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Evaluation of a Pressure Injury Prevention Bundle in an Australian Intensive Care Unit: A Before and After Study

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ABSTRACT

Background: Recent studies indicate that the incidence of pressure injury (PI) in intensive care is significant. Multiple intensive care-specific PI risk assessment tools are available, but only the COMHON Index has been bundled with preventative interventions based on assessed risk level.

Aims: Evaluate the effectiveness of the COMHON Index intervention bundle to reduce PI in an Australian intensive care unit (ICU) and to assess compliance with bundle implementation.

Study Design: Before and after study including all patients admitted to a general ICU during the study period (3-month before/after-phases, 2-month wash-out). Standard care in the before-phase comprised the Braden Scale and interventions selected with clinical judgement. In the after-phase, the COMHON Index and its risk-stratified intervention bundle were implemented. The primary outcome was PI incidence.

Results: PI incidence reduced from 4.9% in the before-phase (sample $n = 296$) to 3.9% in the after-phase (sample $n = 295$), resulting in a 21% relative risk reduction. Three significant factors associated with PI development were identified using logistic regression: intensive care length of stay (odds ratio [OR] 1.2), high-risk cases (OR 4.5) and male gender (OR 3.9). In the after-phase, overall bundle compliance was good (81%) but all-or-nothing compliance was poor (30%) although individual intervention compliance varied (range 53%–100%).

Conclusions: Implementation of the COMHON index risk-stratified bundle resulted in a small reduction in PI incidence. However, compliance with some interventions was poor, especially repositioning frequency. The relationship between intervention and bundle compliance and PI outcomes requires further research.

Relevance for Clinical Practice: The results suggest that the use of the COMHON Index intervention bundle may be beneficial to prevent PI in ICU patients. Further research is needed to examine its effectiveness, while controlling for bundle compliance. Future efforts of translation into clinical practice should be underpinned by a relevant implementation framework to enhance local contextualisation and bundle adherence.

Impact Statements

- What is known about the topic
  - Pressure injury is an ongoing challenge within intensive care, with significant consequences for patients, and prevention is a fundamental component of nursing care.
  - Pressure injury prevention is underpinned by a risk assessment, which should then guide the implementation of preventative interventions.
  - The COMHON Index is an intensive care-specific pressure injury risk assessment tool which has been bundled with a set of preventative interventions for implementation relative to assessed risk, but it requires testing in different international contexts to confirm its effectiveness.
- What this paper adds
  - This study suggests the implementation of the COMHON Index bundle is beneficial for preventing pressure injury within intensive care.
  - Further benefits may be observed with improved bundle compliance, particularly for patients at high risk of developing pressure injury.
  - Future implementation into clinical practice should be supported by motivational methods and relevant frameworks.

1 | Introduction

Hospital-acquired pressure injury (PI) is a patient safety priority [1, 2], with preventative measures widely available and international recommendations and good practice statements guiding their use [3]. Individuals admitted to intensive care units (ICUs) are particularly vulnerable to PI [4, 5] due to risk factors associated with their critical illness, including immobility, impaired perfusion, and vasopressor and mechanical ventilation use [6, 7]. Subsequently, PI prevention within ICU is crucial. The first step of PI prevention is risk assessment to identify individual risk and inform preventative intervention use [8]. One approach commonly practiced, in aid of clinical judgement, is use of a risk assessment tool. However, many tools often used in ICU (e.g., Braden Scale, Waterlow Score, Norton Scale) were not designed for ICU. Consequently, they do not account for ICU-specific PI risk factors [9] and may not detect varying levels of risk within this highly vulnerable group [10]. More recently this has been recognised, and more ICU-specific tools have emerged [11, 12] (e.g., CALCULATE, COMHON Index, EVARUCI scale, RAPS-ICU). However, risk assessment alone does not prevent PI; it must inform the implementation of preventative interventions [8].

2 | Background

Only one ICU-specific risk assessment tool (COMHON Index) has been aligned with the use of preventative interventions [13]. The COMHON Index assesses ICU-specific PI risk factors: Consciousness [14], Mobility, Haemodynamics, Oxygenation and Nutrition [15, 16]. These factors are scored and summed, with the summation categorising risk as low, moderate or high. During initial development and testing in Spain, the COMHON Index demonstrated promising psychometric properties [15]. It has since been translated into English (version 1), Chinese Mandarin and Turkish (version 2.1) and has demonstrated excellent interrater reliability in all languages [9, 17, 18]. In an Australian ICU, the COMHON Index interrater reliability was superior to three non-ICU-specific risk assessment scores (Braden, Norton and Waterlow) and was more sensitive in identifying changes in an individual's condition [9]. These results were also replicated in a Chinese ICU in a comparison between the COMHON Index and Braden Scale [17].

The COMHON Index has also been combined with a 'minimum PI preventative intervention set' in a prevention care bundle, which guides the selection of preventative interventions based on assessed risk [13] (Appendix A). The bundle ensures that, *at a minimum*, appropriate preventative interventions are implemented relative to an individual's assessed PI risk. The selected interventions can then be adjusted based on individual need. Recently, the COMHON Index has been implemented alongside the risk-stratified bundle in Spain, demonstrating a clinically significant reduction in PI incidence [19]. However, there is a need for further studies to test the bundle's effectiveness to reduce PI in different ICU contexts to support generalisability and to inform policy and practice locally and more broadly.

3 | Aims

This study aimed to evaluate the effectiveness of the COMHON Index intervention bundle to reduce PI in an Australian ICU. The secondary aim was to assess compliance with the implementation of the COMHON Index bundle.

4 | Design and Methods

A before-after study was conducted to address the aim. As the bundle was not designed to prevent device-related PIs, the primary outcome was ICU-acquired non-device-related PI; for simplicity, hereafter referred to as PI.

4.1 | Setting and Sample

The setting was a 16-bed Australian general ICU, with ICU and high dependency unit patients, from a range of specialties, including general medicine, surgery, cardiothoracic, neurosurgery and burns. All patients admitted to the ICU during the before- and after-phases were included; those present at the start of either phase but admitted prior to the start of data collection were excluded.

4.2 | Data Collection Tools and Methods

From June 2022 to February 2023, before- and after-phases were 3 months' duration, separated by a 2-month washout.

4.2.1 | Before-Phase: Standard Practice

During the before-phase, standard PI prevention practice was provided for all patients. Standard PI prevention practice was to assess PI risk using the Braden Scale and to implement preventative measures according to nurses' clinical judgement, guided by national standards [20], and a locally developed ICU PI prevention roadmap, which specified daily skin inspection and use of the SSKIN care bundle [21]. Heel PI prevention was guided by an algorithm [22]. Reactive and active support surface mattresses were available for all beds and usual repositioning frequency was 2–3 h unless clinically unstable. Prophylactic sacral and heel dressings, and heel-lift suspension boots were available for all patients at clinical discretion.

4.2.2 | Wash-Out: Education

In the wash-out, education sessions were conducted to prepare nursing staff for the following phase. No data were collected during this period. Education comprised face-to-face teaching during in-service time, allowing active engagement and questions from staff. Potential barriers to bundle adherence were discussed and solutions put forward. The education presentation was also uploaded onto the unit's online education platform for those working night shifts. Staff who did not receive the education during in-service time or online were captured during clinical time and provided with face-to-face teaching on an individual basis.

4.2.3 | After-Phase: Intervention

In the after-phase, the intervention (COMHON Index bundle) was implemented for all patients. The intervention was a risk-stratified bundle of evidence-based interventions [23] that were agreed via international consensus for each risk level [13]. The bundle mandates the frequency of risk assessment using the COMHON Index and indicates a minimum intervention set for each risk level (Appendix A). Interventions may be individualised based on patient need, with variations including exclusion of contra-indicated interventions and additional interventions implemented based on nurses' judgement. To support implementation, intervention resources (e.g., prophylactic dressings) were stocked within the department for use; staff were able to approach investigators with questions during daily rounds and additional education was performed *ad hoc*; an educational resource was available on the department's education website; laminated hard copies of the COMHON Index were attached to each bedspace desk where documentation was completed to prompt use and the COMHON Index risk assessment and bundle tool (Appendix A) were incorporated into the unit's medical record observation charts and daily safety checklist to ensure assessment and intervention compliance documentation.

4.2.4 | Data Collection

Demographic data were collected on ICU admission. Project nurses reviewed the chart of each patient twice weekly to identify and/or verify any ICU-acquired PI. Follow-up continued to the first occurring endpoint: 30 days, ICU discharge, death or last day of data collection period. Patient readmissions to the ICU were recorded as a new case (i.e., a new care episode). In the after-phase, project nurses also monitored compliance with the COMHON Index bundle twice weekly. Project nurses followed up on the stage of identified ICU-acquired PI during chart reviews until study exit. Time to PI was time to initial development and identification, regardless of stage. The most severe stage of identified PI was the final outcome.

4.3 | Data Analysis

Episodes of ICU care (i.e., cases) were the analysis unit. Length of stay (days) was calculated from ICU admission and discharge dates/times. If a patient was discharged after the end of a phase, their ICU discharge date was modified according to their partial length-of-stay. As the maximum follow-up was 30 days, ICU length of stay of cases discharged after 30 days was adjusted to reflect this value. PI occurring beyond these times was not included.

Baseline characteristics are described using mean (M) with standard deviation (SD) for scale and proportions (%) for categorical variables. Differences were analysed using *t*-tests for scale and Fisher's exact or chi-squared tests for categorical variables. Differences in risk level were not analysed statistically because it cannot be assumed that Braden Scale and COMHON Index levels are equivalent. Mobility level on admission to ICU was assessed on a scale of 1–5 (1 = unable to change position; 2 = very limited; 3 = limited to bed, chair; 4 = assisted walking; 5 = independent). For baseline comparison, mobility was recoded into a dichotomous variable [immobile (categories 1–3) or mobile (categories 4–5)]. PI incidence [(numerator = number of episodes with ICU-acquired PI/denominator = total number of ICU episodes) × 100%] was calculated for each phase and analysed using Fisher's exact test. Risk ratios were calculated to compare the risk [24].

Direct logistic regression (forced-entry) determined predictive factors for ICU-acquired PI. The area under the receiver operating characteristic curve summarised the overall accuracy of the risk assessment admission scores and was compared between phases, with optimal cut-off scores determined with Youden's index. Risk assessment tool performance was summarised using sensitivity, specificity and positive and negative predictive values.

In the after-phase, intervention compliance rates (individual, overall bundle, 'all-or-nothing') were analysed for each risk level and overall. All-or-nothing compliance indicated whether all interventions required for each risk level were implemented (or not). Differences in all-or-nothing compliance between risk levels were analysed using the chi-squared test, and differences in overall compliance were analysed using one-way analysis of variance (ANOVA). Compliance with individual interventions was assessed using proportions, with differences analysed using chi-squared or Fisher's exact tests. The intervention was assessed as being compliant where contraindicated, deemed not applicable or an alternative intervention was used.

4.4 | Ethical and Institutional Approvals

Formal ethics approval was received from The Prince Charles Hospital Human Research Ethics Committee (reference: HREC/2022/QPCH/83555, 13 January 2022) and the Research Integrity and Ethics Unit, University of Tasmania (reference: 25050, 8 September 2021). A waiver of patient consent was approved. Access to re-identifiable patient data by on-site researchers was approved for the duration of the study by the Health Information Management Services, Tasmanian Health Service. All patient data were de-identified prior to data analysis.

5 | Results

5.1 | Sample Characteristics

There were 330 before-phase cases and 349 after-phase cases, of which 46 (13.9%) before-phase and 67 (19.2%) after-phase cases were lost to follow-up ($p = 0.079$), giving final samples of 284 and 282, respectively. The characteristics were similar (Table 1), except for a larger proportion of cases in the after group with a previous history of PI (17.2% vs 3.0%, $p < 0.001$). This information was unknown in a large proportion of cases (Table 1). There were 15 present-on-admission PIs (range 1–2) in 14 before-phase cases and 17 present-on-admission PIs (range 1–6) in 8 after-phase cases.

5.2 | ICU-Acquired Pressure Injury

Incidence of ICU-acquired PI in the before-phase was 4.9% ($n = 14$) compared to 3.9% ($n = 11$) in the after-phase ($p = 0.683$), giving a relative risk reduction of 20.9%.

In the before-phase, cases developing a PI had significantly lower Braden scores (lower score = higher risk), were more likely to have a PI present-on-admission and had longer ICU length of stay. In the after-phase, cases that developed PI were mostly male, had higher COMHON Index scores (higher score = greater risk), higher APACHE II scores and had longer ICU length of stay. There were no statistically significant differences in cases that developed PI between the phases (Table 2).

Fourteen cases developed 22 PIs in the before-phase and 11 cases developed 16 PIs in the after-phase (Table 3). The median time to PI in the before group was 5.5 days (interquartile range [IQR] 1–9.25, range 1–14) compared to 7 days (IQR 2.25–13.5, range 1–15) in the after group ($p = 0.191$).

Based on the before and after differences shown in Table 2, a predictive model containing two scale (APACHE II score, ICU length of stay) and three categorical (gender, high PI risk, before-/after-phase) predictor variables was tested. Collinearity between the variables was first checked, with variables displaying collinearity tolerances of between 0.85 and 0.99. The full model was statistically significant [χ^2 (5, $n = 566$) = 73.87, $p \leq 0.001$] and explained between 12.2% (Cox and Snell R^2) and 40.30% (Nagelkerke R^2) of the variance in PI incidence, and correctly classified 95.6% of cases. Three variables made a unique statistically significant contribution to the model. The strongest predictor of PI was ICU length of stay: for each additional day in ICU, patients were 1.2 times more likely to develop an ICU-acquired PI (odds ratio [OR] 1.20, 95% confidence interval [CI] 1.14–1.27; $p < 0.001$). Patients at high risk of PI were 4.5 times more likely than others to develop a PI (OR 4.50, 95% CI 1.31–15.4; $p = 0.017$), and males were 3.9 times more likely to develop a PI (OR 3.86, 95% CI 1.22–12.22; $p = 0.022$).

TABLE 1 | Baseline sample characteristics.

	Before $n = 284$	After $n = 282$	Significance p
Age in years, mean (SD)	60.2 (17.4)	60.0 (18.0)	0.928[1]
Gender: male % (*n*)	55.3 (157)	58.2 (164)	0.490[2]
Body mass index, mean (SD) *n*	30.4 (9.1)	29.9 (9.2)	0.532[1]
Previous history of pressure injury (%)[a] *n*	3.0 (5/164)	17.0 (30/176)	< 0.001[3]
Pressure injury present on admission (%) *n*	4.9 (14)	2.8 (8)	0.277[3]
Mobility: immobile (%) *n*	90.5 (257)	90.1 (254)	0.888[1]
Braden Scale admission score, mean (SD)	13.8 (3.3)	—	—
COMHON Index admission score, mean (SD)	—	12.5 (4.7)	—
At high-risk of pressure injury on admission (%) *n*	44.0 (125)	39.7 (112)	0.308[1]
APACHE II admission score, mean (SD) *n*	14.6 (6.4)	14.9 (6.1)	0.508[2]
APACHE II admission score, mean (SD) *n*	50.8 (21.6)	51.3 (21.7)	0.755[2]
SOFA admission score, mean (SD) *n*	7.7 (4.0)	8.1 (3.6)	0.233[2]
Intensive care length of stay (days), mean (SD) *n*	4.1 (4.8)	4.6 (5.4)	0.254[1]
Mortality (%) *n*	9.9 (28)	14.2 (40)	0.122[3]

[1]*t*-test.
[2]Chi-squared test.
[3]Fisher's exact test.
[a]Missing $n = 226$.

TABLE 2 | Intensive care–acquired pressure injuries.

		No pressure injury before $n = 270$ after $n = 271$	Pressure injury before$n = 14$ after $n = 11$	Significance p
Mean age in years (SD) *n*	Before	60.5 (17.4)	54.3 (17.0)	0.195[1]
	After	60.0 (18.1)	61.3 (15.2)	0.816[1]
Male gender % (*n*)	Before	54.4 (147)	71.4 (10)	0.275[2]
	After	56.8 (154)	90.9 (10)	0.027[2]
Pressure injury present on admission % (*n*)	Before	4.4 (12)	14.3 (2)	0.146[2]
	After	2.6 (7)	9.1 (1)	0.276[2]
Mean body mass index (SD) *n*	Before	30.5 (9.0)	28.5 (9.4)	0.436[1]
	After	29.9 (9.3)	28.4 (7.3)	0.577[1]
Mean APACHE II admission score (SD) *n*	Before	14.5 (6.5)	16.5 (5.1)	0.257[1]
	After	14.8 (6.1)	18.2 (4.8)	0.070[1]
Mean APACHE III admission score (SD) *n*	Before	50.6 (21.9)	53.6 (14.5)	0.618[1]
	After	51.2 (21.9)	55.9 (17.4)	0.477[1]
Mean SOFA admission score (SD) *n*	Before	7.8 (4.0) 282	8.5 (3.2) 1	0.501[1]
	After	8.1 (3.6)	7.8 (3.3)	0.790[1]
Mean Braden Scale admission score (SD) *n*	Before	10.9 (1.5)	10.9 (1.5)	< 0.001[1]
Mean COMHON Index admission score (SD) *n*	After	12.4 (4.7)	15.7 (3.8)	0.020[1]
At high-risk of pressure injury *n* (%)	Before	41.5 (112)	92.9 (13)	< 0.001[2]
	After	38.4 (104)	72.7 (8)	0.029[2]
Intensive care length of stay mean days (SD) *n*	Before	3.5 (3.5)	16.3 (9.0)	< 0.001[1]
	After	4.2 (4.9)	14.1 (9.1)	0.005[1]
Mortality % (*n*)	Before	9.6 (26)	14.3 (2)	0.636[2]
	After	13.3 (36)	36.4 (4)	0.055[2]

[1]*t*-test.
[2]Fisher's exact test.

5.3 | Sensitivity and Specificity

In the before-phase (Braden Scale), the area under the curve was fair (78.5%, 95% CI 69.9–87.2) and was also fair in the after-phase using the COMHON Index (70.9%, 95% CI 58.8–83.0). Using Braden admission scores, the optimal cut-off score to predict PI was ≤12, giving a sensitivity of 92.9% and a specificity of 58.5%. Using COMHON Index admission scores, the optimal cut-off score was ≥15, giving 72.7% sensitivity and 64.6% specificity. In the before-phase, the risk of developing a PI with a Braden score of ≤12 was 2.2 times greater than those with higher scores. In the after-phase, the risk associated with a COMHON Index score ≥15 was 2.0 times greater than those with lower scores. Overall predictive accuracy of the COMHON Index was slightly better (65%) than that of the Braden Scale (60%) (Table 4).

5.4 | Compliance With Interventions (After-Phase Only)

During the after-phase, following admission, a further 558 risk assessments were made. The largest proportion was low risk (42.7%, $n = 238$), followed by high risk (36.7%, $n = 205$) and moderate -risk (20.6%, $n = 115$).

Across all cases, all-or-nothing compliance was low (30.1%; Table 5). It was significantly lower in low-risk cases than in moderate-risk and high-risk cases ($p < 0.001$). Although overall (mean) compliance for each risk level was reasonable, it was significantly lower in the moderate-risk cases than in both low-risk ($p < 0.001$) and high-risk cases ($p < 0.001$).

For individual interventions by risk level (Table 5), compared to other interventions, compliance with 8-h risk assessment and repositioning frequency was relatively low (53.2% and 54.8%, respectively). Compliance with 2-h repositioning of moderate-risk (28.7%) and high-risk (19.5%) cases was very low and significantly lower than 4-h repositioning compliance of low-risk cases (97.9%, $p < 0.001$).

For 11 patients developing PIs (Table 6), intervention compliance is shown based on the most recent assessment of risk prior to identification of PI. In most cases (73%), the patients were assessed as high-risk. In only two patients were all interventions complied with according to risk level.

TABLE 3 | Characteristics of intensive care–acquired pressure injuries.

	Pressure injury stage	Site of pressure injury												
		Sacrum	Buttock	Coccyx	Natal cleft	Ankle	Heel	Foot	Elbow	Occiput	Scapula	Hip	Thigh	Finger	Total
Before	Stage 1	2	1		1			2	4		1	2		1	14
	Stage 2	1	1	1		1			1	1			1		7
	Unstageable						1								1
	TOTAL	3	2	1	1	1	1	2	5	1	1	2	1	1	22
After	Stage 1	2	2		2	1	3			1					11
	Stage 2	3	1												4
	Stage 3	1													1
	Total	6	3	0	2	1	3	0	0	1	0	0	0	0	16

TABLE 4 | Diagnostic performance of the Braden Scale and COMHON Index.

	Braden Scale	COMHON Index
Admission cut-off score	≤12	≥15
Sensitivity % (95% CI)	92.9 (66.1–99.8)	72.7 (39.0–94.0)
Specificity % (95% CI)	58.5 (52.4–64.5)	64.6 (58.6–70.3)
Positive predictive value % (95% CI)	10.4 (8.7–12.5)	7.7 (5.3–11.0)
Negative predictive value % (95% CI)	99.4 (96.0–99.9)	98.3 (95.7–99.4)
Positive likelihood ratio (95% CI)	2.24 (1.83–2.74)	2.05 (1.38–3.05)
Negative likelihood ratio (95% CI)	0.12 (0.02–0.81)	0.42 (0.16–1.11)
Accuracy % (95% CI)	60.2 (54.3–66.0)	64.9 (59.0–70.5)

Abbreviation: CI, confidence interval.

6 | Discussion

This study found a clinically significant reduction in PI incidence with the use of the COMHON Index bundle. While the significance was not statistical and the absolute reduction in PI incidence was small, baseline incidence was only 4.9%. Arguably, when initial incidence is low, it is more challenging to make significant reductions. Nevertheless, despite some relatively poor intervention compliance rates, there was a 21% relative risk reduction of PI in the after-phase, down to 3.9%. Coupled with the low rates of compliance with preventative interventions, these results suggest potential to enhance outcomes significantly should intervention adherence be improved.

Overall bundle compliance was very good (81%) and ranged from 73% to 85% by risk level. This compares favourably to other studies where overall bundle compliance has been reported between 55% and 79% [25–27], while we found no studies that have reported all-or-nothing compliance. In our study, all-or-nothing bundle compliance was notably lower (30%; range 8%–55%), with compliance falling dramatically as risk level increased. Of course, as risk level increases more interventions are required; thus, there is greater potential for non-compliance. Yet it remains concerning that patients at greatest risk of PI did not receive all of the required interventions. Similar results have been reported in other studies where interventions have been examined relative to PI risk level in the acute setting [8, 28]. Future studies and efforts to translate bundles into clinical practice should be underpinned by an implementation framework [29, 30], which may improve poor adherence.

There was particularly low compliance with 2-h repositioning frequency for moderate- and high-risk patients; less than one in five cases were compliant and a quarter were repositioned 4 h or more. The reasons for this are unclear but signal a cultural shift

TABLE 5 | Compliance with interventions by risk level.

Risk level	Intervention	Intervention compliance % (*n*) Sample (*n*)	Low % (*n*)	Moderate % (*n*)	High % (*n*)	Total % (*n*)	Significance *p*	Comments
All patients on admission	Risk assessment within 2 h of ICU admission	282	75.0[a] (72/96)	67.6[a] (50/74)	71.4[a] (80/112)	71.6[a] (202/282)	0.566[1]	Based on risk level assessed at ICU admission
All patients	Risk assess every 8 h	558	55.9 (133/238)	56.5 (65/115)	48.3 (99/205)	53.2 (297/558)	0.204[1]	In 25 cases, assessments were made <8 h following ICU admission. With these cases excluded, compliance was 51.0% (272/533)
	Incontinence pads (if applicable)	558	100 (238/238)	100 (115/115)	100 (205/205)	100 (558/558)	—	There were no cases where continence pads were required. In 59 (10.6%) cases, the patient was continent. In 499 cases, where patients were incontinent, all were managed using indwelling urinary catheters and/or other devices.
	Low-risk: reposition at least 4 h Moderate/high-risk: reposition 2 h	558	97.9 (233/238)	28.7 (33/115)	19.5 (40/205)	54.8 (306/558)	<0.001[1]	54.6% ($n=130$) of low-risk cases, 13.9% ($n=16$) of moderate-risk cases and no high-risk cases were able to move independently (repositioning not required). 41.7% ($n=48$) of moderate-risk cases were repositioned 3 h; 28.7% ($n=33$) were repositioned 4 h or more. 60.0% ($n=123$) of high-risk cases were repositioned 3 h; 20.5% ($n=42$) were repositioned 4 h or more. Only 2 (0.8%) low-risk cases and 3 (2.6%) moderate-risk cases were considered too unstable to move, compared to 13 (6.3%) cases in the high-risk group.

(Continues)

TABLE 5 | (Continued)

Risk level	Intervention	Intervention compliance % (*n*)						Comments
		Sample (*n*)	Low % (*n*)	Moderate % (*n*)	High % (*n*)	Total % (*n*)	Significance *p*	
Moderate and high risk	Offload heels	320	X	81.7 (94/115)	95.1 (195/205)	90.3 (289/320)	<0.001[2]	A heel offloading device was deemed not applicable in 14.8% ($n=17$) of moderate-risk cases and five (2.4%) high-risk cases. The heels were also offloaded in 25.2% ($n=60$) of low-risk cases.
	Moderate-risk: reactive mattress High-risk: reactive or active mattress	320	X	100 (115/115)	100 (205/205)	100 (320/320)	—	In most cases, active support surfaces were provided (moderate risk: 81.7%, $n=94$; high risk: 90.2%, $n=185$).
High risk	Seat cushion	205	X	X	100 (205)	—	—	In only one high-risk case in which a seat cushion was deemed to be applicable it was implemented.
	Sacral dressing	205	X	X	94.6 (194)	—	—	Sacral dressings were deemed not applicable in only 2 (1.0%) high-risk cases. In 2 (1.0%) non-compliant cases, a dressing was not applied because there was no stock available. Sacral dressings were also applied in 60.0% ($n=69$) of moderate-risk cases and 31.5% ($n=75$) of low-risk cases.
	Heel dressing	205	X	X	88.8 (182)	—	—	Heel dressings were deemed not applicable, or an alternative method was used in 7 (3.4%) high-risk cases. In 2 (1.0%) non-compliant cases, a dressing was not applied because there was no stock available. Heel dressings were also applied in 48.7% ($n=56$) of moderate-risk cases and 24.4% ($n=58$) of low-risk cases.

(Continues)

TABLE 5 | (Continued)

Risk level	Intervention	Intervention compliance % (*n*)						Comments
		Sample (*n*)	Low % (*n*)	Moderate % (*n*)	High % (*n*)	Total % (*n*)	Significance *p*	
	Hip dressing	205	X	X	77.1 (158)	—	—	Hip dressings were deemed not applicable, or an alternative method was used in 11 (5.4%) high-risk cases. In 10 (4.9%) non-compliant cases, a dressing was not applied because there was no stock available. Hip dressings were also applied for 29.6% ($n = 34$) of moderate-risk cases and 8.8% ($n = 21$) of low-risk cases.
	Oral nutrition supplements	205	X	X	98.5 (202)	—	—	There were only three high-risk cases in which oral supplements were deemed applicable, but in all cases, they were not given. Oral supplements were also provided in one moderate-risk case and six low-risk cases.
Overall compliance mean % (SD, *n*)			84.6 (17.5, 238)	73.4 (16.9115)	82.2 (10.7, 205)	81.4 (15.8, 558)	< 0sss.001[3]	
All-or-nothing compliance % (*n*)			55.0 (131/238)	18.3 (21/115)	7.8 (16/205)	30.1 (168/558)	< 0.001[1]	

Note: X = not indicated.
[1]Chi-squared test.
[2]Fisher's exact test.
[3]ANOVA.
[a]Calculated using risk level on admission.

TABLE 6 | After phase: characteristics of pressure injury and compliance with interventions.

Patient ID	Risk level on admission	Pressure injury *n*	Pressure injury site (stage)	Time-to-pressure injury (days)	Most recent risk level	Intervention compliance	Comments
A332	High	3	Heel (S1)	6	High	90% (9/10)	• Not repositioned 2 h (frequency = 4 h) • Heels offloaded and heel dressings applied
			Heel (S1)	6			
			Ankle (S1)	6			
A344	High	1	Sacrum (S1)	1	High	90% (9/10)	• Not repositioned 2 h (frequency = 4 h) • Sacral dressing applied
A373	High	2	Buttock (S1)	15	High	80% (8/10)	• Not reassessed 8 h • Not repositioned 2 h (frequency = 3 h)
			Natal cleft (S1)	15			
A380	High	1	Sacrum (S2)	2	High	90% (9/10)	• Not repositioned 2 h (frequency = 5 h) • Sacral dressing applied
A390	High	2	Heel (S1)	8	High	90% (9/10)	• Not repositioned 2 h (frequency = 3 h) • Heels offloaded and heel dressings applied
			Buttock (S2)	11	High	80% (8/10)	• Not repositioned 2 h (frequency = 4 h) • Heel dressing not applied
A401	High	1	Sacrum (S2)	11	Moderate	60% (3/5)	• Not reassessed 8 h • Not repositioned 2 h (frequency = 4 h) • Sacral dressing applied, but not mandated
A423	Moderate	1	Natal cleft (S1)	1	Moderate	100% (5/5)	
A432	High	1	Sacrum (S2)	12	High	80% (8/10)	• Not reassessed 8 h • Not repositioned 2 h (frequency = 3 h) • Sacral dressing applied
A457	High	1	Sacrum (S1)	1	High	80% (8/10)	• Not reassessed 8 h • Not repositioned 2 h (frequency = 4 h) • Sacral dressing applied
A477	Moderate	2	Occiput (S1)	14	High	100% (10/10)	• Sacral dressing applied
			Sacrum (S3)	14			
A546	Moderate	1	Buttock (S1)	3	Moderate	80% (4/5)	• Not repositioned 2 h (frequency = 4 h)

Note: S1 = Stage 1, S2 = Stage 2, S3 = Stage 3.

around repositioning practice may be required. Time constraints related to workload, availability of orderlies for assistance and a lack of ceiling hoists in all rooms could have contributed to repositioning compliance. Other ICU bundles have specified 2-h [26, 27, 31–35] or 3-h turning [25, 36, 37], but compliance varies widely. Such variability is unsurprising given that the most effective repositioning frequency for PI prevention remains unclear [38].

Only one in two cases was risk-assessed at least 8 h. In the study ICU, one of the contributing factors may have been the standard 12-h shift pattern, with nurses being inclined to assess risk only once per shift. The status of critically ill patients can sometimes change quickly so, arguably, it is important that assessment frequency is sufficient to respond to patient condition changes. Emerging artificial intelligence and machine learning approaches to PI risk assessment have the potential to improve assessment accuracy, timeliness and inform tailoring of early preventative interventions [39–41]. Future research should incorporate the use of such technologies to support pragmatic and frequent PI risk assessment, with the outcome of risk assessment informing prevention, including facilitating COMHON Index assessment and individualisation of the associated bundle.

One of the interventions mandated for all patients with the COMHON Index bundle was the use of continence pads for incontinent patients. However, regardless of risk level, all patients were either continent or managed with other incontinence devices. Other care bundles have focused on the use of regular skin cleansing and/or the use of moisturising/barrier creams to prevent skin damage from incontinence [21, 25–27, 32, 33, 36, 37]. Similarly, the use of a pressure-redistributing seat cushion was never implemented as there were no cases when the patient was able to be sat out. In one other bundle, a seat cushion was advised for high-risk patients when sat out of bed [34]. Given the rarity of the clinical need to implement these two interventions, it may be worth considering their removal from the COMHON Index bundle.

In both phases, patients assessed as high risk were more likely to have developed a PI. The optimal cut-off score to predict PI using the Braden Scale was ≤ 12. This finding is consistent with a recent systematic review of the Braden Scale when used in ICU [12]. In the after-phase, the optimal cut-off score for the COMHON Index was ≥ 15. Other studies have reported cut-off scores for the COMHON Index ranging from ≥ 11 to ≥ 14 [24, 42–44], however, three derived optimal cut-off scores using moving averages [24, 42, 43]. Patients who developed a PI also had a significantly longer length of stay in ICU. Our regression analysis indicated that for each day in ICU, patients were 1.2 times more likely to develop a PI. The median length of stay in ICU before a PI developed was longer in the after-phase (7 days) than the before-phase (5.5 days). While this difference was not statistically significant, it is clinically significant. This finding is consistent with a similar before-after study using the COMHON Index bundle in a Spanish ICU [19], with median time to PI in the after-phase found to be 4 days longer. These findings may indicate a protective element associated with the use of the COMHON Index in different international contexts, which is of significance for future policy and practice globally.

7 | Limitations

These single-centre results should not be generalised and should be considered with those of other studies in different contexts. This study is limited by the low baseline PI incidence and the moderate sample size overall. The use of a before-after design is also a limitation, as other factors that may have influenced the main effect cannot be ruled out. Another important limitation is the relatively poor level of all-or-nothing compliance with some bundle interventions. In future implementation studies, it would be beneficial to focus on motivational methods with a framework to optimise compliance. The care bundle used in this study was not designed to reduce device-related PIs, and these were not included in the incidence data. Given the significant incidence of device-related PIs in ICU it would be beneficial to include evidence-based preventative interventions for these types of PI in future modifications of prevention bundles.

8 | Implications for Practice and Further Research

The development of PI in ICU is an ongoing challenge that carries significant impacts for patients. While PI prevention is a fundamental component of care to maintain patient safety, its application in practice is often lacking, with barriers to implementation including suboptimal nurses' knowledge and workload burdens. The COMHON Index bundle was proposed to address such barriers by providing a risk-stratified approach to intervention implementation to ensure patients receive a *minimum* set of interventions relative to their assessed risk level, which can then be individualised as needed, thus addressing gaps in care [13, 19]. This study indicates that the bundle is beneficial for preventing PI in ICU, even in the absence of full intervention compliance [19] and aligns with a similar study in a different international context [19]. While bundle compliance was suboptimal, anecdotally, the study ICU investigators reported staff enthusiasm for the bundle and local improvements in skin assessment compliance, intervention use and PI reporting following implementation, although we did not examine intervention use in the before-phase. On study completion, the COMHON Index bundle was adopted permanently and became standard practice. To support and sustain future intervention compliance, implementation requires a focused effort using motivational methods and relevant frameworks. Additional research is also required to investigate approaches to optimal implementation, and the relationship between bundle compliance and PI outcomes.

9 | Conclusion

While there was a beneficial clinical effect on the reduction of PI with bundle use, all-or-nothing compliance with bundle interventions was suboptimal. Greater compliance with interventions would have a significant impact that would potentially reduce PI incidence further. Future efforts for translation into clinical practice should be underpinned by a relevant implementation framework to enhance local contextualisation and compliance.

Author Contributions

Paul Fulbrook: conceptualization, formal analysis, investigation, methodology, project administration, writing – original draft, writing – review and editing, supervision. **Richard McAllister:** data curation, investigation, methodology, project administration, writing – review and editing. **Cindy Weatherburn:** data curation, investigation, project administration, writing – review and editing. **Ellen Burke:** data curation, investigation, project administration, writing – review and editing. **Josephine Lovegrove:** writing – original draft, conceptualization, investigation, methodology, project administration, writing – review and editing.

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Ethics Statement

Formal ethics approval was received from The Prince Charles Hospital Human Research Ethics Committee (reference: HREC/2022/QPCH/83555, 13 January 2022) and the Research Integrity and Ethics Unit, University of Tasmania (reference: 25050, 8 September 2021). A waiver of patient consent was approved. Access to re-identifiable patient data by on-site researchers was approved for the duration of the study by the Health Information Management Services, Tasmanian Health Service. All patient data were de-identified prior to data analysis.

Consent

A waiver of patient consent was approved by the ethics committee.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

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

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Appendix A

Interventions by Risk Level

Intervention	COMHON Index risk level		
	Low	Moderate	High
Following admission, pressure injury risk assessment should be completed within 2 h	✓	✓	✓
Patients should be reassessed for pressure injury risk once every 8 h	✓	✓	✓
For intensive care patients who are incontinent of urine and/or faeces, disposable adult incontinence pads should be used	✓	✓	✓
Intensive care patients should be repositioned at least	4 h	2 h	2 h
Pressure should be offloaded from the heels using a heel offloading device	X	✓	✓
Reactive mattress support surfaces should be used	X	✓	✓
Active mattress support surfaces should be used	X	X	✓
When an intensive care patient is sat out of bed, a pressure redistributing seat cushion should be used	X	X	✓
A preventative sacral dressing should be applied	X	X	✓
Preventative heel dressings should be applied	X	X	✓
Preventative trochanteric (hip) dressings should be applied	X	X	✓
For intensive care patients who are able to eat food orally, oral nutritional supplements should be provided in addition to standard nutrition	X	X	✓