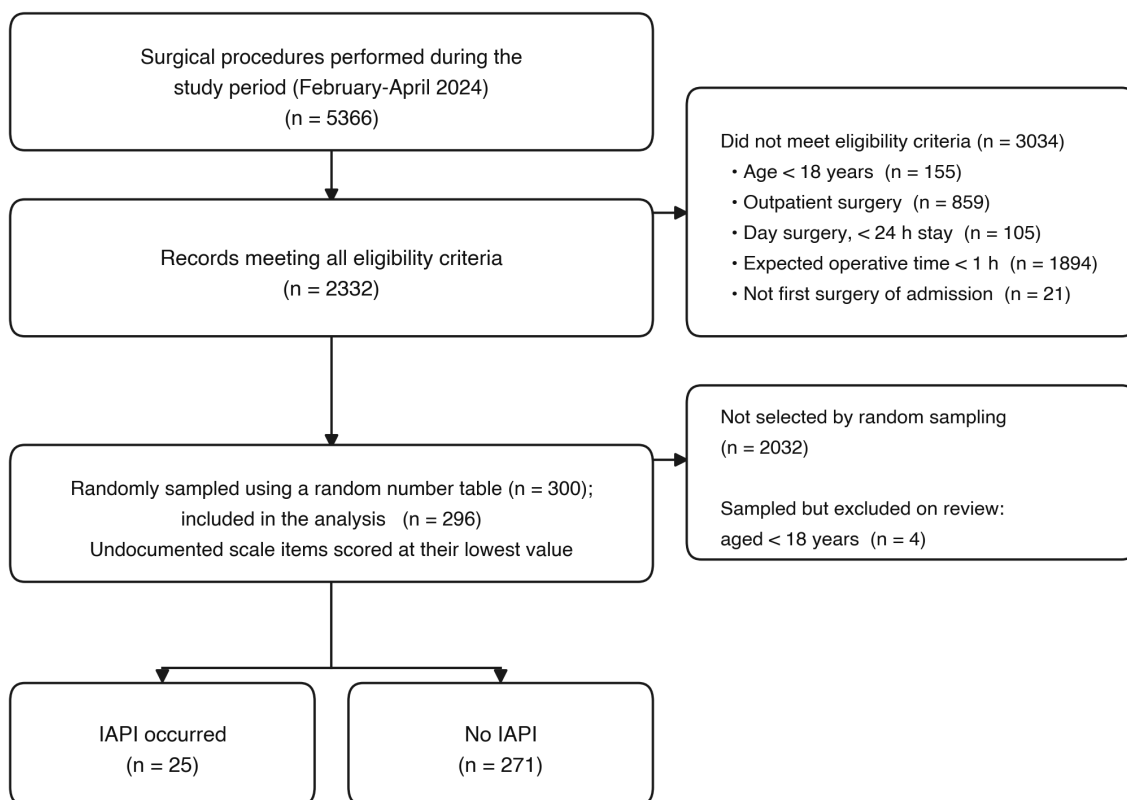
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Figures



Cross-classification of scale results against the outcome

CORN, preoperative (cut-off 8.5)			Munro, preoperative (cut-off 7.5)		
	IAPI	No IAPI		IAPI	No IAPI
Scale positive	24	79	Scale positive	23	165
Scale negative	1	192	Scale negative	2	106
sens 96% spec 70.8%			sens 92% spec 39.1%		

CORN, intraoperative (cut-off 7.5)			Munro, intraoperative (cut-off 22.5)		
	IAPI	No IAPI		IAPI	No IAPI
Scale positive	22	25	Scale positive	23	88
Scale negative	3	246	Scale negative	2	183
sens 88% spec 90.8%			sens 92% spec 67.5%		

Cut-offs are the in-sample Youden-optimal thresholds and were not pre-specified. IAPI, intraoperatively acquired pressure injury.

Figure 1

Participant flow and cross-classification of scale results against the outcome.

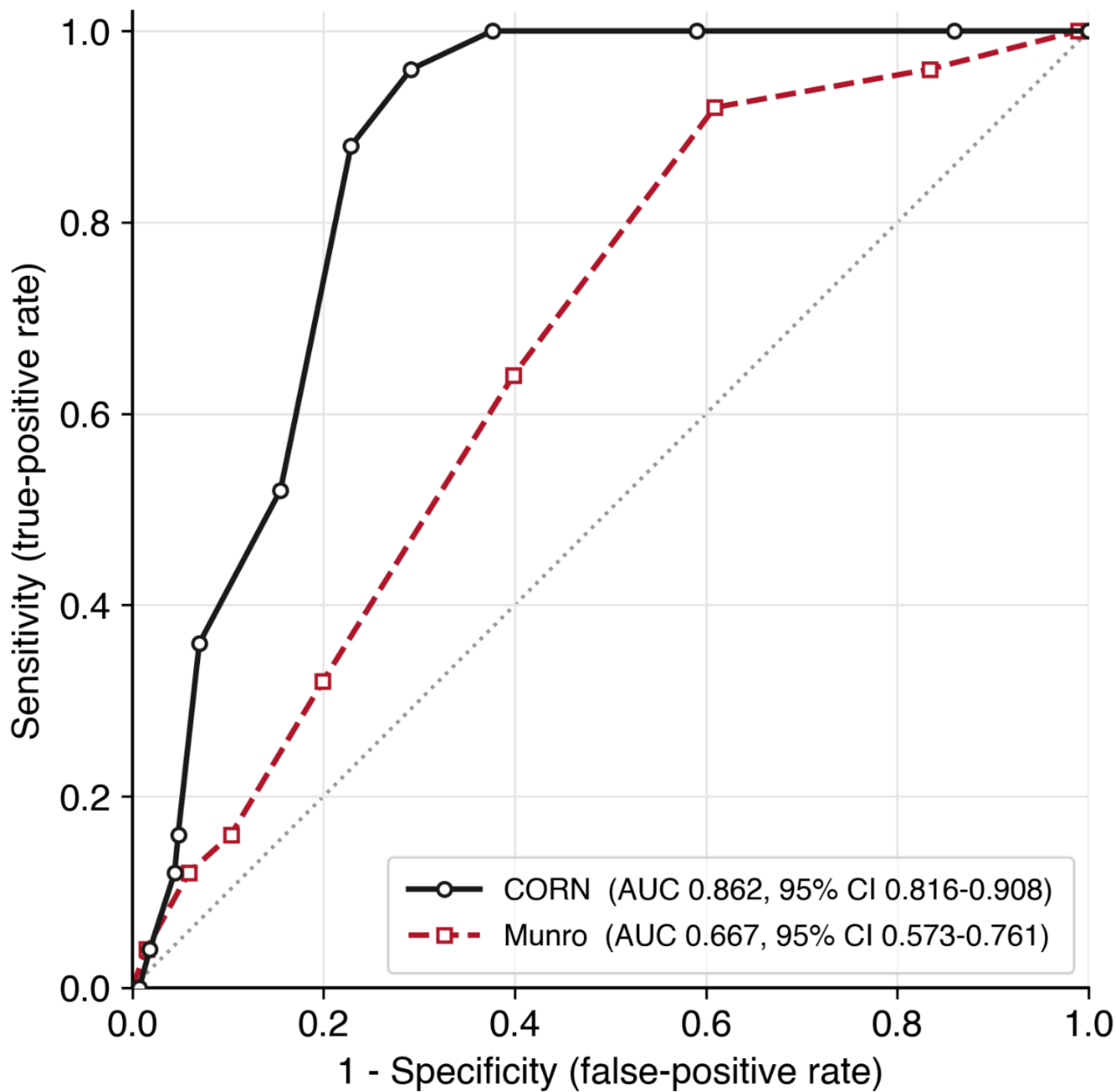


Figure 2

Preoperative ROC curves of the CORN and Munro scales for IAPI prediction.

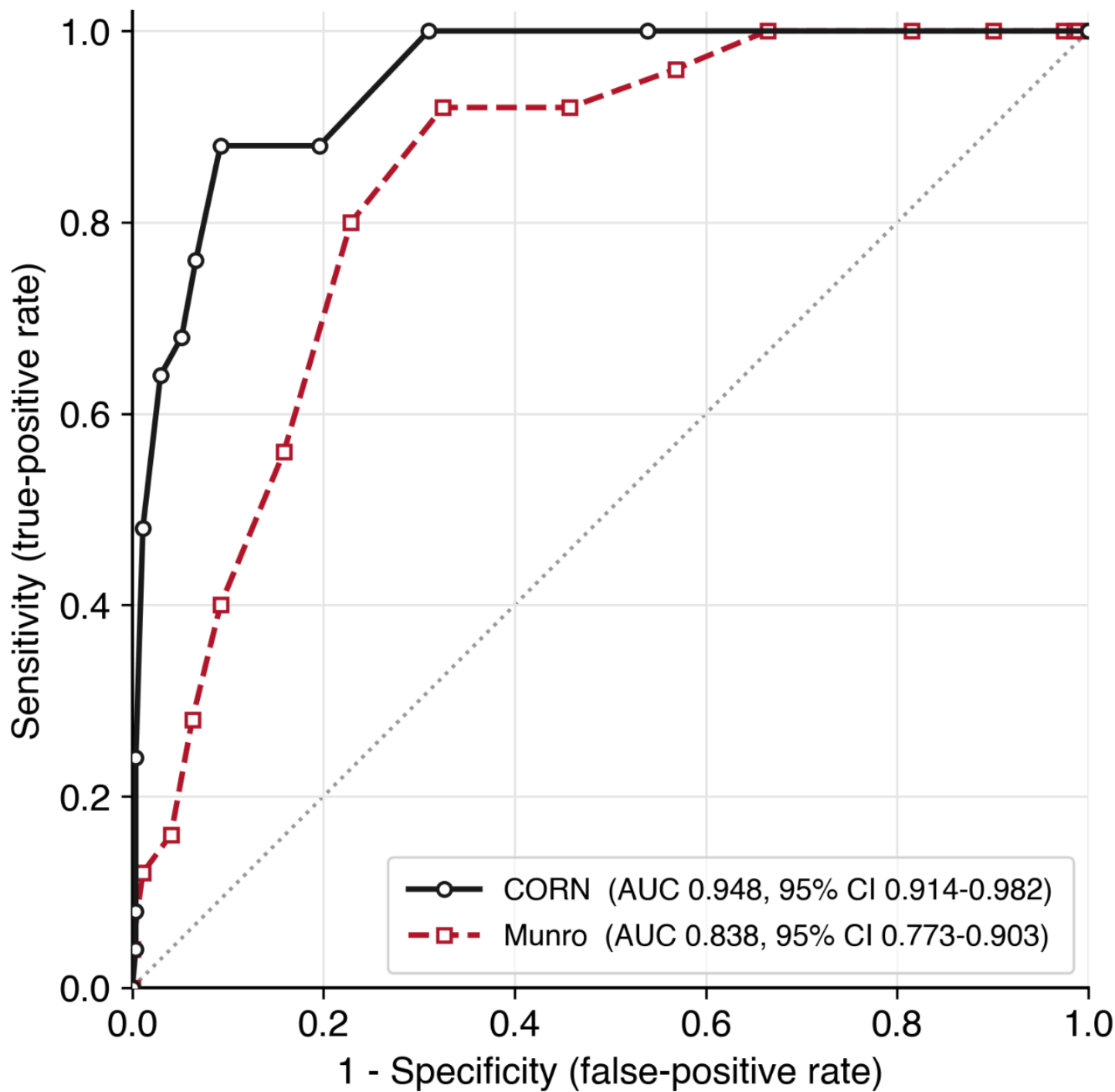


Figure 3

Intraoperative ROC curves of the CORN and Munro scales for IAPI prediction.

Supplementary Files

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