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Systematic reviews with or without meta-analysis

Psychometric properties of the Braden scale to assess pressure injury risk in intensive care: A systematic review

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ABSTRACT

Objective: To analyse the psychometric properties of the Braden scale to assess pressure injury risk in adults in intensive care.
Design: A systematic review was conducted, with literature searches undertaken in five electronic databases. No date limits were applied. Selection, data extraction and risk of bias assessment were completed by two reviewers independently. A customised data extraction template was used, with risk of bias conducted using the COSMIN Risk of Bias checklist. Data were analysed using narrative synthesis.
Results: Thirty-four studies met inclusion criteria. Two studies reported internal consistency with Cronbach's alpha ranging from poor (0.43) to good (0.85). For interrater reliability, only four studies reported intraclass correlation, ranging from 0.66 to 0.96 for Braden sum score. Three studies reported convergent validity, with strong associations found between the COMHON Index ($r = 0.70$), Cubbin-Jackson scale ($r = 0.80$), and Norton scale ($r = 0.77$), but contrasting associations with the Waterlow score ($r = 0.22$ to 0.72). A large majority of studies reported predictive validity ($n = 29$), with wide variability. Several studies investigated optimal cut-off scores, with the majority indicating this was in the range of 12–14.
Conclusions: This review demonstrates inconsistency in the psychometric properties of the Braden scale in ICU settings. Further research is needed to determine suitability of the Braden scale for ICU before it can be recommended as standard for clinical practice, including comparison with other ICU-specific risk assessment tools.
Implications for clinical practice: When used in ICU, the reliability, validity and reported cut-off scores of the Braden scale are variable. As a predictive tool, the scale should be used cautiously. In ICU, the value of the Braden scale resides in its ability to identify patients that are most at risk of developing a pressure injury and to implement preventative measures to mitigate identified risk factors.

Introduction

Pressure injuries (PI) are localised wounds to skin and underlying tissue from a combination of pressure, friction and shear due to contact with a support surface or medical device (Gefen et al., 2022). PI development can be attributed to iatrogenic causes (Alderden et al., 2017; Cox et al., 2020), intrinsic risk factors such as gender, frailty or cognition (Al Aboud & Manna, 2023), and even intensive care unit (ICU) admission (Wang et al., 2024). Pressure injuries can prolong length of stay (Graves et al., 2023), decrease quality of life (Burston et al., 2022), increase morbidity (Jackson et al., 2018) and mortality (Song et al., 2019). Critically ill patients are at increased risk due to illness severity (Rao et al., 2016; Weber et al., 2021), immobility (Alderden et al., 2017; Rao et al., 2016), haemodynamic instability, iatrogenic factors such as ventilation (Lima Serrano et al., 2017; Rao et al., 2016), vasopressor agents (Cox, 2013;Cox et al., 2022; McEvoy et al., 2022) and medical devices (Fu et al., 2023; Weber et al., 2021).

Pressure injury is preventable using evidence-based multidisciplinary approaches to risk assessment (Samuriwo, 2012), yet still develops frequently in ICU patients (Sun et al., 2023) with around four-fold higher rates than non-ICU patients (Fulbrook et al., 2023). Internationally, cumulative incidence in ICU patients was reported between 3.0 % and 34.4 % (Chaboyer et al., 2018). In a recent 90-country study, ICU-acquired prevalence was 16.2 %, and was independently associated with

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lower Braden scores (Labeau et al., 2021). In sub-set analyses of this study, ICU-acquired prevalence was reported as 9.7 % in Australia (Coyer et al., 2022), 8.8 % in the United Kingdom (Rubulotta et al., 2022), and 4.3 % in China (Lin et al., 2022).

The European Pressure Ulcer Advisory Panel, National Pressure Injury Advisory Panel and Pan Pacific Pressure Injury Alliance (EPUAP, NPIAP & PPPIA, 2019) guideline recommends use of structured risk assessment supported by clinical judgement to assess risk. Although around forty PI risk assessment tools are available (Moore & Patton, 2019), none are considered 'gold standard' (Hultin et al., 2022; Moore & Patton, 2019). There is a paucity of quality evidence attesting the efficacy of structured PI risk assessment tools compared to nurses' use of clinical judgement, further limiting clarity as to which method of risk assessment is most effective (Lovegrove et al., 2023). A recent systematic review of the diagnostic accuracy of PI risk assessment scales within ICU, reported the Braden scale as the most frequently used, however the authors concluded that it was not the best tool for this setting (Zhang et al., 2021). Originally, it was developed for use in long-term care settings and subsequent testing in a diversity of settings and multiple countries demonstrates conflicting results in validity and reliability (Chen et al., 2017; Huang et al., 2021; Šateková et al., 2017; Wei et al., 2020). Thus, the aim of this systematic review was to analyse existing literature to determine the psychometric properties of the Braden scale when used in ICU.

Methods

Design

The systematic review protocol was registered *a priori* with the International Prospective Register of Systematic Reviews PROSPERO (ref: CRD42023407545). It is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021).

Eligibility criteria

Peer-reviewed primary quantitative or mixed-methods research studies were included. Included studies tested at least one psychometric property of the Braden scale in a sample of adult ICU patients (aged $\geq$ 18 years). For studies assessing reliability, a sample of nurse-raters must have been included. The study setting was limited to ICU, or studies that included and reported ICU as a sub-setting. Grey literature, editorials, conference papers, non-peer reviewed articles from internet websites, and qualitative studies were excluded. Also, studies were excluded reporting data used to develop the original instrument, as this can lead to overly optimistic results (Streiner & Kottner, 2014). Studies were limited to those published in English, and no date limits were set.

Information sources and search strategy

The search strategy was developed using the Population (adult patients admitted to acute hospital settings), Intervention (Braden scale risk assessment), Comparison (nil), Outcome (psychometric properties) (PICO) framework, with MESH terms and keywords based upon PICO, and Boolean operators (AND, OR) used to combine search terms. The strategy was tested and refined in consultation with a health specialist librarian, with final searches undertaken in June 2023 using these databases: Cumulative Index to Nursing and Allied Health Literature (CINAHL) Complete, Ovid Excerpta Medica database (EMBASE), EBSCO Medical Literature Analysis and Retrieval System Online (MEDLINE) Complete, Scopus and Web of Science (see Search Strategy example, Supplementary File 1). Final studies for inclusion were cross-referenced with studies included in a larger systematic review by the authors (unpublished) of all risk assessment scales. Reference lists of systematic reviews found were reviewed to identify potential articles for inclusion.

Search outcome and selection process

References were exported into EndNote™ for duplicate removal, then transferred into Covidence™ for screening, selection and data extraction. Two reviewers independently completed title and abstract screening, followed by full text screening to determine eligibility. A third reviewer arbitrated conflicts. Studies meeting inclusion criteria progressed to data extraction and quality appraisal.

Quality appraisal

Risk of bias was assessed using the COnsensus-based Standards for the selection of health Measurement INstruments (COSMIN). Risk of bias was assessed manually, using the COSMIN Risk of Bias checklist (Mokkink et al., 2018). Risk of bias assessment was not used to exclude studies.

Data extraction and synthesis

As there was no universally available data extraction template for the psychometric properties of a measurement scale, a customised data extraction template was devised. Two reviewers independently extracted data from each article, with a third arbitrating for consensus. The following information was collected: general information, study design and type of testing (reliability and/or reliability), participant population and setting, methodological approach, and main results. Due to the heterogenous nature of the studies, extracted data were consolidated and presented in a tabulated format and synthesised narratively.

Results

Study selection

A total of 2099 articles were identified from the database searches, and one from citation searching. Following removal of duplicates, titles and abstracts of 1660 articles were screened. 1535 studies were deemed irrelevant, with 125 articles kept for full-text screening. Of these, 34 studies met all inclusion criteria and were included in this review (see Fig. 1).

Risk of bias

Results of risk of bias assessments are shown in Table 1. Two reviewers independently assessed each study with a third reviewer arbitrating. Most studies were judged to be 'very good' according to the COSMIN risk of bias checklist.

Characteristics of included studies

The characteristics of included studies are summarised in Table 2. Studies were conducted in eleven countries, with most conducted in Brazil ($n = 8$), the USA ($n = 8$) and Korea ($n = 5$). Most ($n = 20$) collected data from more than one ICU, with sample sizes ranging from very small ($n = 3$) to very large ($n = 12566$). The ICUs were of various specialties including general, surgical, trauma, cardiac, and neurological. Fifteen studies reported a sample size for nurse-raters, ranging from $n = 1$ to $n = 53$.

Most studies were prospective ($n = 21$) with only seven studies testing two or more psychometric properties. For reliability testing, two studies reported internal consistency with Cronbach's alpha of 0.85 (Adibelli et al., 2019) and a range of 0.43-0.72 (Lima-Serrano et al., 2018) respectively, six studies (see Table 3) tested interrater reliability (Bergstrom et al., 1987b; Fulbrook & Anderson, 2016; Kottner and Dassen, 2010; Simão et al., 2013; Veiga et al., 2022; Wang et al., 2015) of which three reported instrument measurement error (Fulbrook & Anderson, 2016; Kottner and Dassen, 2010; Veiga et al., 2022). Inter-

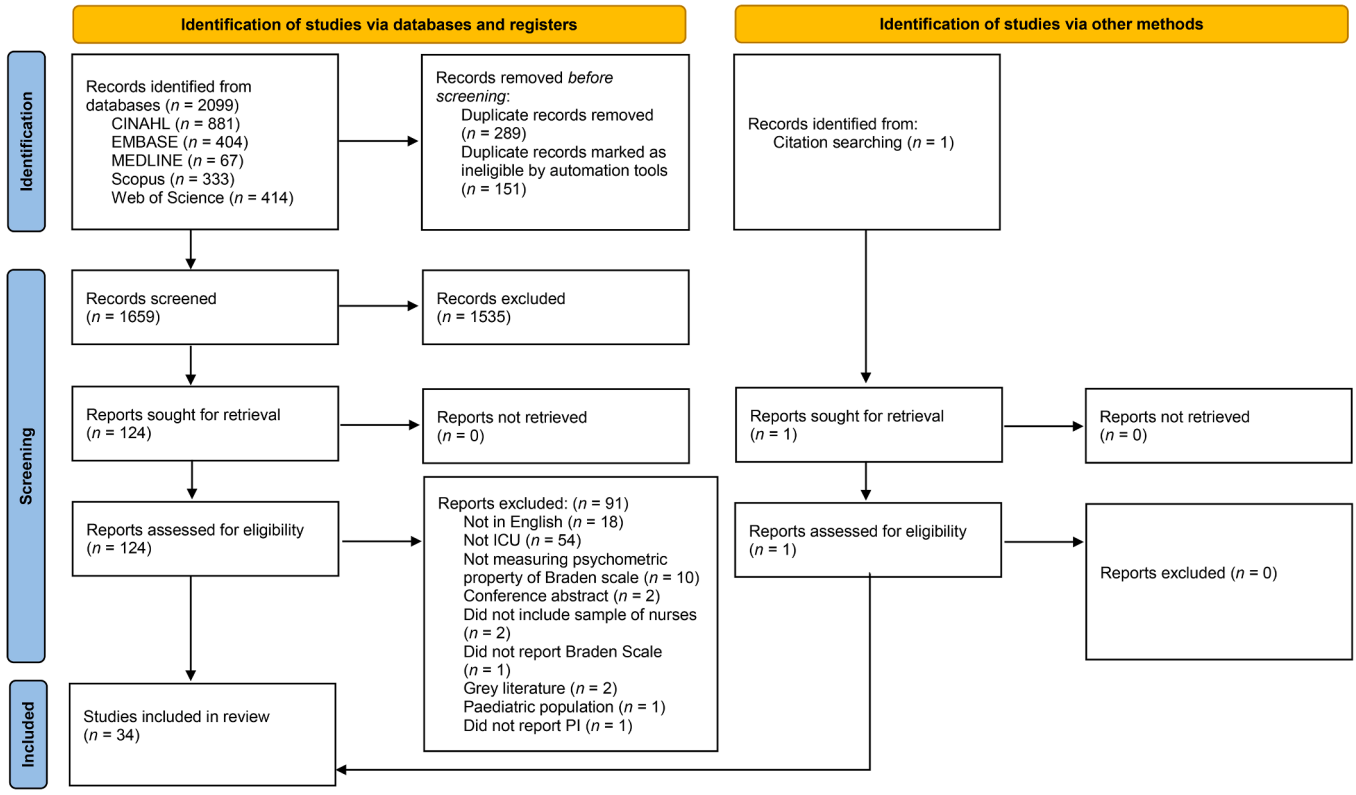


Fig. 1. PRISMA flow diagram. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. https://doi.org/10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/.

rater reliability was reported using either Pearson's correlation or intraclass correlation (ICC), with varied findings particularly between subscales (Table 3). No studies tested intra-rater reliability.

Thirty-one studies tested validity, with a large majority (n = 29) testing predictive validity (see Table 3) with three studies testing convergent validity (Delawder et al., 2021; Fulbrook & Anderson, 2016; Kottner and Dassen, 2010). When examining predictive validity, reported sensitivities ranged from 41 % to 100 %, specificity from 5 to 79 %, positive predictive value (PPV) from 14 % to 85 %, negative predictive value from 38 % to 100 % and the area under curve (AUC) from 29 % to 86 %. Cut-off scores for predictive validity ranged from 12 to 20.

Discussion

The purpose of this study was to explore the psychometric properties of the Braden scale to assess PI risk in adults within the ICU setting.

Reliability

The reliability of a scale reflects the degree to which it measures a construct consistently, which in the case of the Braden scale is *risk* of PI. Internal consistency is a reliability property measuring consistency between various items on a scale. It was reported in only two studies, with Adibelli and Korkmaz (2019) reporting Cronbach's alpha of 0.85 and Lima-Serrano et al. (2018) reporting values ranging from 0.43 to 0.72. In the latter study higher values were reported on different days, with lowest values reported on the first day of admission. However, Kring (2007) suggests that due to the exclusivity of the Braden scale items and their lack of similarity, internal consistency is not an appropriate or effective method to determine its reliability.

Interrater and intrarater reliability are measures indicating the degree of consistency (or agreement) between two or more assessments of a patient, either between independent assessors (interrater reliability) or over time by the same assessor (intrarater reliability). For both types of reliability assessment, it is important that there has been no change in the patient's condition during the time interval between assessments. As PI risk assessment tools are utilised frequently during daily nursing practice in dynamic clinical environments, such as the ICU, a high level of agreement between users is expected when assessing patient risk levels (Charalambous et al., 2018). In this review, only six studies were found investigating reliability of the Braden scale in the ICU setting (Bergstrom et al., 1987b; Fulbrook & Anderson, 2016; Kottner and Dassen, 2010; Simão et al., 2013; Veiga et al., 2022; Wang et al., 2015); all reported interrater reliability.

Bergstrom et al., (1987b) did not report ICC, which is the most appropriate method to assess reliability for repeated measures on a scale (de Vet et al., 2006; Streiner & Kottner, 2014). Instead, they reported Pearson's correlation value to justify the accuracy of the nurse participants' assessments, which appears to have been calculated before the study commenced. Of the other five studies, four reported ICC values for Braden sum score of 0.66 (Fulbrook & Anderson, 2016), 0.68 (Veiga et al., 2022) and 0.72 and 0.84 (Kottner and Dassen, 2010), and 0.96 (Wang et al., 2015). Fulbrook and Anderson (2016) also reported an ICC of 0.65 for risk level, although Veiga et al. (2022) reported poor interrater agreement (weighted kappa = 0.17) and Simão et al. (2013) reported kappa ranging from 0 to 0.86 in the four ICUs in their study, although they did not calculate weighted values. Values of ICC between 0.5 and 0.75 indicate moderate reliability (Koo & Li, 2016) with the minimum acceptable value considered to be 0.60 (Shoukri et al., 2004).

Both Fulbrook and Anderson (2016) and Kottner and Dassen (2010) reported values for instrument measurement error. In both studies, the standard error of measurement (SEM) was around 2 points of the sum score (1.83 and 1.67–1.64, respectively), although a slightly smaller SEM of 1.31 was reported by Veiga et al. (2022). Fulbrook and Anderson (2016) and Veiga et al. (2022) also reported sum score minimal detectable change (MDC) values of 3.63 and 5.07, respectively. These

Table 1
Risk of bias assessment.

Internal consistency								
Study	Does the scale consist of effect indicators, i.e., is it based on a reflective model?	Was an internal consistency statistic calculated for each unidimensional scale or subscale separately?	For continuous scores: Was Cronbach's alpha or omega calculated?	For dichotomous scores: Was Cronbach's alpha or KR- 20 calculated?	For IRT-based scores: Was standard error of the theta (SE (θ)) or reliability coefficient of estimated latent trait value (index of (subject or item) separation) calculated?	Were there any other important flaws in the design or statistical methods of the study?		
Adibelli et al., 2019	Yes	VG	VG	NA	NA	VG		
Lima-Serrano et al., 2018	Yes	VG	VG	NA	NA	VG		
Interrater reliability								
Study	Were patients stable in the interim period on the construct to be measured?	Was the time interval appropriate?	Were the test conditions similar for the measurements? e.g., type of administration, environment, instructions	For continuous scores: Was an intraclass correlation coefficient (ICC) calculated?	For dichotomous/ nominal/ ordinal scores: Was kappa calculated?	For ordinal scores: Was a weighted kappa calculated?	For ordinal scores: Was the weighting scheme described? e.g., linear, quadratic	Were there any other important flaws in the design or statistical methods of the study?
Bergstrom et al., 1987b	D	D	D	D	NA	NA	NA	D
Fulbrook and Anderson, 2016	VG	VG	VG	VG	NA	NA	NA	VG
Kottner and Dassen, 2010	VG	VG	VG	VG	NA	NA	NA	VG
Simão et al., 2013	VG	VG	VG	I	I	I	NA	I
Veiga et al., 2022	VG	VG	VG	VG	VG	VG	VG	VG
Wang et al., 2015	D	D	VG	VG	NA	NA	NA	I
Measurement error								
Study	Were patients stable in the interim period on the construct to be measured?	Was the time interval appropriate?	Were the test conditions similar for the measurements? e.g., type of administration, environment, instructions	For continuous scores: Was the standard error of measurement (SEM), smallest detectable change (SDC) or limits of agreement (LoA) calculated?	For dichotomous/nominal/ ordinal scores: Was the percentage (positive and negative) agreement calculated?	Were there any other important flaws in the design or statistical methods of the study?		
Fulbrook and Anderson, 2016	VG	VG	VG	VG	NA	VG		
Kottner and Dassen, 2010	VG	VG	VG	VG	NA	VG		
Veiga et al., 2022	VG	VG	VG	VG	NA	VG		
Predictive validity								

(*continued on next page*)

Table 1 (*continued*)

Internal consistency			
Study	For continuous scores: Were correlations, or the area under the receiver operating curve calculated?	For dichotomous scores: Were sensitivity and specificity determined?	Were there any other important flaws in the design or statistical methods of the study?
Adibelli et al., 2019	VG	VG	VG
Alderden et al., 2022	VG	VG	VG
Bergstrom et al., 1987bb	I	VG	VG
Borghardt et al., 2015	VG	VG	VG
Carlson et al., 1999	I	I	I
Cho and Noh, 2010	VG	VG	VG
Costa and Larcher, 2011	I	VG	VG
Delawder et al., 2021	VG	VG	VG
Deng et al., 2017	VG	VG	VG
Feuchtinger et al., 2007	I	VG	VG
Griswold et al., 2017	I	VG	VG
Guimarães et al., 2023	VG	VG	VG
Han et al., 2018	VG	VG	VG
Higgins et al., 2020	VG	VG	VG
Hyun et al., 2013	VG	VG	VG
Jansen et al., 2020	I	I	I
Jin et al., 2015	VG	VG	VG
Kim et al., 2009	VG	VG	VG
Lima-Serrano et al., 2018	VG	VG	VG
Liu et al., 2013	VG	VG	VG
Ranzani et al., 2016	VG	VG	VG
Roca-Biosca et al., 2017	VG	VG	VG
Seongsook et al., 2004	VG	VG	VG
Serpa et al., 2011	VG	VG	VG
Suriadi et al., 2006	VG	VG	VG
Tescher et al., 2012	I	I	I
Theeranut et al., 2021	VG	VG	VG

(*continued on next page*)

Table 1 (*continued*)

Internal consistency					
Valiee et al., 2022	I	VG	VG		
Xu et al., 2022	VG	I	VG		
Convergent validity					
Study	Is it clear what the comparator instrument(s) measure (s)?	Were the measurement properties of the comparator instrument (s) sufficient?	Was the statistical method appropriate for the hypotheses to be tested?	Were there any other important flaws in the design or statistical methods of the study?	
Delawder et al., 2021	VG	D	D	D	
Fulbrook and Anderson, 2016	VG	VG	VG	VG	
Kottner and Dassen, 2010	VG	VG	VG	VG	

*COSMIN Risk of Bias checklist. D = doubtful, I = inadequate, NA = not applicable, VG = very good.

Table 2
Interrater reliability: main results.

Author, year	Inter-rater reliability	Measurement error
Bergstrom et al., 1987b	Pearson's $r = 0.89$ (appears to have been measured *a priori*).	
Fulbrook and Anderson, 2016	**ICC (95 % CI):** ***Sum score:*** 0.66 (0.50-0.80). ***Risk category***: 0.65 (0.49-0.79). **Braden items ICC (95 % CI):** ***Sensory perception***: 0.80 (0.69–0 89); ***Moisture***: 0.20 (0.06-0.40); ***Activity***: 0.73 (0.59-0.85); ***Mobility***: 0.60 (0.42-0.76); ***Nutrition***: 0.37 (0.20-0.58); ***Friction/shear***: 0.24 (0.09-0.44)	**SEM:** ***Sum score*** = 1.83 (MDC 5.07). ***Risk category*** = 0.68. **Braden items SEM:** ***Sensory perception*** = 0.49; ***Moisture*** = 0.76; ***Activity*** = 0.38; ***Mobility*** = 0.49; ***Nutrition*** = 0.63; F***riction/shear*** = 0.53
Kottner and Dassen, 2010	**ICC (95 % CI):** ***Sum score:*** ICU 1 = 0.72 (0.52–0.87); ICU 2 = 0.84 (0.72–0.92). **Braden items ICC (95 % CI):** ***Sensory perception:*** ICU 1 = 0.64 (0.40-0.81); ICU 2 = 0.17 (0.06-0.45). ***Moisture:*** ICU 1 = 0.49 (0.22–0.73); ICU 2 = 0.75 (0.58-0.87). ***Activity:*** ICU 1 = 0.08 (0.16-0.39); ICU 2 = 0.71 (0.52-0.85). ***Mobility:*** ICU 1 = 0.53 (0.27-0.76); ICU 2 = 0.75 (0.58-0.87). ***Nutrition:*** ICU 1 = 0.56 (0.31-0.78); ICU 2 = 0.64 (0.43-0.81). ***Friction/shear:*** ICU 1 = 0.48 (0.21-0.72); ICU 2 = 0.42 (0.18-0.67).	**SEM:** ***Sum score*****:** ICU 1 = 1.67; ICU 2 = 1.64. **Braden items SEM:** ***Sensory perception:*** ICU 1 = 0.58; ICU 2 = 0.61. ***Moisture:*** ICU 1 = 0.78; ICU 2 = 0.52. ***Activity:*** ICU 1 = 0.43; ICU 2 = 0.51. ***Mobility:*** ICU 1 = 0.46; ICU 2 = 0.44. ***Nutrition:*** ICU 1 = 0.49; ICU 2 = 0.7. ***Friction/shear:*** ICU 1 = 0.40; ICU 2 = 0.45.
Simão et al., 2013	**Sum score mean difference:** ICU 1: $p = .0001$; ICU 2: $p = .0001$; ICU 3: $p = 0$; ICU 4: $p = .76$. **Risk level (kappa):** ICU 1 = 0.561 ($p = .0001$); ICU 2 = 0.862 ($p = .0001$); ICU 3 = 0 ($p = 0$); ICU 4 = 0.333 ($p = .76$). **Braden items ICC (95 % CI):** ***Sensory perception:*** ICU 1 = 0.99 (0.99 – 1.00); ICU 2 = 0.96 (0.90 -0.98); ICU 3 = 0.91 (0.78 - 0.96); ICU 4 = 0.85 (0.62 -0.95). ***Moisture:*** ICU 1 = 0.84 (0.64 - 0.94); ICU 2 = 0.27 (0.20 - 0.63); ICU 3 = -0.04 (-0.47 - 0.41); ICU 4 = 0.21 (-0.32 - 0.64). ***Activity:*** ICU 1 = 0.77 (0.50 - 0.91); ICU 2 = 0.56 (0.15 - 0.80); ICU 3 = 0.00 (-0.44 - 0.44); ICU 4 = 0.00 (-0.50 - 0.50). ***Mobility:*** ICU 1 = 0.96 (0.89 – 0.98); ICU 2 = 0.91 (0.79 -0.97); ICU 3 = 0.88 (0.72 - 0.95); ICU 4 = 0.80 (0.50 - 0.93). ***Nutrition:*** ICU 1 = 0.45 (0.01 – 0.75); ICU 2 = -0.55 (-0.80 - −014); ICU 3 = 0.60 (0.22 - 0.83); ICU 4 = 0.16 (-0.37 - 0.61). ***Friction and Shear:*** ICU 1 = 0.91 (0.79 - 0.97); ICU 2 = 0.86 (0.67-0.94); ICU 3 = 0.69 (0.35 - 0.87); ICU 4 = 0.64 (0.21 - 0.86).	
Veiga et al., 2022	**Sum score ICC** = 0.68 (95 % CI 0.50–0.80). **Risk level**: kappa = 0.17. **Braden items**: kappa range 0.20–0.53	**Sum score SEM** = 1.31, MDC = 3.63
Wang et al., 2015	**Sum score ICC** = 0.964 (95 % CI 0.827–0.999).	

*CI = confidence interval, MDC = minimal detectable change, SEM = standard error of measurement.

Table 3
Predictive validity: main results.

Author, year	Cut-off score	Sensitivity %	Specificity %	PPV %	NPV %	AUC %	Comments
Adibelli and Korkmaz, 2019	16	96	63	29	99	86	
Alderden et al., 2022	*12 (COVID -ve)	88	20	NR	NR	72	Cut-off because scores ≤ 12 are considered to indicate high risk.
	*12 (COVID + ve)	82	33	NR	NR	71	
Bergstrom et al., 1987b	16	83	64	61	85	NR	
Borghardt et al., 2015	12 (24 h)	41	21	(+ve LR 2.79)	(-ve LR 0.52)	29	Optimal cut-off scores determined based on AUC.
	12 (48 h)	53	39	(+ve LR 1.19)	(-ve LR 0.87)	44	
	11 (72 h)	41	18	(+ve LR 3.19)	(-ve LR 0.50)	54	
Carlson et al., 1999	NR	NR	NR	NR	NR	NR	Cox regression: mean total Braden score significant as a single-variable predictor (coefficient -0.28, p =.046).
Cho and Noh, 2010	13	76	47	18	93	62	Cut-off score 13 identified as optimal; with false negative probability 26 %, false positive probability 26 %
	16	92	22	15	95	NR	
	18	94	12	14	93	NR	
Costa and Larcher, 2011	*14 (at 24 h)	95	45	52	94	NR	*Optimal cut-off scores derived based on best balance between sensitivity and specificity.
	16 (at 24 h)	100	24	44	100	NR	
	*13 (at 48 h)	95	55	56	95	NR	
	16 (at 48 h)	100	27	45	100	NR	
	*12 (at 72 h)	94	77	85	91	NR	
	16 (at 72 h)	100	23	64	100	NR	
Delawder et al., 2021	NS	100	28	84	100	76	
Deng et al., 2017	12	74	79	29	96	79	
Feuchtinger et al., 2007	16	78	29	70	38	NR	*Use of cut-off score 20 based on previous research in non-ICU cardiac patients.
	*20	97	5	69	50	NR	
Griswold et al., 2017	18	100	39	NR	NR	NR	Odds ratio of PI = 1.33 (p < 0.001) for each 1-unit decrease in score.
Guimarães et al., 2023	12 (Braden)	26	93	4	(1/PPV = 26)	74	Braden scale simplified by removing two subscales: nutrition and sensory perception. 1/PPV = number of patients classified at risk for each correctly predicted case of PI.
	8 (simplified Braden)	47	85	3	(1/PPV = 31)	73	
Han et al., 2018	16 (1st score)	49	73	64	59	62 (YI = 0.21)	Youden index (YI) used to determine optimal cut-off scores.
	16 (last score pre-PI)	81	56	65	74	70 (YI = 0.37)	
	18 (1st score)	63	55	58	60	(YI = 0.18)	
	18 (last score pre-PI)	92	32	57	79	(YI = 0.24)	
Higgins et al., 2020	18	78	53	95	17	71	
Hyun et al., 2013	*13	78	47	14	95	67	*Optimal cut-off 13 determined based on AUC.
	16	95	21	11	98	NR	
	18	98	15	11	98	NR	
Jansen et al., 2020	NR	NR	NR	NR	NR	NR	High risk: 20.9 % developed PI; very high risk: 37.7 % developed PI.
Jin et al., 2015	16 (1st score)	53	74	85	37	NR (YI = 0.27)	Seven cut-off scores (12–19) analysed. Optimal cut-off score was found to be 18.
	16 (last score)	81	72	89	58	NR (YI = 0.53)	
	16 (lowest score)	83	55	83	53	NR (YI = 0.38)	
	18 (1st score)	64	68	85	41	66 (YI = 0.32)	
	18 (last score)	87	66	88	65	78 (YI = 0.53)	
	18 (lowest score)	88	47	83	59	70 (YI = 0.35)	
Kim et al., 2009	14	93	70	41	98	88	
Lima-Serrano et al., 2018	*12 (phase 1, 1st day)	95	56	12	95	67	*Cut-off 12 was found to be optimum, as it offered best balance between sensitivity and specificity. Stage 1 PIs not included in phase 2.
	*12 (phase 1, 2nd day)	78	73	20	98	80	
	10 (phase 1, day of min score)	78	67	17	97	73	
	12 (phase 2, 1st day)	71	56	8	97	66	
	11 (phase 2, 2nd day)	82	77	17	99	82	

(*continued on next page*)

Table 3 (*continued*)

Author, year	Cut-off score	Sensitivity %	Specificity %	PPV %	NPV %	AUC %	Comments
	10 (phase 2, day of min score)	82	67	12	99	73	
Liu et al., 2013	16	92	63	19	99	16	
Ranzani et al., 2016	13	81	66	4	99	80	
Roca-Biosca et al., 2017	*12 (1st day)	83	34	23	90	60	*Cut-off 12 set based on high risk according to original scale.
	12 (max risk score)	90	26	31	78	63	
	12 (1st 48 h average)	80	36	32	83	62	
	12 (all observations average)	73	50	36	83	71	
Seongsook et al., 2004	16	97	26	37	95	71	
Serpa et al., 2011	12 (admission)	86	65	21	98	79	Only patients with admission score ≤ 18 with 3 consecutive assessments included. Best cut-off scores at each assessment determined based on AUC.
	13 (48 h)	71	82	29	96	79	
	13 (96 h)	71	83	31	96	80	
Suriadi et al., 2006	12	80	54	47	84	79	
Tescher et al., 2012	18	NR	NR	NR	NR	NR	Cut-off 18 highly predictive of PI (p <.001, C = 0.71).
Theeranut et al., 2021	*12 (Braden)	50	80	24	93	67 (YI = 0.30)	Braden (ALB) scale modified from Braden scale by defining nutritional subscale based on serum albumin. Optimal cut-off scores determined by AUC.
	*13 (Braden ALB)	66	73	23	94	69 (YI = 0.38)	
Valiee et al., 2022	18	97	35	64	90	NR	
Xu et al., 2022	NR (training cohort)	54	67	NR	NR	64	AUC used to assess performance of Braden score.
	NR (test cohort)	NR	NR	NR	NR	65	

AUC = area under the curve, LR = likelihood ratio, NR = not reported, PI = pressure injury, YI = Youden index.

values are clinically significant, as a difference in sum score of between 4 and 5 points would be required to indicate that a 'real' change in risk level has occurred (Terwee et al., 2009).

Further examination of Braden scale items revealed less favourable ICC values. Kottner and Dassen (2010) reported ICCs of less than 0.60 for all items except *sensory perception* (ICC = 0.64) in ICU 1 and ICCs above 0.60 for all items except two in ICU 2 (*friction and shear* = 0.42; *sensory perception* = 0.17). In contrast, the *activity* item ICC in ICU 1 was 0.08 compared to 0.71 in ICU 2. Fulbrook and Anderson (2016) reported ICCs less than 0.60 for three items (*moisture*, *nutrition*, *friction and shear*) whereas Simão et al. (2013) reported values less than 0.60 mainly for the *moisture*, *activity*, and *nutrition* items in most of the four ICUs in their study. In the study by Theeranut et al. (2021), a modified version of the Braden scale (Braden ALB), in which serum albumin replaced the *nutrition* item, better sensitivity and specificity was reported using an optimal cut-off score of 13. It has been suggested some of the Braden scale items feature subjectivity, resulting in nurses reporting difficulty completing consistent assessment (Choi et al., 2014; Miller et al., 2020) and others have suggested that training and user buy-in play a key role in the level of agreement of scores between users (Ho et al., 2016; Kottner & Dassen, 2008).

Validity

Validity is the extent to which a scale measures what it is supposed to measure. In this review, two types of validity were reported: convergent validity and predictive validity. The former is established by comparing the scale with other scales that are said to measure the same construct (risk of PI) whereas predictive validity relates to the degree to which a scale predicts a future outcome (PI occurrence).

Convergent validity was tested in only three studies, with the Braden scale compared with four comparator tools: the Cubbin-Jackson scale (Delawder et al., 2021), the COHMON Index and Norton scale (Fulbrook & Anderson, 2016), and the Waterlow score (Fulbrook & Anderson, 2016; Kottner and Dassen, 2010). In the two studies comparing the Waterlow score contrasting results were found, with Fulbrook and Anderson reporting a weak correlation (r = 0.22) and Kottner and Dassen (2010) reporting strong correlations (r = 0.72 and 0.71) between sum scores. In the former study, weak correlations were also found between three similar items measured by both tools: *mobility* (r = 0.19), *neurological* (r = 0.02), and *nutrition* (r = 0.15). In that same study, the authors reported a strong correlation between the Braden and Norton sum scores (r = 0.77) as well as strong correlations between two similar items: *mobility* (r = 0.78) and *neurological* (r = 0.77). In the two studies comparing ICU-specific tools to the Braden scale, strong sum score correlations were reported with the COMHON Index (Fulbrook & Anderson, 2016: r = 0.70) and the Cubbin-Jackson scale (Delawder et al., 2021: r = 0.80), with the former study also reporting strong correlations with two similar items: *mobility* (r = 0.63) and *neurological* (r = 0.80), and a moderate correlation with *nutrition* (r = 0.46). Whilst these results provide some information that supports equivalence of the Braden scale to two tools designed specifically for ICU, the available data are limited, and further research is required to help determine the relevance of the Braden scale in the ICU setting.

A key finding in this review was that most studies reporting psychometric properties of the Braden scale in ICU have investigated its predictive validity. Whilst this property is important for most scales, it is argued that when PI occurrence is the outcome of interest, predictive validity is an invalid property to measure, as it is not ethically permissible to not implement preventative interventions in clinical practice, when it is known that a patient is at risk (Walsh & Dempsey, 2011). Thus, the relevance and quality of preventive interventions will confound the primary outcome measure. Risk assessment alone cannot prevent PI, therefore it cannot predict PI as an outcome if mitigation strategies are implemented, as it is the preventative interventions that prevent PI development not the risk assessment *per se* (Anthony et al., 2008; Charalambous et al., 2018; Kring, 2007; Lovegrove, Fulbrook & Miles, 2018; 2020; Lovegrove, Miles & Fulbrook, 2018; Lovegrove et al., 2023). It is important therefore to appreciate that the Braden scale is used to assess the construct of *risk* of *possibly* developing a PI; not to predict PI as an outcome therefore it is best regarded as a screening tool. It is not a diagnostic test as it does not diagnose those with PI, thus

studies claiming to report Braden scale *diagnostic accuracy* (of PI) are inappropriate. If appropriate intervention strategies are implemented to mitigate risk, then theoretically a PI should be avoided. Nevertheless, twenty-nine studies included in this review reported predictive validity of the Braden scale and the results should be regarded within the context of the above discussion.

Initial validation studies of the Braden scale determined a cut-off score of 18 or less (to indicate *at risk* versus *not at risk*) with optimal sensitivity and specificity (Bergstrom et al., 1987a), however in the earliest ICU-specific study, the optimal cut-off score was found to be 16 or less (Bergstrom et al., 1987b). The remainder of studies in this review report a variety of different cut-off scores, ranging from 10 to 20, with several studies aiming to determine the most accurate cut-off score for the ICU setting. Wide ranges of sensitivity and specificity (41 % to 100 % and 39 % to 79 %, respectively), PPV (11 % to 95 %), and NPV (17 % to 100 %) were reported. Results clearly demonstrate wide variability in the ICU setting (see Table 3). Several ICU-specific risk assessment tools (CALCULATE, COMHON Index, Cubbin/Jackson, Jackson/Cubbin, Song and Choi) were reported in several studies, demonstrating in most cases better, predictive validity properties than the Braden scale (Adibelli et al., 2019; Delawder et al., 2021; Higgins et al., 2020; Kim et al., 2009; Liu et al., 2017; Seongsook et al., 2004; Theeranut et al., 2021).

For a test to be useful, the sum of sensitivity plus specificity (when expressed as decimal fractions) should be at least 1.5, with values of less than 1 considered to be "useless" (Power et al., 2013, p.6). If this threshold was applied, most of the results found in this review would not meet this criterion. Arguably, the most important property of a risk assessment tool is its sensitivity i.e., its ability to identify patients at risk. A highly sensitive tool is unlikely to produce false negative outcomes (Trevethan, 2017). However, in clinical practice many patients identified as being at risk may not be at risk when assessed against a subsequent outcome such as PI. In this context the PPV value is also important as it describes the proportion of patients in a sample identified at being at risk who were at 'true' risk i.e., they developed a PI. Several studies used AUC to determine the optimal cut-off score for the Braden score, with most values in the range of 12 to 14, indicating that it is probable the cut-off score for the Braden scale should be set much lower than the recommended score of 18 or less (Bergstrom et al., 1987a). Further *meta*-analytical work is needed before an appropriate score can be recommended. However, Braden (2012) indicated that the Braden scale should not be actioned as per the sum score (i.e., risk level), rather each item should be actioned individually and used as a prompt to nurses to perform further assessment or implement preventative interventions, implying that clinical judgement plays a significant role in PI prevention alongside use of a risk assessment tool.

Limitations

This review was limited to articles published in English and therefore studies investigating psychometric properties published in other languages were not included. Notably, several Chinese articles were found in the initial searches and full text reviews. To ensure comprehensiveness, no date limits were set for this review. Thus, some of the older studies may have introduced some bias into the results, especially regarding predictive validity, as recognition of the importance of PI prevention and implementation of new interventions and technology have significantly reduced PI incidence in more recent years. The findings of this review relate to use of the Braden scale in the ICU setting only and should not be generalised to other PI risk assessment tools in this setting or other settings.

Conclusion

This systematic review provides a comprehensive analysis of existing studies of the psychometric properties of the Braden scale when used in the ICU setting. The results provide variable evidence of its reliability and validity. Although interrater reliability was moderate to good, there were only a few studies of this property. Similarly, there were only a few studies that reported internal consistency and convergent validity. Furthermore, several predictive validity studies indicate that a much lower cut-off score is most likely appropriate for ICU. Thus, this review indicates further research is required before the Braden scale can be recommended for use in the ICU setting. Although not a primary focus for this review, several included articles reported psychometric properties for several ICU-specific PI risk assessment tools. Further research is recommended to compare and contrast these tools with the Braden scale to help determine which tools are most suitable for this setting.

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Ethical statement

As this study was a systematic review of published literature, patients and/or the public were not involved in the design, conduct, reporting, or dissemination of this study.

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CRediT authorship contribution statement

Aldiana Mehicic: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis. **Adam Burston:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Paul Fulbrook:** Writing – review & editing, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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