Received: 27 March 2024 | Revised: 3 May 2024 | Accepted: 5 May 2024

DOI: 10.1111/iwj.14928

REVIEW ARTICLE

IWJ WILEY

A systematic review on the impact of sub-epidermal moisture assessments on pressure ulcer/injury care delivery pathways

Pinar Avsar[1,2] | **Declan Patton**[3,4,5,6,7] | **Janet Cuddigan**[8] | **Zena Moore**[2,3,4,5,6,9,10,11,12]

[1]Skin Wounds and Trauma Research Centre, The Royal College of Surgeons in Ireland (RCSI), University of Medicine and Health Sciences, Dublin, Ireland

[2]Cardiff University School of Medicine, University of Wales, Cardiff, UK

[3]Skin Wounds and Trauma Research Centre, RCSI University of Medicine and Health Sciences, Dublin, Ireland

[4]School of Nursing and Midwifery, RCSI University of Medicine and Health Sciences, Dublin, Ireland

[5]Fakeeh College of Health Sciences, Jeddah, Saudi Arabia

[6]School of Nursing and Midwifery, Griffith University, Gold Coast, Queensland, Australia

[7]Faculty of Science, Medicine and Health, University of Wollongong, Wollongong, New South Wales, Australia

[8]Nebraska Medical Center, University of Nebraska Medical Center, College of Nursing, Omaha, Nebraska, USA

[9]Faculty of Medicine, Nursing and Health Sciences, Monash University, Melbourne, Victoria, Australia

[10]Department of Public Health, Faculty of Medicine and Health Sciences, Ghent University, Ghent, Belgium

[11]Lida Institute, Shanghai, China

[12]National Health and Medical Research Council Centre of Research Excellence in Wiser Wound Care, Menzies Health Institute Queensland, Southport, Queensland, Australia

Correspondence
Pinar Avsar, Skin Wounds and Trauma Research Centre. The Royal College of Surgeons in Ireland (RCSI), University of Medicine and Health Sciences, Dublin.
Email: pinaravsar@rcsi.ie

Abstract

To assess all published studies which describe what happens to the delivery of pressure ulcer/injury (PI/PU) care pathways as a result of detecting raised sub-epidermal moisture (SEM) delta ($\Delta \geq 0.6$). We undertook a systematic review of the literature, and included original research studies using either a prospective or retrospective study design that report the impact that assessment using SEM assessments have on healthcare practitioners' delivery of PI/PU care pathways in adults at risk of developing PI/PUs. The review protocol was registered on PROSPERO (CRD42023416975). A literature search was conducted in May 2023, using PubMed, CINAHL, Scopus, Cochrane, EMBASE, Web of Science and Science Direct databases. Data were extracted using a data extraction tool including elements such as country, setting, sample size, intervention, control and quality appraisal was undertaken using the Evidence-based Librarianship. We identified nine papers published between 2017 and 2022. The majority of these studies were conducted in England ($n = 6$; 67%). The systematic review included studies conducted across multiple care settings including acute care,

medical-surgical units, and palliative care, highlighting the importance of PI/PU prevention and management across diverse patient populations. The PI/PU care pathways implemented in the studies varied, but commonly included elements such as the application or increased use of pressure-redistributing mattresses/cushions, implementation of repositioning plans, management of incontinence and moisture, regular skin inspection, and assessment of patient mobility. Out of the nine studies identified, seven reported PI/PU incidence. A meta-analysis of seven studies ($N = 18\,451$) demonstrated a statistically significant reduction in visual PI/PU development in favour of SEM-guided care pathways compared to usual care (the odds ratio = 0.36 [95% confidence interval: 0.24–0.53, $p < 0.00001$]). This systematic review provides evidence that implementing SEM assessments in patients at risk of developing PI/PUs prompts anatomy-specific clinical actions. The subsequent implementation of enhanced and targeted skin care interventions leads to consistent and sustained reductions in hospital-acquired PU incidence. The findings emphasise the importance of incorporating SEM assessments as part of comprehensive PI/PU prevention strategies in all care settings and patient populations. This systematic review is limited by the predominance of observational studies and variable study quality. Future research should focus on randomised trials in different care settings that monitor the efficacy of preventive interventions and their impact in reducing PI/PU incidence when implemented based on SEM assessments.

KEYWORDS

pressure ulcer/injury, prevention, sub epidermal moisture, systematic review

Key Messages

- Healthcare providers should consider using sub-epidermal moisture (SEM) assessment to assess the risk of pressure ulcer/injury (PI/PU) development.
- SEM assessment should be used to inform the development and implementation of PI/PU care pathways.
- Further research is needed to confirm the efficacy of interventions in SEM assessment based care pathways for preventing PI/PU in randomised controlled trials.

1 | INTRODUCTION

Pressure injuries/ulcers (PI/PU) are localised damage to the skin and/or underlying tissue, as a result of pressure, or pressure in combination with shear.[1] In epidemiology, 'prevalence' refers to the proportion of individuals in a population who have a particular condition at a specific point in time or within a specified period. It represents the total number of existing cases of the condition divided by the total population at risk. On the other hand, 'incidence' refers to the rate of new cases of a condition that develop within a defined population over a specified period. It represents the number of new cases occurring within a specific time period divided by the population at risk during that time period.[2] Around the world, PI/PU prevalence in healthcare settings ranges from 0%–72.5%, with large variations observed between different countries and clinical settings.[1] Individuals who develop PI/PUs often present with compromised mobility and a reduced tissue tolerance.[3]

It is widely recognised that early and effective risk assessment and PI/PU detection are important. Evidence indicates that decreased mobility[4]/excess movement[5,6] and the presence of pressure/shear are central to PI/PU

formation. As such, the international PI/PU prevention and management guidelines recommend a structured risk assessment and comprehensive skin assessment for each patient.[4] The most common method of assessing skin is using visual and tactile skin tissue assessments (STA), which has been shown to vary greatly in terms of reliability.[7,8] This means that in practice there is generally only moderate agreement among healthcare practitioners (HCPs) when assessing the same patient for evidence of PI/PU development.[9–14] Further, assessment of early evidence of PI/PUs, before the skin is broken is even more challenging, particularly among individuals with dark skin tones.[12] This is a real problem for clinical practice, as STAs are fundamental to determining an individual's responses to pressure and shear, in addition to their responses to prevention strategies offered.

Existing risk assessment tools include several direct and indirect risk factors, all weighted the same, diluting the importance of immobility as a risk factor. Further, these assessments are subjective, may depend on HCP experience, specialised training and more importantly, lack anatomic specificity. Patients, therefore, may be subjected to interventions that are not effective for the anatomy truly at risk. This poses a challenge in clinical practice in providing timely PI/PU preventive interventions to the right anatomy, more so in high acuity care settings where a majority of the patients are typically considered high risk and very high risk based on standard risk assessment tools.[5,15] Furthermore, visual skin assessment, the current diagnostic standard, is unable to detect damage that is manifesting beneath the skin, which, if left unnoticed, can progress to irreversible visible tissue damage.[5,6] Delayed diagnosis and intervention latency is more severe in patients with dark skin tones. Considering the burden that PI/PUs and their incidence places on the patient and the healthcare system objective, and skin tone agnostic.[15] Early detection tools and technologies are needed that can reliably detect the onset of PI/PU damage.[12,16]

Elevated sub-epidermal moisture (SEM) has been shown to be an indicator of early-stage PI/PU damage (Byrne et al., 2023). Further, when this damage is detected, HCPs can be directed to specific anatomical areas of the patient, thus enabling the targeting of interventions to prevent PI/PU progression (Byrne et al., 2023). Early PI/PU detection via SEM assessments is performed using the Provizio® SEM Scanner (Bruin Biometrics, LLC, CA, USA).[5,6,17–19] The Provizio SEM Scanner is a hand-held, portable device that consists of a single non-invasive sensor that measures biocapacitance of the tissue; electrical capacitance of soft tissue which varies with changes in sub-epidermal moisture beneath the skin. Increasing SEM values, represented by a SEM delta value, is a sign of microscopic oedema caused by pressure-induced cell death and subsequent inflammation that triggers a continuous damage cycle; the more the pressure, shear or friction at the bony prominence, the more tissue degradation will occur resulting in increasing levels of sub-epidermal moisture or localised oedema at the specific anatomy.[20,21] This localised oedema that starts at a microscopic level is detected by SEM assessments and is displayed as a SEM delta value on the device—the mathematical difference between the highest and the lowest SEM measure across the anatomy of interest. An SEM delta (Δ) value of ≥0.6, when left untreated, is associated with a higher incidence of visually identifiable PI/PUs upon follow-up.[22] SEM assessments differentiate between healthy and inflamed tissue providing an objective and anatomically specific measure of early pressure-related damage that is not yet visible to the naked eye and aids health care practitioners (HCPs) in providing timely interventions to the right anatomies developing tissue damage.

The Provizio SEM Scanner is the only FDA-authorised (Class I) and CE marked (Class IIa) device indicated for the measurement and early detection of localised oedema (non-visible developing tissue damage). Literature and authorised indications for use describe daily assessments of the sacrum and heels from the point of admission through to discharge in at-risk adult populations.[23] The device is available for use by HCPs in more than 28 global markets.

Research has demonstrated consistency in the detection of changes in SEM and the development of subsequent PI/PUs 1 week later.[5] Further, the use of the Provizio SEM Scanner series (Model 200 and Provizio) has high inter-rater reliability and accuracy in early PI/PU detection with equal measurement performance for both the described models.[24–28] No previous systematic review has investigated if identifying elevated SEM in patients at risk of PI/PU, and correspondingly implementing enhanced skin care interventions, reduces the incidence of PI/PU when compared to a control group receiving usual care. Thus, this is the background for the current systematic review.

2 | RESEARCH QUESTION

The research question explored in this systematic review was:

> Do SEM assessments impact healthcare practitioners' delivery of PI/PU care pathways, among adults at risk of developing PI/PUs?

2.1 | Aim

The aim of this systematic review was to evaluate all publications which describe changes in clinical decision-making and in the delivery of PI/PU care pathways as a result of detecting an abnormally raised SEM delta ($\Delta \geq 0.6$). In other, words, what difference does the detection of an abnormal SEM delta make to clinical care pathways? The end goal is to answer the 'so what' and 'what next' after HCPs detect localised oedema via SEM assessments.

3 | METHODS

3.1 | Design

The design was a systematic review. The author team followed the standard approach advocated for systematic reviews and used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to guide the conduct and reporting of the meta-review. The study protocol was pre-registered with the International Prospective Register of Systematic Reviews (CRD42023416975). To focus the review, the components of the PEO were employed as follows:

1. Population: Adults at risk of developing PI/PUs
2. Exposure: Assessment using SEM measurement and implementing surface, skin inspection, keep moving, incontinence/moisture, nutrition (SSKIN) bundle or other PI/PU prevention interventions based on SEM assessments. Each component of SSKIN represents a key aspect of pressure injury prevention. Skin assessment involves regular inspection and care of the skin to identify any signs of damage or breakdown. Surface selection emphasises the importance of choosing appropriate support surfaces to reduce pressure and friction on vulnerable areas. Keep moving stresses the need for regular repositioning of patients to alleviate prolonged pressure on specific body areas. Incontinence management involves maintaining skin integrity by promptly addressing moisture-related issues. Finally, ensuring adequate nutrition and hydration supports overall skin health and resilience, further reducing the risk of pressure injuries
3. Outcome: Primary-changes in the delivery of PI/PU care pathways. Secondary-PI/PU incidence, SEM deltas, change in SEM delta scores, nurse experience and feedback on the use of the SEM Scanner and the care pathway.

3.2 | Inclusion and exclusion criteria

The inclusion criteria were as follows:

1. Publication includes the use of sub-epidermal moisture assessment for PI/PU prevention
2. English
3. Original research design; prospective and retrospective
4. All settings
5. All types of articles and online materials including publicly available conference proceedings, national and international guidelines

The exclusion criteria were as follows:

1. Review articles, animal studies, and bench/laboratory tests
2. Non-English

3.3 | Electronic searches

The following databases were searched:

1. PROSPERO, PubMed, Cochrane Wounds Group Specialized Register, CENTRAL (The Cochrane Central Register of Controlled Trials), EMBASE, EBSCOCINAHL, ClinicalTrials.gov, Web of Science, ScienceDirect, Scopus and Google Scholar.
2. PubMed Search Strategy: (Sub-epidermal Moisture) OR (SEM) OR (Subepidermal Moisture) AND (Pressure ulcer)
3. This search was adapted to other online databases according to the syntax required in each database.

To identify further published, unpublished and ongoing studies, this systematic review;

1. Scanned reference lists of all identified studies and reviews to assess for further relevant citations;
2. Performed a manual search of relevant grey literature, to enhance the capture of relevant and unique literature (i.e., OpenGrey www.opengrey.eu);
3. Searched conference proceedings, research reports and dissertations.

Search limits: Inception (earliest search date in databases) until April 2023 with no limitations applied.

The keywords used in the search included: SSK

1. #1 Pressure Ulcer OR Ulcer, Pressure OR Ulcers, Pressure

2. #2 Bedsore OR Bedsores OR Bed Sores OR Bed Sore OR Sore, Bed OR Sores, Bed
3. #3 Pressure Sore OR Pressure Sores
4. #4 Decubitus Ulcer OR Decubitus Ulcers OR Ulcer, Decubitus OR Ulcers, Decubitus
5. #5 Pressure Injury OR Pressure Injuries
6. #6: #1 OR #2 OR #3 OR #4 OR #5
7. #7: SEM OR Subepidermal moisture OR Sub-epidermal moisture OR Sub-epidermal moisture
8. #8: #6 AND #7

3.4 | Study selection

Article titles were assessed by two authors independently, and the abstracts of the studies (when available) identified by the search strategy were screened for their eligibility, according to the inclusion and exclusion criteria. The full-text versions of potentially relevant studies were obtained, and the same two authors independently screened these against the inclusion criteria. Consensus between the two authors in relation to the studies and the data to be included was obtained through a discussion when discrepancies were identified.

3.5 | Data extraction

Data from the included articles were extracted and entered into a pre-designed table using the following headings: study name, author, date of the study, setting, sample size, design, outcomes, and limitations. This was undertaken independently by two authors.

3.6 | Data analysis and quality appraisal

Following data extraction both a narrative analysis and a meta-analysis statistical synthesis was considered appropriate. First, the data were narratively summarised, giving an overview of the study setting, geographical location, study settings, sample sizes, and primary and secondary outcomes. Data are presented using means and standard deviations to depict the data obtained.

Meta-analysis statistical synthesis was undertaken using RevMan.[29] Results of comparable trials were pooled using either a fixed-effect model or random effects model, depending on heterogeneity which was investigated using the I^2 statistic. Relative risks (RRs) and 95% confidence intervals (CI) were calculated for dichotomous outcomes.

The quality of the studies was assessed independently by two authors. The methodological quality of the included articles was assessed using the Evidence-based Librarianship (EBL) Checklist. This quality appraisal tool assesses the validity, applicability, and appropriateness of a study, based on four main steps of the research process: Population; Data collection; Study design; Results. According to this checklist, if the overall validity of the study (Yes/Total) is ≥75% or (No + Unclear/Total) is ≤25% then the study is valid.[30]

4 | RESULTS

4.1 | Overview of all included studies

Figure 1 outlines the flow of articles through the reviews. As can be seen, following reviews of titles and abstracts from a total of 746 hits, 728 were excluded. Then, following a review of the full papers of the remaining hits, five were rejected as they did not report results on changes in the delivery of PI/PU care pathways (see Table 1). Finally, 10 studies (conducted between 2017 and 2022) were deemed to meet the inclusion criteria.[31–40] These studies form the basis of this review.

4.2 | Study design

The research was conducted from 2017 to 2022. A total of 30% ($n = 3$) of the studies employed a pragmatic design.[34,37,40] Additionally, one study was quantitative quasi-experimental observational,[31] one was a pilot randomised controlled trial,[32] one case study,[33] one was a pilot study,[35] one was a retrospective study[36] and one was a before-after study.[38] Finally, one was a descriptive study[39] (see Table 2).

4.3 | Geographical location

The studies were conducted in various geographical locations. One study was conducted across multiple countries, including the UK, Ireland, Belgium, and Spain.[36] The majority of the remaining studies were conducted in the UK ($N = 7$, 70%),[33–37,39,40] followed by Ireland,[31] Australia,[32] and Canada[38] (see Table 2).

4.4 | Study settings

The study settings included hospitals, long-term care, community care and palliative care settings. The most common setting was the hospital ($n = 8$, 80%) (see Table 2).

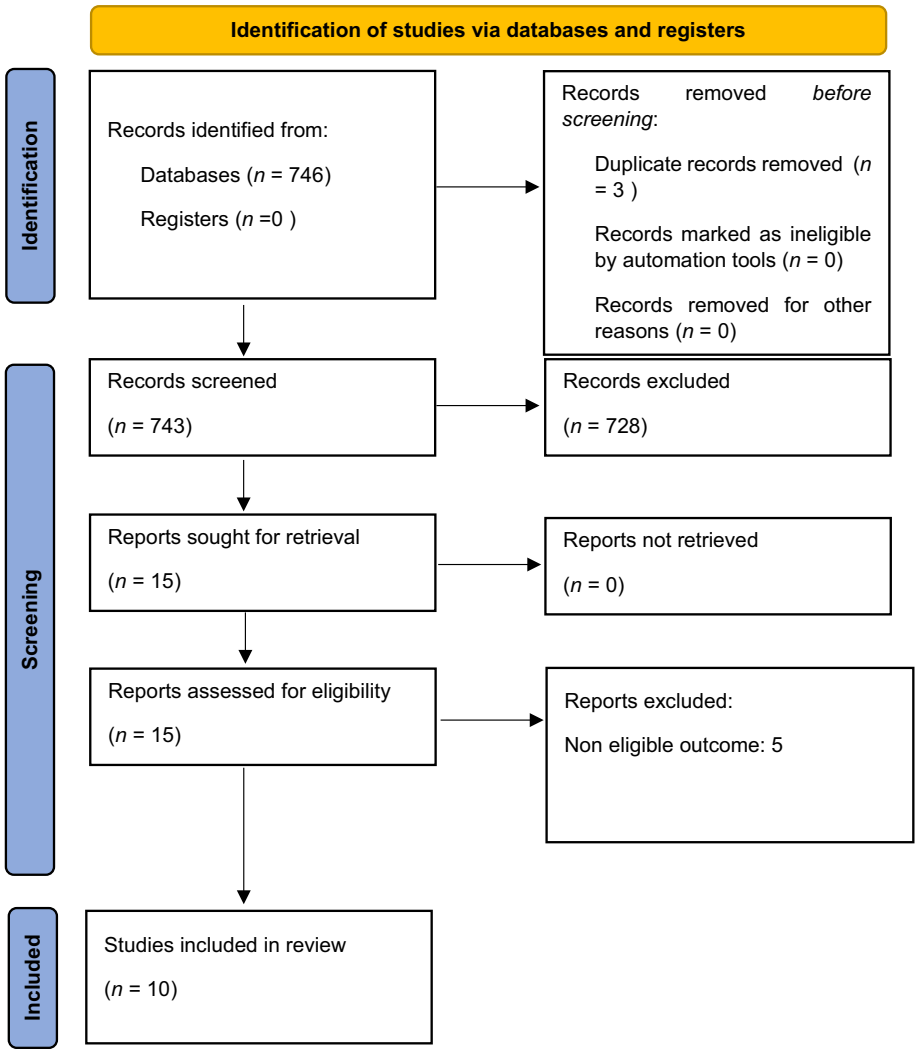

FIGURE 1 PRISMA flow diagram for study selection.

TABLE 1 Excluded studies with reasons.

Author	Reason for exclusion
Martins de Oliveira, O'Connor[41]	Non-eligible outcome
Okonkwo, Bryant[42]	Non-eligible outcome
Budri[43]	Non-eligible outcome
O'Brien, Moore[44]	Non-eligible outcome
Kim, Park[13]	Non-eligible outcome

4.5 | Sample size

The mean sample size was 502 (SD = 653; min 17,[35] max 1995[36]).

4.6 | Subepidermal moisture assessment technolgy

The studies employed either the first-generation SEM Scanner model 200[33–40] or the second-generation Provizio® SEM Scanner.[31,32]

4.7 | Elements of care pathways

The studies included diverse care pathways to prevent PI/PUs, including the SSKIN bundle, pressure-redistributing mattresses, barrier creams, repositioning schedules, patient education, ward-based care, and nutrition plans. See Table 3 for detailed information on these elements.

4.8 | Results for the primary outcome: impact of SEM assessments on the delivery of PI/PU care pathways

4.8.1 | Change in practice

All the studies included in this systematic review, except one, reported that a change in clinical practice took place as a result of SEM assessments. One study[32] reported the proportion of time participants received the PIP. In seven of the studies, use of the scanner was reported to impact care delivery, through the implementation of a guided

TABLE 2 Study characteristics.

Authors	Country	Setting	Unit	Design	Sample sizes (*n*)	SEM device	Intervention	Control
Byrne, Patton[31]	Ireland	Acute hospital	Acute medical wards	Quantitative quasi-experimental observational approach	$N = 149$ (78 in the intervention group and 71 in the control group)	The Provizio® SEM (Bruin Biometrics)	• SEM deltas and VSA recorded daily for a maximum of 5 days using the SEM Scanner (Bruin Biometrics LLC, Los Angeles, CA), on three sites: the sacrum, the right heel, and the left heel. • The participants in the intervention group received SSKIN bundle care based on their daily SEM delta, if they had an abnormal delta, the researcher requested the participant's nurse to arrange additional enhanced SSKIN interventions as appropriate.	• SEM deltas and VSA recorded daily for a maximum of 5 days using the SEM Scanner (Bruin Biometrics LLC, Los Angeles, CA), on three sites: the sacrum, the right heel, and the left heel. • The participants in the control group had usual care used in the hospital and received prevention care based on the SSKIN bundle with the need for the use of the bundle based on their risk assessments and visual skin assessments.
Campbell, Chaboyer[32]	Australia	Tertiary hospital	Medical and surgical wards	Pilot randomised controlled trial	$N = 99$ (intervention $N = 50$; control $N = 49$)	The Provizio® SEM (Bruin Biometrics)	• The intervention group underwent daily SEMS of the sacrum and heels Monday to Friday as well as receiving routine care. • The RA reported SEM delta values	• The control group received routine care without SEMS, measurement.

(Continues)

TABLE 2 (Continued)

Authors	Country	Setting	Unit	Design	Sample sizes (*n*)	SEM device	Intervention	Control
							to the nurse <0.6 reported as normal, and ≥0.6 as abnormal. • If abnormal, the RA told the bedside nurse that the SEMS results indicated early tissue damage that may develop into a PI, but no suggestions for PI prevention provided.	
Fletcher[33]	England	Hospital	Medical and surgical wards	Case study	$N = 35$	SEM Scanner (Bruin Biometrics)	• Patients with a Waterlow score of 10 or above, who could not be repositioned were assessed • Scanning took place on admission and at the same time daily thereafter • Patients followed up from admission to discharge and beyond and monitoring continued during the outpatient phase, for comparison with patients in the ward's care • Registered nurses interpreted the	N/A

TABLE 2 (Continued)

Authors	Country	Setting	Unit	Design	Sample sizes (*n*)	SEM device	Intervention	Control
							results and adjusted the clinical preventative interventions in accordance with the findings.	
Nightingale and Musa[34]	England	Hospital	Four wards, Ward A (Orthopaedic Trauma), Ward B (Stroke/ Neurology Rehab), Ward C (Medical) and Ward D (Orthopaedic Trauma)	Pragmatic design	$N = 697$ N (Ward A) = 194 N (Ward B) = 155 N (Ward C) = 212 N (Ward D) = 136	SEM Scanner (Bruin Biometrics)	• Enrolled patients scanned once daily using the device at the sacrum and heels per the instructions for use. • Patients with an SEM delta <0.6 were considered at lower risk of developing PI/PUs. • When a high delta (≥0.6) was recorded, nurses alerted by the device to an increased risk of developing PI/PUs. Additional early SoC interventions provided based on device readings in conjunction with clinical judgement. • For each day scanned per patient, risk assessment scores,	N/A

(Continues)

TABLE 2 (Continued)

Authors	Country	Setting	Unit	Design	Sample sizes (*n*)	SEM device	Intervention	Control
							SEM delta values from the sacrum, left and right heels, skin and tissue assessments, results, and interventions provided recorded	
Ore[35]	England	Two district nursing centres	Palliative care	Pilot study	$N = 17$	SEM Scanner (Bruin Biometrics)	• Patients with Waterlow scores 10–19 who were able to be scanned for three consecutive days were included. • Broken skin not scanned, and visual skin checks were documented after SEM scans. • Patients with SEM delta ≥0.6 were considered at high risk and preventive interventions were escalated using a clinical decision matrix aligning with SoC.	N/A
Ousey, Stephenson[36]	UK, Ireland, Belgium, Spain	Hospital, long-term care	Setting type was dichotomised into two categories using the ward classification: ● Category A (including older patients/long-term	Retrospective study	15 574 patient assessments ('cases') reported on 1995 patients.	SEM Scanner (Bruin Biometrics)	• The relationship between technology-generated prompts for clinical action (patient turning, application of	N/A

TABLE 2 (Continued)

Authors	Country	Setting	Unit	Design	Sample sizes (*n*)	SEM device	Intervention	Control
			care, orthopaedic/ trauma, rehabilitation, stroke, neurology, medium-to-long-term stay medical and community settings) ● Category B (including general medical, ICU, mixed surgical, renal, vascular, orthopaedic/short stay trauma, diabetes and palliative settings).				pressure redistributing equipment, heel protection or cream) and consequent clinical action was evaluated using data cross-tabulations (using data aggregated over multiple anatomical sites);	
Raizman, MacNeil[38]	Canada	Three hospitals and five satellite sites	N/A	Before-after study	$N = 284$; Phase 1 $N = 89$; Phase 2 $N = 195$	SEM Scanner (Bruin Biometrics)	• Phase 1: Patients provided standard-of-care risk assessment and interventions and scanned with the SEM Scanner, but the resulting SEM scores not used to determine interventions. This gave a baseline pressure ulcer incidence rate. • Phase 2: This phase is the same as Phase 1 except the resulting SEM scores used in conjunction with risk assessment scores to	N/A

(Continues)

TABLE 2 (Continued)

Authors	Country	Setting	Unit	Design	Sample sizes (*n*)	SEM device	Intervention	Control
							determine appropriate interventions and care planning.	
Ropper[39]	England	Hospital	Medicine for the elderly, Stroke ward, Trauma orthopaedics, Orthopaedic rehab	Descriptive study	$N = 126$	The Provizio®SEM Scanner (Bruin Biometrics)	• If a delta value of ≥0.6 noted, this prompted staff to make a decision on how to intervene using current practice guidelines to prevent a HAPU developing.	N/A
Raine[37]	England	Hospital	Palliative care	Pragmatic design	$N = 146$	SEM Scanner (Bruin Biometrics)	• Pre-study PI/PU incidence data in the preceding 12-month period obtained through Marie Curie Hospice's central database. • Initial assessments including SEM scans, Waterlow, and STAs performed at patient admission. While all patients considered at-risk of developing a PI/PU due to the long-term hospice setting, subsequent assessments performed as described in a detailed care	N/A

TABLE 2 (Continued)

Authors	Country	Setting	Unit	Design	Sample sizes (*n*)	SEM device	Intervention	Control
							pathway, introducing SEM scanning into routine practice. • A positive SEM Scanner indication defined as a patient having SEM delta (Δ) ≥0.6 in three consecutive SEM assessments at a specific area of their anatomy. • Preventive interventions were prompted by SEM data • All other care procedures continued as per standard of care • Any new PI/PU recorded and reported as per facility protocols.	
Musa[40]	UK	Multi-site	15 participating sites: 13 acute care, onepalliative care and one community care setting.	Pragmatic design	$N = 1478$	SEM Scanner (Bruin Biometrics)	• The study used a pragmatic 'real-world' approach. HAPU data before and during SEM Scanner use obtained through routine audits. • Patients had regular visual and daily SEM Scanner skin assessments over	N/A

(Continues)

TABLE 2 (Continued)

Authors	Country	Setting	Unit	Design	Sample sizes (*n*)	SEM device	Intervention	Control
							the sacrum and heels. • Nursing care otherwise followed standard of care according to the established protocols of individual participating sites.	

Abbreviations: HAPU, hospital acquired pressure ulcer; ICU, intensive care unit; PI, pressure injury; PU, pressure ulcer; RA, research assistant; SEMS, sub-epidermal moisture scans; SoC, standard of care; SSKIN, surface, skin inspection, keep moving, incontinence/moisture, nutrition; STA, skin tissue assessments; VSA, visual skin assessment.

care plan.[31,32,34–37,40] However, not all of the studies specified which interventions were given to whom within the study; rather the assumption was that the care was delivered as directed facility protocols and flow charts which outlined SEM assessment integrated care plans.[33,38,39]

The studies of Nightingale and Musa,[34] Ropper,[39] Ousey, Stephenson[36] and Musa[40] reported the percentage of patients with changes in care planning. The mean rate of change in clinical decision-making was 62.4% (SD = ±20.4). The minimum rate of change was 35.3%,[36] and the maximum was 83%.[34] Specifically the percentage change in care planning was 83% in Nightingale and Musa,[34] 75% and 79% for Ward A and Ward B, respectively, in Ropper,[39] 40% in Musa[40] and 35.3% Ousey, Stephenson,[36] (see Table 4).

4.8.2 | Nature of the change in practice

Some authors were more specific about the intervention the patients' received, for example, use of a support surface, a repositioning schedule, application of a barrier cream, off-loading of heels and use of a prophylactic dressing.

Support surfaces

Five of the studies reported a change in clinical decision-making with reference to use of support surfaces.[31,34,35,37,40] The mean increase in use of support surfaces was 66.6% (SD = ±13; min: 41% [Raine 2021], max: 77.19%)[31] (see Table 4). Campbell, Chaboyer[32] reported the time participants received support surfaces and this was the same in both the intervention and control groups.

Repositioning schedule. Five studies[31,34,35,37,40] reported changes in clinical decision-making regarding reposition schedules. The mean increase repositioning was 74.6% (SD = ±9; min: 41%,[37] max: 91%[31]) (see Table 4).

Barrier cream. Four studies[31,34,40] reported changes in their clinical decision-making regarding the application of barrier cream. The mean rate of use of a barrier cream was 66.2% (SD = ±6.3; min: 60% [Ore,[35] Musa,[40]], max: 71% [Nightingale and Musa[34]]) (see Table 4).

Prophylactic dressing (heels and/or sacrum). Three studies[34,35,40] reported changes in their clinical decision-making regarding the use of prophylactic dressing (heels and/or sacrum). The mean increase rate in the use of prophylactic dressings was 65% (SD = ±6.5; min 60% [Ore[35] and Musa[40] studies], max: 77.19% [Nightingale, 2021]) (see Table 4). Further Campbell (2022) reported the time

TABLE 3 Elements of care pathways.

Author	SSKIN	Use or escalation in the use of pressure redistributing mattresses/ cushions	Application of barrier cream	Implementation or escalation of repositioning schedule	Implementation of offloading techniques for heels	Application of prophylactic dressings to heels and/or sacrum	Increased frequency of full-body assessments by team members	Nutrition care plan	Implementation of patient education initiatives	Implementation of ward-based preventative measures for pressure ulcers
Byrne, Patton[31]	X	X	X	X	X					
Campbell, Chaboyer[32]		X	X	X	X	X		X	X	
Fletcher[33]										X
Nightingale and Musa[34]	X	X	X	X	X	X				
Ore[35]	X	X		X	X	X				
Ousey 2022		X		X	X	X				
Raizman, MacNeil[38]		X		X	X	X	X			
Ropper[39]	X	X	X	X	X	X				
Raine[37]	X	X		X	X	X				
Musa[40]		X	X	X	X	X				

TABLE 4 Impact of sub-epidermal moisture (SEM) assessments on the delivery of pressure ulcer/injury (PI/PU) care pathways.

Author	Intervention	Control
Byrne, Patton[31]	• *Pressure redistribution device* use on day one was 35.38% ($n = 51/78$); on day 2, 80% ($n = 56/70$); on day 3, 84.13% ($n = 53/63$); on day 4, 93.62% ($n = 44/47$) in the treatment group. Finally, on day 5, 92.86% ($n = 26/28$). • *Application of skin cleansing and barrier cream*, occurred for 50% of participants ($n = 39/78$) on day 1, 72% ($n = 46/64$) on day 2, 81% (46/57) on day 3, 77% (34/44) on day 4 and 75% (21/28) on day 5. • *Offloading of heel(s) and/or repositioning schedule of 2 h or less* occurred for 76% of participants ($n = 59/78$) on day 1, 98% ($n = 63/64$) on day 2, 100% (57/57) on day 3, 93% (41/44) on day 4 and 89% (25/28) on day 5.	• *Pressure redistribution device* use on day one was 23.94% ($n = 17/71$), on day 2, 23.44% ($n = 15/64$), on day 3, 25.42% ($n = 15/59$), on day 4, 28.57% ($n = 10/35$), on day 5, 40% ($n = 10/25$) • No participant in the control group had *application of skin cleansing and barrier cream* throughout the study period. • One patient in the control group received *offloading of heel(s) and/or repositioning schedule of 2 h or less* during the study period.
Campbell, Chaboyer[32]	*Proportion of time participants received the PIP (based on their duration in study)*: *Support Surfaces* 92.9% • Non-reactive foam mattress 45.1% • Heel wedge (foam) 8.6% • Other heel elevation or offload device; pillow/bootie 9.2% • Active alternating air cell mattress—replacement 44.5% • Active alternating air cell mattress—overlay 3.3% • Pressure redistributing chair cushion 6.3% *Dressing* • Prophylactic dressing (heels) 2.1% • Prophylactic dressing (sacrum) 31.4% *Nutrition* care plan 3.2% *Repositioning* plan 4.4% *Specialised skin care* (e.g., skin barrier product) 0.0% *Patient education* 92.1%	*Proportion of time participants received the PIP (based on their duration in study)*: *Support Surfaces* 93.0% • Non-reactive foam mattress 48.9% • Heel wedge (foam) 11.5% • Other heel elevation or offload device; pillow/bootie 8.9% • Active alternating air cell mattress—replacement 39.8% • Active alternating air cell mattress—overlay 4.7% • Pressure redistributing chair cushion 0.8% *Dressing* • Prophylactic dressing (heels) 3.7% • Prophylactic dressing (sacrum) 31.6% *Nutrition* care plan 4.5% *Repositioning* plan 2.0% *Specialised skin care* (e.g., skin barrier product) 0.5% *Patient education* 90.2%
Fletcher[33]	• States: Registered nurses interpreted the results and adjusted the clinical preventative interventions in accordance with the findings.	N/A
Nightingale and Musa[34]	• Change in clinical decision-making 83% (578/697) • Increased turning or mobilisation 76% (528/697) • Introducing a specialist surface or mattress 76% (380/697) • Introducing a heel support or elevation of heels 55% (528/697) • Introducing a prophylactic dressing or barrier cream 74% (515/697)	N/A
Ore[35]	Clinical judgement informed by skin and tissue assessments (STAs) and SEM deltas resulted in 94% ($n = 16$) of patients, receiving interventions • increased turning or mobilisation (71%, $n = 10$), • specialist mattress (71%, $n = 10$), • heel support or elevation (86%, $n = 12$), • and prophylactic dressing or barrier cream (60%, $n = 9$)	N/A

TABLE 4 (Continued)

Author	Intervention	Control
	Clinical judgement informed by SEM deltas alone, where STAs did not show visible discoloration, resulted in changed clinical decision-making in 82% of patients ($n = 14/17$).	
Ousey, Stephenson[36]	Consequence of scanner readings at all locations ($n = 15\ 574$) • Prompt for nurse action given 13 071 (83.9%) • No prompt for nurse action given 2503 (16.1%) Consequence of prompt ($n = 15\ 574$) • Action taken by nursing staff: 5494 (35.3%) • No action taken by nursing staff 10 080 (64.7%)	N/A
Raizman, MacNeil[38]	SEM values triggered increased interventions: • more advanced support surfaces, • increased turning and repositioning schedules, • more frequent full-body assessment by the SOS team member, • Heel boots or positioning devices, and a special sacral dressing. • The subscales of the Braden and the SEM value at the individual body site directed targeted interventions.	N/A
Ropper[39]	In wards A and B, for 75% and 79% of patients respectively, use of the SEM Scanner changed the clinical decision-making of staff that day and they introduced additional interventions into patient's care plans • Increased turning/mobilisation today • Introduced specialist surface/mattress today • Heel supports or elevation introduced today • Started prophylactic dressing or barrier cream today.	
Raine[37]	• Impact of SEM data in health practitioners' clinical decision-making and subsequent anatomically specific interventions health practitioners' change in clinical decision-making from subepidermal moisture assessments 58/145 patients (40%) • Increased turning or mobilisation 37/58 (64%) • Introducing a specialist surface 24/58 (41%) • Introducing heel support or elevation of heels 33/58 (57%).	
Musa[40]	• Results from the palliative care setting showed that health professionals changed their clinical decisions for 58 (40%) of the 146 patients who were SEM scanned. • Clinical judgement informed by SEM deltas alone, where skin and tissue assessments did not show visible discolouration, resulted in changed health professional clinical decision-making in 82% of patients ($n = 14/17$). ○ 71% had an increase in mobilisation or turning and a change in speciality or high-specification foam mattress. ○ 86% had heel supports or elevation of heels implemented ○ 60% received a prophylactic dressing or application of a barrier cream.	

participants received prophylactic dressings and this was the same in both the intervention and control groups.

Offloading of heels. Five studies[31,34,35,37,40] reported changes in their clinical decision-making regarding offloading of heels. The mean increase rate heel offloading was 75% (SD = ±15.6; min 55% [Nightingale 2021], max: 91% [Byrne 2022]) (see Table 4).

4.9 | Results for the secondary outcomes

4.9.1 | Development of pressure ulcers/injuries

Visual pressure ulcer/injury development

Ten studies were included in the analysis, all of which reported rates of visual PI/PU development. Three of these studies specifically focused on post-implementation of care pathways (Fletcher, 2017; Ousey, 2022; Ropper 2021). Among these, Fletcher[33] and Ropper[39] found no PI/PU development, whereas in Ousey, Stephenson,[36] 33.6% of the patient assessments by anatomy (5172 out of 15 375) showed skin reddening (see Table 5).

A meta-analysis was performed using the data from the remaining seven studies.[31,32,34,35,37,38,40] Figure 2 outlines the results of the meta-analysis and as can be seen, the I^2 is 12%, indicating low heterogeneity, therefore, a fixed-effects model was used for the meta-analysis.

As can be seen from Figure 2, there is a statistically significant difference in visual PI/PU development in favour of the use of care pathways based on SEM assessments (PU incidence 1%, 27/2661, care pathway group, versus 25%, 401/15 790 usual care group). The odds ratio (OR) = 0.36 (95% CI: 0.24–0.53, $p < 0.00001$), which suggests that there is a 64% reduction in the odds of PI/PU development for the care pathway implementation group. We are 95% confident that the true population parameter lies between a 47% reduction to a 76% reduction in PI/PU development.

SEM pressure ulcer/injury development

One study reported SEM-detected early PI/PU development rates.[31] In this study, 'SEM Pressure Ulcer' was operationally defined as SEM readings ≥0.5 sustained over two or more days over any anatomical site, after day 1. In the treatment group: 23% ($n = 18/78$), developed a SEM-detected early PI/PU, whereas in the control group, this was 38% ($n = 27/71$). The OR of developing a SEM-detected early PI/PU was 0.59 (95% CI: 0.24–1.00; $p = 0.05$). This indicates a statistically significant reduction in the odds of SEM-detected early PI/PU development, in favour of the treatment group (see Table 5).

4.9.2 | Change in SEM delta scores over time

One study reported on the change in SEM delta scores over time. In Byrne, Patton[31] the participants in the treatment group experienced a statistically significant reduction in mean SEM delta scores from baseline to study end, in favour of the treatment group (mean difference: 0.49; 95% CI: 0.59–0.39; $p < 0.0001$).

4.9.3 | Nurse experience and feedback on the use of the SEM Scanner as a component of pressure ulcer/injury prevention strategies

Two studies (Raizman, MacNeil,[38] Raine,[37]) provide data on the nurse experience and feedback on the use of the SEM Scanner in the context of patient pressure injury/ulcer prevention (see Table 6). Both studies noted that nurse experience and confidence in using the SEM Scanner improved with increased exposure and experience. In both studies, the SEM Scanner demonstrated its effectiveness in identifying patients with a deviation (delta) of ≥0.6, which alerts nurses to take appropriate clinical action promptly. Raine[37] showed that the majority of nursing staff found the SEM Scanner easy to learn, operate, and integrate into their clinical practice and all nursing staff (100%) agreed that the data provided by the SEM Scanner was clinically meaningful.

4.9.4 | Staff feedback for the care pathway

The feedback data from Ropper[39] indicates that staff responded positively to the clarity and user-friendliness of the implemented care pathway for PI/PU prevention, finding it easy to follow and beneficial in their clinical practice. The study also highlights the importance of addressing concerns about consistent adherence to the pathway and accommodating staff requests for the inclusion of additional equipment decision-making factors through ongoing education and pathway improvement (see Table 7).

4.10 | Quality appraisal of included studies

The quality appraisal assessment is summarised in Table 8, which provides the validity figures in each domain. The mean validity score for all studies was 87% (SD: ±5.56%; min: 80.5%,[33] max: 96%[32]). As shown in Table 8, all studies scored ≥75%, indicating validity.

TABLE 5 Development of pressure ulcers/injury (visual/PI/PU–SEM PI/PU).

Author	Visual PU	SEM PU
Byrne, Patton[31]	• *Treatment group*: 0/78 • *Control group*: 1.41% ($n = 1/71$); two PUs, one on the left heel and one on the right	• *Treatment group*: 23% ($n = 18/78$) • *Control group*: 38% ($n = 27/71$) $p = 0.05$
Campbell, Chaboyer[32]	• *Treatment group*: 0% (0/50) • *Control group*: 2% ($N = 1/49$) (stage 1, located on the sacrum).	*Treatment group*: 34 participants remained in the study for ≥3 days, • 13 (38.2%), 14 (41.1%), 15 (44.1%) participants respectively having a sacral, left, and right heel abnormal SEM delta (≥0.6) for ≥3 consecutive measurement days. Unclear whether these are all separate patients or whether some of them are patients with more than one anatomical location affected. Control group: N/A not scanned using SEM
Fletcher[33]	• *Post-implementation*: 0% (0/35) (no control group) One patient on the ward and one patient followed in the community after discharge developed a PU, but this was also not due to care on the ward	N/A
Nightingale and Musa[34]	• *Pre-implementation*: *Total*: 2% ($n = 42/2846$) • *During implementation*: *Total*: 3% ($n = 2/697$)	N/A
Ore[35]	• *Pre-implementation*: 16.1% (37/230) • *Post-implementation*: 11.8%; ($n = 2/17$)	N/A
Ousey, Stephenson[36]	• *Post-implementation*: Skin Reddening observed: 33.6% (5172/15375)	N/A
Raizman, MacNeil[38]	• *Pre-implementation*: 13.5% (12/89) ○ Stage I: 4 (33%); Stage II: 6 (50%); Stage III: 1 (8%); Stage IV: 0 (0%); Unstageable/deep tissue injury 1 (8%) • *Post-implementation*: 1.0%. (2/195) ○ Stage I: 1 (50%); Stage II: 1 (50%); Stage III: 0 (0%); Stage IV: 0 (0%); Unstageable/deep tissue injury 0 (0%)	N/A
Ropper[39]	• *Post-implementation*: 0% (0/126)	N/A
Raine[37]	• *Pre-implementation*: 9% (34/377) • *During implementation*: 4.8% (7/146)	N/A
Musa[40]	• *Pre-implementation*: HAPU incidence • Acute care setting 1.6% (192/11521) • Palliative care 9.0% (34/377) • Community care: district nursing 16.1% (37/230) ○ *Total*: 22% (263/12128) • *Post-implementation*: HAPU incidence • Acute care setting 0.3 (5/1315) • Palliative care 4.8 (7/146) • Community care: district nursing 11.8 (2/17) ○ *Total*: 9% (14/1478)	N/A

Abbreviations: HAPU, hospital acquired pressure ulcer; PI/PU, pressure ulcer/injury; SEM, sub-epidermal moisture.

5 | DISCUSSION

The aim of this systematic review was to explore the literature on the delivery of PI/PU care pathways as a result of detecting abnormal SEM deltas ($\Delta \geq 0.6$), and 10 studies met the inclusion criteria. The primary outcome of this systematic review was to explore the impact of SEM assessments on the delivery of PI/PU care pathways. Nine studies reported that SEM assessments led to a change in clinical practice. This stems from the utility of SEM assessments in detecting developing localised oedema and developing tissue damage prior to visible and tactile signs, enabling HCPs to provide tailored PI/PU care plans to the right anatomy that is developing

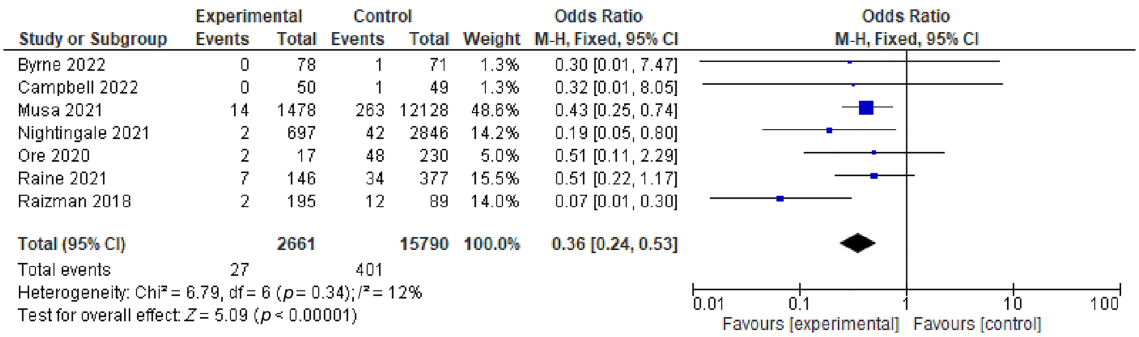

FIGURE 2 Forest plot, implementation of care pathways based on sub-epidermal moisture assessments versus usual care, Outcome: Visual pressure ulcer/injury development. CI, confidence interval.

TABLE 6 Nurse experience and feedback on the use of the SEM Scanner.

Raizman, MacNeil[38]	• Nurse experience and feedback on the device improved with experience. Initial training and follow-up skills checks were important in ensuring consistency and accuracy. • Examiners gained confidence in their skills and in the results of the implementation of the scanner as their experience increased and data results were shared with them.
Raine[37]	Feedback in percentage of 'yes' responses from nursing staff ($n = 26$) who completed the post-study survey in adopting the SEM Scanner to the patient pressure ulcer/injury care pathway: • In my experience, it was easy to learn to use and operate the device 92% (24/26) • Scanning each patient was quick and I was able to scan each patient easily 88% (23/26) • Finding patients with a deviation (delta) of ≥0.6 alerted me to take appropriate clinical action 100% (26/26) • The device provides additional information to support my decision-making about my patient's PU care 100% (26/26) • Did the device provide clinically meaningful data about tissue damage (Y) 100% (26/26)

Abbreviations: SEM, sub-epidermal moisture; PU, pressure ulcer.

TABLE 7 Staff feedback for the care pathway.

Ropper[39]	• The majority of staff who provided written comments on the feedback forms noted that they found the pathway clear to follow and easy to use. ○ 'Flow chart easy to read and follow' ○ 'No issues with understanding this' ○ 'Very helpful and concise.' • One registered nurse commented: 'Pathway is good, but will staff use it often or keep referring to old guideline for mattress ordering?' This raises the issue of the need for ongoing staff education to support implementation of new guidance. • Two staff requested that the pathway include a range of other factors to consider when deciding on equipment.

damage. This indicates a promising shift toward more personalised and evidence-based care for patient at risk of PI/PU. It is important to note that some studies did not specify the precise interventions administered. Conversely, other studies provided more specific insights into the nature of changes in practice driven by SEM assessments. These changes ranged from the increased and appropriate use of support surfaces and repositioning schedules to the application of barrier creams, off-loading of heels, and prophylactic dressing. Furthermore, in one study[24] this targeting of abnormal SEM deltas with appropriate anatomy-specific interventions halted the progression of tissue damage and reduced localised oedema. In seven studies[24,25,27,28,30,31,33] a reduction in SEM deltas reduced the incidence of a visual PI/PU. This systematic review of published data, therefore, identified evidence to suggest that implementing SEM assessments can positively impact PI/PU care delivery and improve key quality targets in PI/PU prevention.

Current standard care for PI/PU prevention includes patient risk factor assessment tools (Braden, Waterlow, Norton, etc.,), subjective visual and tactile skin assessments and clinical judgement that is subjective to HCP experience However, a systematic review by Moore and Patton[7] found that the Braden and Waterlow risk assessment tools have a low certainty of evidence. Other similar studies regarding the use of risk assessment tools have reported poor predictive validity, issues with inter-rater reliability, low sensitivity, and low specificity. Further, these risk assessments tools are designed to indicate risk

TABLE 8 Validity scores of included studies.

The validity of included studies %					
	Study category %				
Author	Population	Data collection	Study design	Results	Overall results %
Byrne, Patton[31]	98% (valid)	98% (valid)	80% (valid)	100% (valid)	92.6% (valid)
Campbell, Chaboyer[32]	100% (valid)	100% (valid)	100% (valid)	83.3% (valid)	96.3% (valid)
Fletcher[33]	42% (not valid)	80% (valid)	100% (valid)	100% (valid)	80.5% (valid)
Musa[40]	100% (valid)	75% (valid)	50% (valid)	66% (not valid)	81% (valid)
Nightingale and Musa[34]	100% (valid)	75% (valid)	80% (valid)	83% (valid)	85% (valid)
Ore[35]	95% (valid)	100% (valid)	80% (valid)	66% (not valid)	92.6% (valid)
Ousey, Stephenson[36]	98% (valid)	75% (valid)	80% (valid)	83% (valid)	85.5% (valid)
Raizman, MacNeil[38]	95% (valid)	100% (valid)	80% (valid)	66% (not valid)	92.6% (valid)
Ropper[39]	100% (valid)	75% (valid)	80% (valid)	66% (not valid)	81.5% (valid)
Raine[37]	95% (valid)	75% (valid)	80% (valid)	83% (valid)	83.2% (valid)

as opposed to objective detection of developing PI/PU damage. Variability in providing consistent risk assessments, in addition to these risk assessments not being anatomy-specific, results in HCPs' inability to provide timely and effective PI/PU prevention interventions. The consequence is a persistent PI/PU incidence rate.[45–47] Additionally, it should be noted that the diagnosis of PI/PUs is usually documented after visual assessment which implies that tissue damage at the macroscopic level has already occurred.[26] Implementing SEM assessments enables to HCPs to avoid this diagnostic and intervention latency and provides a window of opportunity to provide effective interventions in a timely manner. It must be noted that this is "early detection" relative to visual and tactile skin assessments but is "timely" from an etiological perspective, given that localised *oedema* is the earliest sign of cell and tissue death in the PI/PU damage cascade. While SEM assessments are reported to provide real time data on tissue health, it seems that daily assessments of SEM delta provide HCPs with a longitudinal view on how each patient anatomy individually responds to preventive interventions, allowing HCPs to rely on objective data to implement, modify or change interventions effectively. Literature suggests a significant reduction in PI/PU incidence when SEM assessments are implemented as part of daily PI/PU care practices. Moore et al., in their systematic review reported a 93% reduction in PI/PU incidence in the studies they reviewed where HCPs acted based on SEM assessment data. In the meta-analyses identified in this review, Ousey et al. (2022) report a three-fold reduction in the RR of PI/PU incidence (RR: 0.38; 95% CI: 0.26–0.56; $p < 0.001$) when SEM assessments are implemented in daily care practices. These data support the findings of this review in that early detection of tissue damage is critical in directing healthcare practitioners to implement timely preventative interventions when damage is still microscopic and reversible level. Treating localised edema as if it were a stage 1 PI/PU in anatomies that exhibit raised levels of SEM, halts the progression of tissue damage before cells reach the point of death and prevents the development of visible PI/PU. Latencies in providing interventions and diagnosing early stage PI/PU damage may be resolved using SEM assessments that guide anatomy-targeted clinical actions.[22]

Positive nurse experiences and feedback on implementing SEM assessments in routine care practices further highlight the importance of clinical education and HCP training that is necessary to successfully implement new technologies into existing PI/PU prevention pathways. The positive trend of improved confidence and experience among HCPs reported in the reviewed studies suggest that integration of SEM assessments into clinical practice can be successful by proper support and training.

5.1 | Limitations

This systematic review has limitations. First, the majority of the studies included in the review were observational studies. While our systematic review included observational studies, which provide valuable insights, we acknowledge the need for higher-level evidence such as randomised controlled trials to establish a firmer causal

relationship between SEM assessments and the delivery of PI/PU care pathways. It is however important to note that the pragmatic designs and quality improvement approaches explored by the studies identified in this review are significant when considering translating the clinical utility of SEM assessments to the bedside.

Second, the quality of the studies included in the review was variable. Randomized controlled trials and observational studies were well-designed and conducted, while other pragmatic studies were less rigorous. Additionally, it is noted that SEM assessments primarily minimise PI/PU progression via early detection and treatment of damage rather than focusing on risk-based prevention. Despite its limitations, this systematic review suggests that SEM assessments maybe a valuable tool for preventing PI/PU at the bedside. Further research, including randomised controlled trials, is needed to confirm the efficacy of interventions for consistent PI/PU prevention in a variety of settings as measured by SEM assessments.

Cost considerations are also crucial when evaluating the implementation of new technologies like SEM assessments. Although the studies identified in this review did not discuss or specifically account for cost efficacy, we note other published data that describe the cost consequences of implementing SEM assessments in multiple care settings. Padula et al.[48] described a Markov cohort model reporting that integrating SEM assessments resulted in a $4054 USD cost-savings per acute care admission. Similarly, Posnett et al.[49] demonstrated a cost-saving of £8.9 GBP per admission in a representative acute care NHS hospital. Relative risk reduction in PI/PU incidence may result in significant cost-savings to healthcare facilities.

5.2 | Recommendations

Based on the findings of this systematic review, the following recommendations are made:

1. Healthcare providers should consider using SEM assessments for early detection of PI/PU development.
2. SEM assessments could be used to inform the development and implementation of tailored PI/PU care pathways.
3. SEM assessments should be considered as the basis for timely interventions prior to visible and tactile manifestation of pressure-induced tissue damage. Clinical decisions based on risk factors and risk assessment tools maybe categorically followed to guide additional interventions.
4. Randomised controlled trials are needed to confirm the efficacy interventions provided based on SEM assessments-based care pathways for preventing PI/PU.

6 | CONCLUSION

This systematic review provides evidence that implementing SEM assessments in patients at risk of developing PI/PU prompts anatomy-specific clinical actions. Furthermore, the subsequent implementation of enhanced and targeted skin care interventions leads to reductions in PI/PU incidence. The findings emphasise the importance of incorporating SEM assessments as part of comprehensive PI/PU prevention strategies in a variety of care settings and patient populations. Further research is needed to confirm the efficacy of interventions via SEM assessments-based care pathways for preventing PI/PU in randomised controlled trials.

ACKNOWLEDGEMENT

Open access funding provided by IReL.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest. We disclose the following financial interest or relationship related to this article: the RCSI School of Nursing & Midwifery has a research collaboration with Bruin Biometrics.

DATA AVAILABILITY STATEMENT

Given that this is a systematic review, there is no requirement for a Data Availability Statement to be provided.

ORCID

Pinar Avsar https://orcid.org/0000-0002-7637-1700
Zena Moore https://orcid.org/0000-0002-4692-9718

REFERENCES

1. European Pressure Ulcer Advisory Panel, National Pressure Injury Advisory Panel and Pan Pacific Pressure Injury Alliance. *Prevention and Treatment of Pressure Ulcers/Injuries: Clinical Practice Guideline*. The International Guideline; 2019.
2. Spronk I, Korevaar J, Poos R, et al. Calculating incidence rates and prevalence proportions: not as simple as it seems. *BMC Public Health*. 2019;19:19. doi:10.1186/s12889-019-6820-3
3. Moore Z, Cowman S, Conroy RM. A randomised controlled clinical trial of repositioning, using the 30 degrees tilt, for the prevention of pressure ulcers. *J Clin Nurs*. 2011;20:2633-2644. doi:10.1111/j.1365-2702.2011.03736.x
4. European Pressure Ulcer Advisory Panel NPIAPaPPPIA, EPUAP/NPIAP/PPPIA. *Prevention and Treatment of Pressure Ulcers/Injuries: Clinical Practice Guideline*. The International Guideline; 2019.
5. Budri AMV, Moore Z, Patton D, et al. Impaired mobility and pressure ulcer development in older adults: excess movement

and too little movement-two sides of the one coin? *J Clin Nurs*. 2020;29:2927-2944. doi:10.1111/jocn.15316

6. Avsar P, Budri A, Patton D, Walsh S, Moore Z. Developing algorithm based on activity and mobility for pressure ulcer risk among older adult residents: implications for evidence-based practice. *Worldviews Evid Based Nurs*. 2022;19:112-120. doi:10.1111/wvn.12545
7. Moore ZE, Patton D. Risk assessment tools for the prevention of pressure ulcers. *Cochrane Database Syst Rev*. 2019;1:CD006471. doi:10.1002/14651858.CD006471.pub4
8. Pancorbo-Hidalgo PL, Garcia-Fernandez FP, Lopez-Medina IM, Alvarez-Nieto C. Risk assessment scales for pressure ulcer prevention: a systematic review. *J Adv Nurs*. 2006;54:94-110. doi:10.1111/j.1365-2648.2006.03794.x
9. Bennett MA. Report of the task force on the implications for darkly pigmented intact skin in the prediction and prevention of pressure ulcers. *Adv Wound Care*. 1995;8:34-35.
10. Bates-Jensen BM, McCreath HE, Pongquan V. Subepidermal moisture is associated with early pressure ulcer damage in nursing home residents with dark skin tones: pilot findings. *J Wound Ostomy Continence Nurs*. 2009;36:277-284. doi:10.1097/WON.0b013e3181a19e53
11. Thoroddsen A, Sigurjónsdóttir G, Ehnfors M, Ehrenberg A. Accuracy, completeness and comprehensiveness of information on pressure ulcers recorded in the patient record. *Scand J Caring Sci*. 2013;27:84-91. doi:10.1111/j.1471-6712.2012.01004.x
12. Oozageer Gunowa N, Hutchinson M, Brooke J, Jackson D. Pressure injuries in people with darker skin tones: a literature review. *J Clin Nurs*. 2018;27:3266-3275. doi:10.1111/jocn.14062
13. Kim CG, Park S, Ko JW, Jo S. The relationship of subepidermal moisture and early stage pressure injury by visual skin assessment. *J Tissue Viability*. 2018;27:130-134. doi:10.1016/j.jtv.2018.05.002
14. Black J. Using thermography to assess pressure injuries in patients with dark skin. *Nursing*. 2018;48:60-61. doi:10.1097/01.Nurse.0000544232.97340.96
15. McEvoy NL, Patton D, Curley GF, Moore Z. Pressure ulcer risk assessment in the ICU. Is it time for a more objective measure? *Intensive Crit Care Nurs*. 2024;83:103681. doi:10.1016/j.iccn.2024.103681
16. Black J, Cox J, Capasso V, et al. Current perspectives on pressure injuries in persons with dark skin tones from the National Pressure Injury Advisory Panel. *Adv Skin Wound Care*. 2023;36:470-480. doi:10.1097/asw.0000000000000032
17. Harrow JJ, Mayrovitz HN. Subepidermal moisture surrounding pressure ulcers in persons with a spinal cord injury: a pilot study. *J Spinal Cord Med*. 2014;37:719-728. doi:10.1179/2045772313y.0000000193
18. Clendenin M, Jaradeh K, Shamirian A, Rhodes SL. Inter-operator and inter-device agreement and reliability of the SEM Scanner. *J Tissue Viability*. 2015;24:17-23. doi:10.1016/j.jtv.2015.01.003
19. Moore Z, Patton D, Rhodes SL, O'Connor T. Subepidermal moisture (SEM) and bioimpedance: a literature review of a novel method for early detection of pressure-induced tissue damage (pressure ulcers). *Int Wound J*. 2017;14:331-337. doi:10.1111/iwj.12604
20. Bliss MR. Aetiology of pressure sores. *Rev Clin Gerontol*. 1993;3:379-397. doi:10.1017/S0959259800003622
21. Gefen A. The Sub-Epidermal Moisture Scanner: the principles of pressure injury prevention using novel early detection technology. *Wounds Int*. 2018;9:10-15.
22. Moore Z, McEvoy NL, Avsar P, et al. Measuring subepidermal moisture to detect early pressure ulcer development: a systematic review. *J Wound Care*. 2022;31:634-647. doi:10.12968/jowc.2022.31.8.634
23. Bryant RA, Moore ZEH, Iyer V. Clinical profile of the SEM Scanner — modernizing pressure injury care pathways using Sub-Epidermal Moisture (SEM) scanning. *Expert Rev Med Devices*. 2021;18:833-847. Review. doi:10.1080/17434440.2021.1960505
24. Gefen A, Brienza DM, Cuddigan J, Haesler E, Kottner J. Our contemporary understanding of the aetiology of pressure ulcers/pressure injuries. *Int Wound J*. 2022;19:692-704. doi:10.1111/iwj.13667
25. Park S, Kim CG, Ko JW. The use of sub-epidermal moisture measurement in predicting blanching erythema in jaundice patients. *J Wound Care*. 2018;27:342-349. doi:10.12968/jowc.2018.27.5.342
26. Gershon S. Using subepidermal moisture level as an indicator of early pressure damage to local skin and tissue. *Adv Skin Wound Care*. 2020;33:469-475. doi:10.1097/01.ASW.0000655380.86380.7b
27. Peko L, Gefen A. Sensitivity and laboratory performances of a second-generation sub-epidermal moisture measurement device. *Int Wound J*. 2020;17:864-867. doi:10.1111/iwj.13339
28. Latimer SL, Bone M, Walker RM, Thalib L, Gillespie BM. Inter-device agreement of sacral subepidermal oedema measurement in healthy adults during prolonged 60° head of bed elevation. *Nurs Open*. 2024;11:e2103. doi:10.1002/nop2.2103
29. The Nordic Cochrane Centre and The Cochrane Collaboration. *Review Manager (RevMan)*. Version 5.3.5. Copenhagen; 2014.
30. Glynn L. A critical appraisal tool for library and information research. *Libr Hi Tech*. 2006;24:387-399. doi:10.1108/07378830610692154
31. Byrne S, Patton D, Avsar P, et al. Sub epidermal moisture measurement and targeted SSKIN bundle interventions, a winning combination for the treatment of early pressure ulcer development. *Int Wound J*. 2023;20:1987-1999. doi:10.1111/iwj.14061
32. Campbell J, Chaboyer W, Tobiano G, et al. The effect of subepidermal moisture on pressure injury prevention strategies and incidence of pressure injuries: a feasibility pilot randomised controlled trial. *J Tissue Viability*. 2022;31:776-782. doi:10.1016/j.jtv.2022.07.008
33. Fletcher J, Moore Z, Smith G. Early detection technology transforms care and releases productivity: an NHS case study. *Wounds UK*. 2017;2017(13):74-78.
34. Nightingale P, Musa L. Evaluating the impact on hospital acquired pressure injury/ulcer incidence in a United Kingdom NHS Acute Trust from use of sub-epidermal scanning technology. *J Clin Nurs*. 2021;30:2708-2717. doi:10.1111/jocn.15779
35. Ore N, Carver T. Implementing a new approach to pressure ulcer prevention. *J Community Nurs*. 2020;34:52-57.
36. Ousey K, Stephenson J, Blackburn J. Sub-epidermal moisture assessment as a prompt for clinical action in treatment of pressure ulcers in at-risk hospital patients. *J Wound Care*. 2022;31:294-303. doi:10.12968/jowc.2022.31.4.294

37. Raine G. Is it time to re-evaluate the inevitability of ulcers at the end of life? *Int J Palliat Nurs*. 2021;27:440-448. doi:10.12968/ijpn.2021.27.9.440
38. Raizman R, MacNeil M, Rappl L. Utility of a sensor-based technology to assist in the prevention of pressure ulcers: a clinical comparison. *Int Wound J*. 2018;15:1033-1044. doi:10.1111/iwj.12974
39. Ropper R. The benefits of using a first generation SEM scanner versus an equipment selection pathway in preventing HAPUs. *Br J Nurs*. 2021;30:S12-S23. doi:10.12968/bjon.2021.30.15.S12
40. Musa L. Clinical impact of a sub-epidermal moisture scanner: what is the real-world use? *J Wound Care*. 2021;30:198-208. doi:10.12968/jowc.2021.30.3.198
41. Martins de Oliveira AL, O'Connor T, Patton D, Strapp H, Moore Z. Sub-epidermal moisture versus traditional and visual skin assessments to assess pressure ulcer risk in surgery patients. *J Wound Care*. 2022;31:254-264. doi:10.12968/jowc.2022.31.3.254
42. Okonkwo H, Bryant R, Milne J, et al. A blinded clinical study using a subepidermal moisture biocapacitance measurement device for early detection of pressure injuries. *Wound Repair Regen*. 2020;28:364-374. doi:10.1111/wrr.12790
43. Budri A. Identification of increased risk of pressure damage with a sub-epidermal moisture scanner: clinical outcomes and cost-effectiveness. *Br J Health Care Manag*. 2020;26:1-10. doi:10.12968/bjhc.2020.0035
44. O'Brien G, Moore Z, Patton D, O'Connor T. The relationship between nurses assessment of early pressure ulcer damage and sub epidermal moisture measurement: a prospective explorative study. *J Tissue Viability*. 2018;27:232-237. doi:10.1016/j.jtv.2018.06.004
45. Hyun S, Vermillion B, Newton C, et al. Predictive validity of the Braden scale for patients in intensive care units. *Am J Crit Care*. 2013;22:514-520. doi:10.4037/ajcc2013991
46. Iranmanesh S, Rafiei H, Sabzevari S. Relationship between Braden scale score and pressure ulcer development in patients admitted in trauma intensive care unit. *Int Wound J*. 2012;9:248-252. doi:10.1111/j.1742-481X.2011.00852.x
47. Tannen A, Balzer K, Kottner J, Dassen T, Halfens R, Mertens E. Diagnostic accuracy of two pressure ulcer risk scales and a generic nursing assessment tool. A psychometric comparison. *J Clin Nurs*. 2010;19:1510-1518. doi:10.1111/j.1365-2702.2009.03005.x
48. Padula WV, Solowiej K, Narbrink MN, Allen L, Laurent DD, Mishra MK. The cost-effectiveness of sub-epidermal moisture scanning to assess pressure injury risk in U.S. hospitals. *J Wound Care*. 2020;29(9):S4-S10.
49. Posnett J, Gottrup F, Lundgren H, Saal G. Modelling the cost-effectiveness of subepidermal moisture measurement as part of a process of assessment and intervention to prevent hospital-acquired pressure ulcers. *Int Wound J*. 2023;20(7):2688-2699.

How to cite this article: Avsar P, Patton D, Cuddigan J, Moore Z. A systematic review on the impact of sub-epidermal moisture assessments on pressure ulcer/injury care delivery pathways. *Int Wound J*. 2024;21(6):e14928. doi:10.1111/iwj.14928