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REVIEW ARTICLE

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Skin hydration measurement and the prediction of the early development of pressure ulcers among at risk adults: A systematic review

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Abstract

This systematic review aimed to examine skin hydration and determine if this biophysical parameter can predict pressure ulcer development in at risk adults. A literature search was conducted in March 2022, using PubMed, CINAHL, SCOPUS, Cochrane, and EMBASE databases. A total of 1727 records were returned, with 9 studies satisfying the inclusion criteria. Data were extracted using a pre-designed extraction tool and a narrative synthesis of the data was undertaken. The methodological quality of the included articles was assessed using the evidence-based librarianship checklist. Included studies were published between 1997 and 2021, with most using a prospective cohort design (88.9%, n = 8). The mean sample size was 74 participants (SD = 38.6; median 71). All studies measured skin hydration objectively, with 55.6% (n = 5) using the Corneometer® CM825 and 33.3% (n = 3) of studies reported a statistically significant association between skin hydration and pressure ulcer development. The mean evidence-based librarianship percentage was 66.6% (SD: 20.7%), however, only 33.3% (n = 3) of studies scored ≥75%, indicating validity.

The quality of included studies, methodology variation, and reported results has reduced the homogeneity of outcomes. This review highlights the requirement for future research evidence to ascertain the role of skin hydration in pressure ulcer development.

KEYWORDS

pressure injury, pressure ulcer, skin barrier, skin hydration

Key Messages

- This systematic review examines skin hydration measurements for the prediction of early pressure ulcer (PU) development in at risk adults.
- A lower skin hydration was associated with PU development in two studies, whereas a higher skin hydration was associated with PU development in one study. On the sacrum, both a lower and higher skin hydration was associated with PU development.
- The quality and heterogeneity of included studies highlight the requirement for future research evidence.

1 | INTRODUCTION

Pressure ulcer (PU) development pathways have been shown to range from superficial tissue damage occurring at the skin's surface level, to an escalating injury mechanism that results in cell and tissue deformation within the deeper tissue layers.[1] The aforementioned superficial damage results from the mechanical forces of friction and shearing of the skin surface, increasing the likelihood of skin barrier disruption, further exacerbated in the presence of moisture.[2]

The epidermis with emphasis on the stratum corneum (SC) which exists as the outermost layer of this tissue structure, is predominantly responsible for skin barrier protection.[3] The SC not only exists as a physical barrier, but its role extends to involve an interconnected microbiome, chemical and immune system function.[4] Through the maintenance of skin hydration, the SC is able to uphold its structural integrity, which enables the aforementioned barrier functions to succeed.[3]

From a physiological perspective, the SC contains a matrix of microbial communities, which act as a first level of defence to environmental factors.[4] These microbial communities send signals to the functional immune network of the skin, stimulating a response in resident immune cells located within the epidermis and dermis.[5] The chemical function of the skin's barrier comprises of factors contributing to the acidic surface pH and compounds that make up the natural moisturising factor (NMF)[4] such as amino acids, organic acids and inorganic ions.[6] The NMF is responsible for barrier homeostasis and maintaining hydration levels,[7] thus the chemical function of the SC plays a key role in maintaining its physical barrier. Maintenance of a normal skin barrier is dependent upon an acidic pH level, whereby a deviation in PH results in an abnormal permeability, reduced barrier integrity and inhibits optimal microbiome function.[8] A disruption to this functional network would therefore contribute to inflammation, loss of hydration and alteration in pH, ultimately leaving the SC vulnerable to breakdown.[3] Therefore, the SC can provide vital information on the function and biophysical properties of the skin.[9]

Skin that is dry, or inadequately hydrated, is increasingly vulnerable to PU development,[10] as the fragility and inelasticity of the superficial skin becomes more susceptible to breakdown from external mechanical forces.[11] Excessive hydration or moisture, on the other hand, can result in maceration, impaired barrier function, and breakdown.[12,13] This refers to moisture-associated skin damage (MASD), whereby moisture from the external environment causes an altered PH and breakdown of the SC lipid matrix.[14] Despite the differing aetiologies of MASD and PU's, previous research literature has established a link between excessive skin surface moisture and the development of PUs.[15] Thus, examining skin hydration may provide vital information regarding the skin's integrity and subsequently help to identify the potential for breakdown associated with early PU development.

Supporting this, clinical guidelines advocate for future research evidence surrounding skin moisture and the risk of PU development.[1] A systematic review (SR) assessing PU risk factors concluded that skin moisture is important to consider among a complex interplay of factors.[16] Assessment of skin moisture has been categorised throughout the research literature as the presence of moisture because of perspiration,

urine, faeces, or exudate.[17] Compton[18] assessed moist skin as a risk factor in patients admitted to the intensive care unit (ICU) and found that this subjective nursing parameter predicted PU risk ($\beta = 0.85$, OR 2.35, $P = 0.001$). Despite this, variable correlations have been identified between visual assessment of skin hydration and objective measurements over bony prominences.[19] Therefore, increasing the objectivity of assessing skin hydration may lead to more consistent and reliable assessments.

Objective biophysical parameters to measure skin hydration in the context of PU development have demonstrated promising results.[19] The authors acknowledge however that while measurement of skin hydration may prove useful as a tool in research, this may not translate to its use in clinical practice. Despite this, the research points to the requirement of future studies to ascertain the role of skin hydration in the early PU development phase. It is important to differentiate between the assessment of skin hydration and subepidermal moisture however, as both measures are explored in PU research. Skin hydration focuses on the moisture content of the epidermis, yet subepidermal moisture assesses the level of moisture in the subdermal tissues, which are located beneath the epidermal skin layers.[20] This is the first systematic review to date that has reviewed all current evidence regarding skin hydration in the context of early PU development.

2 | RESEARCH QUESTION

The research question was developed using the *PEO* format[21]:

- *Population*: Adults at risk of PU development, without a visible PU at baseline, cared for in any clinical setting.
- *Exposure*: Skin hydration
- *Outcome*:
  - The primary outcome was to determine if skin hydration can predict PU development in at risk adults.
  - The secondary outcome was to explore the assessment and measurement techniques used to assess skin hydration within the included studies.

Thus, the research question explored in this systematic review of the literature was:

"What is the role of skin hydration measurement in the prediction of early PU development among at risk adults?"

2.1 | Aim

This systematic review aims to determine if skin hydration can predict early signs of PU development.

The objectives were to determine:

1. Whether skin hydration predicts early signs of PU development.
2. The assessment techniques used throughout the literature to assess skin hydration.

3 | METHODS

3.1 | Criteria for considering studies for this review

The systematic review (SR) included published studies that assessed skin hydration and its relationship with PU development. Measurement techniques used to assess skin hydration were of interest as were all qualitative or quantitative study designs. There were no language, or date of publication restrictions applied. This systematic review was registered with PROSPERO (CRD42021226205).

Inclusion and exclusion criteria

The population of interest was participants at risk of PU development, with no visible PU at baseline of study commencement. Studies examining skin hydration over soft tissue compression sites, prior to the development of a visible PU were included.

- *Inclusion*: Patients (adults >18 years), in any healthcare setting, at risk of PU development, with skin hydration assessed over a bony prominence and no PU at baseline.
- *Exclusion*: Assessment of established PUs of any grade at baseline. Studies that did not examine skin hydration and its relationship to PU development. Studies assessing a healthy cohort of patients who were not at risk of PU development.

3.2 | Electronic searches

The following electronic databases were searched to identify relevant literature, from inception until March 2022:

- Cochrane Central Register of Controlled Trials (CENTRAL) (The Cochrane Library) (latest issue)
- PubMed MEDLINE

- EMBASE
- EBSCO CINAHL Plus
- Scopus.

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

- Scanned reference lists of all identified studies and reviews.
- Searched grey literature using Open Grey (www.opengrey.eu).
- Searched conference proceedings, research reports, and dissertations.

Search Limits: inception until March 2022, no limitations applied.

The keywords used in the search included:

#1 "Pressure Ulcer" OR Ulcer OR Pressure OR Ulcers.

#2 Bedsore OR Bedsores OR "Bed Sores" OR "Bed Sore".

#3 "Pressure Sore" OR "Pressure Sores".

#4 "Decubitus Ulcer" OR "Decubitus Ulcers" OR Decubitus.

#5 "Pressure Injury" OR "Pressure Injuries".

#6 1 OR #2 OR #3 OR#4 OR #5.

#7 "Skin barrier" OR "Skin moisture" OR "Skin hydration" OR "Stratum corneum" OR "Epidermal hydration" OR corneometer.

#8 #6 AND #7.

3.3 | Study selection

The title of identified records were assessed by two authors independently (Hannah Wilson & Pinar Avsar) and abstracts from these records were screened against the eligibility criteria. The full text of records sought for retrieval was then reviewed independently by two authors (Hannah Wilson & Pinar Avsar). A third reviewer was involved to reach a consensus on the final corpus of included studies when discrepancies were identified between the two primary reviewers (Zena Moore). PRISMA was adapted as a framework for reporting this SR. A PRISMA flow chart provides a visual display of literature flow and the studies included in the final review.[22]

3.4 | Data extraction

Data were extracted from included studies and inserted into a table with the following headings: author, study year and country, setting, sample characteristics, study design, intervention, comparison (if applicable), key findings, and limitations.

3.5 | Data analysis

Following the extraction of the main findings from the papers, meta-analysis was considered inappropriate because of the heterogeneity of findings in this review. Therefore, the findings were narratively summarised, providing an overview of the study setting, geographical location, setting, and sample characteristics. Results from the quality appraisal is then reported, followed by a structured narrative synthesis of the results of included studies.

3.6 | Quality appraisal

All studies were quality appraised using the evidence-based librarianship (EBL) checklist.[23] Quality appraisal of the included studies was carried out by two authors independently (Hannah Wilson & Pinar Avsar). This quality appraisal tool assesses the validity, applicability, and appropriateness of a study based on four main concepts: population, data collection, study design, and 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 regarded as valid.[23]

4 | RESULTS

4.1 | Overview of all included studies

As shown in Figure 1, following reviews of titles & abstracts from a total of 1332 non-duplicate citations, 1319 were excluded. Next, a full-text review of the remaining citations resulted in a further four exclusions for the following reasons: non-eligible participants and non-eligible study design[19,24-26] (Table S1). Finally, nine studies were deemed to meet the inclusion criteria.[27-35] An overview of the studies is provided in Table S2.

4.2 | Study design

The studies were published between 1997 and 2021 and 88.9% (n = 8) used a prospective cohort design.[27,28,30-35] One study was a single-blind randomised controlled trial (RCT).[29]

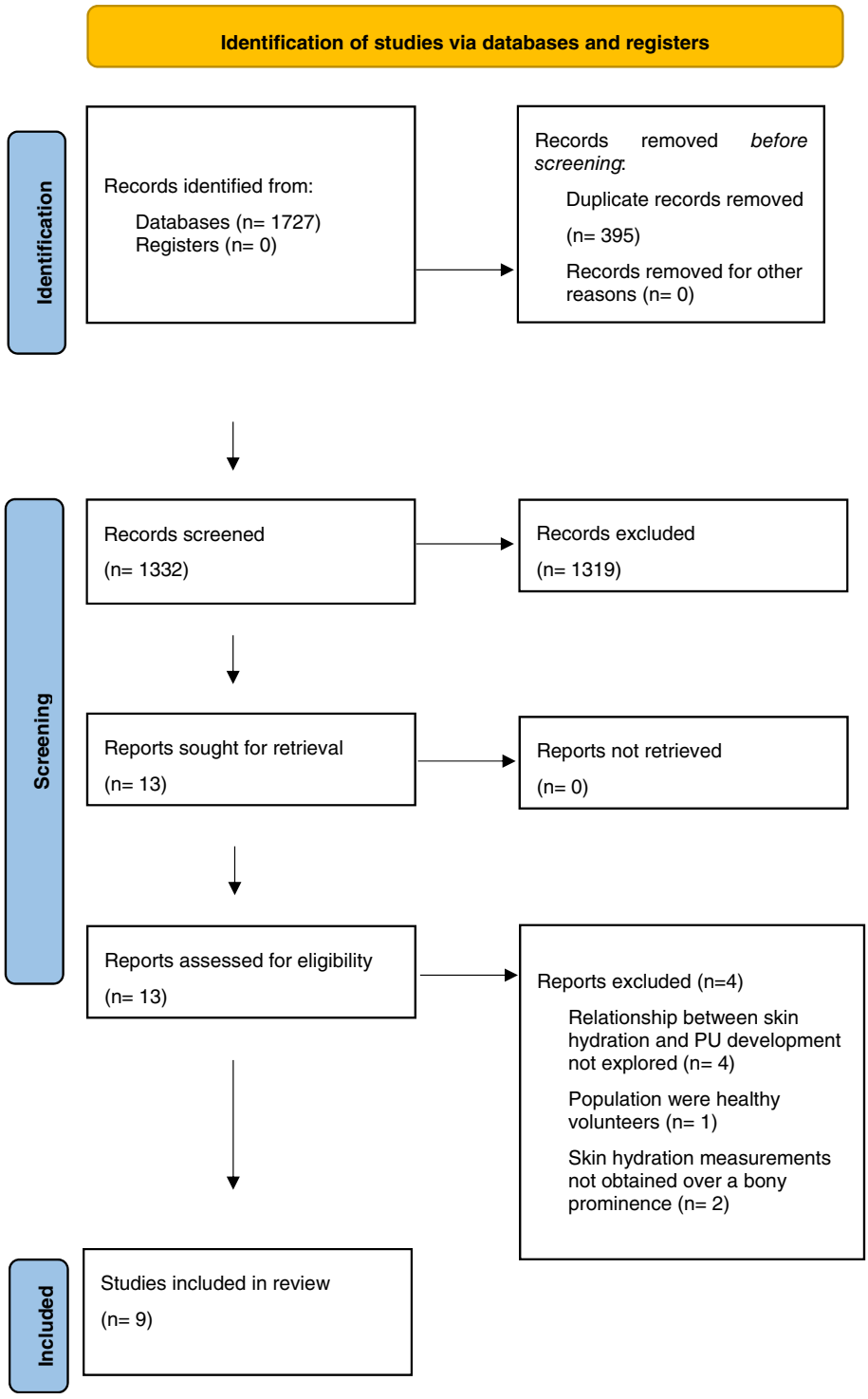

FIGURE 1 PRISMA 2020 Flow Diagram

4.3 | Geographical location

The geographical location of the studies varied between Japan,[27,31,34] Indonesia,[28,32,35] Korea,[29] China[30] and the United States of America (USA).[33]

4.4 | Study settings

The studies were conducted within a variety of health care settings including long-term care facilities,[27,34] hospitals[28-32,35] and nursing homes.[33] The ICU accounted for

66.7% (n = 4) of the 6 hospital settings. Other hospital settings included participants within convalescence wards[31] and acute care wards.[35] It is not specified if the long-term care facilities were nursing home settings, however, one study recruited older participants[27] and one study indicated the facility was within a hospital.[34]

4.5 | Sample size

The mean sample size was 74 participants (SD = ±38.6), and varied between 20 participants[27] and 135 participants.[29]

4.6 | Quality appraisal of included studies

The mean validity score for all combined studies was 66.6% (SD: 20.7%). The minimum score was 26%[28] and the highest result was 92%.[29] A lower percentage of studies had a result ≥75% (33.3%, n = 3) reflecting validity.[29,30,32] However, a total of 66.7% (n = 6) did not meet the validity criteria.[27,28,31,33-35] A summary of these outcomes is provided in Table S3, whereby the results reflect unreported outcomes, or any unclear issues identified within each domain. As a result of the reduced quality of studies, the results of this SR should be interpreted with caution.

Within the population domain, the main areas of concern were related to the small sample size within two studies (22.2%)[27,34] and the potential bias surrounding the baseline PU status of participants within 33.3% of studies (n = 3).[28,31,33] One study did not clearly outline the exclusion criteria or informed consent process[28] and one study had a high participant dropout rate.[35] In the data collection domain, potential bias surrounding the visual skin assessment outcomes were identified in a high number of studies (77.8%, n = 7)[27,28,31-35] and similarly follow-up was identified as a potential limitation for capturing reliable outcomes in 77.8% of studies (n = 7).[27-29,31,33-35] Unclear detail surrounding the data collection methodology was found in one study,[28] with one study documenting that data collection was carried out by trained nurses[30] however, it was unclear if those involved in data collection were delivering a service to the target population in 33.3% of studies (n = 3).[28,31,34]

Face validity was a problem in six studies, all these studies had issues in the study design domain.[28,31-35] Lack of clarity surrounding the methodology was identified in one study[28] and one study found it difficult to obtain all measures during follow-up.[35] Two studies (22.2%) provided no detail of ethical approval[32,33] and two studies did not clearly report all outcomes relating to the data collected.[28,33] Finally, in the results domain, external validity was questionable within a high number of studies (77.8%, n = 7).[27,28,31-35] Potential confounding variables were identified within six studies (66.7%)[28,29,31-34] and unclear result reporting in 33.3% (n = 3).[28,33,35]

4.7 | Outcomes

4.7.1 | Assessment and measurement techniques used to assess skin hydration

A total of 55.6% (n = 5) of studies measured skin hydration using the Corneometer® CM825 (Courage & Khazaka GmbH Germany).[27,30,31,34,35] This device measures SC hydration in arbitrary units (AU), with values ranging from 0 (dry) to 120 (wet) (AU). A total of 33.3% (n = 3) of studies used a moisture meter, whereby one study used the Daom-609 device (Daom Networks, Seoul, Korea), with measures ranging from 0% to 99.9%[29] and one study used the MY707s (Scalar America, Scalar Kabushiki Company, Tokyo, Japan).[32] Bubun[28] did not report the specific moisture meter used. Last, one study measured skin hydration with the Nova DPM 9003 (NOVA Technology Corporation, 75 Congress St., Portmouth, NH).[33]

The anatomical sites that skin hydration was assessed varied between the sacrum (77.8%, n = 7),[27,29-32,34,35] heels (22.2%, n = 2),[30,31] scalpula (22.2%, n = 2),[27,30] trochanter and coccyx (22.2%, n = 2),[27,34] hip (11.1%, n = 1)[30] and four perineal regions (11.1%, n = 1).[33] One study did not report the specific anatomical locations assessed.[28] It is worthy of note that three studies reported a combined skin hydration across multiple anatomical sites.[27,28,34] Table 1 provides an overview of the result outcomes and methodologies used to assess skin hydration and visual skin assessment throughout included studies.

4.7.2 | Skin hydration and PU development

All included studies measured skin hydration and analysed its association with PU development, within a cohort of patients at risk of PU development.[27-35]

Arisandi[27] examined risk factors for recurrent PU development following conservative treatment, which involved measuring SC hydration over healed PU sites every 2 weeks. A total of 57 observations were conducted among 20 participants, over an eight-week period. Results were reported as median (IQR), showing no significant differences in SC hydration (AU) between observations from those that developed a recurrent PU (n = 8) versus observations from those with non-recurrent PU's (n = 49) (30.4, IQR: 8.0-38.5; 27.5, IQR: 16.2-46.4) respectively ($P = 0.30$).

TABLE 1 Association between skin hydration and PU development with used methodologies

Study author	Skin hydration assessment	PU assessment	Anatomical location(s) assessed	Follow-up	Association between skin hydration and PU development
Arisandi[27]	Corneometer CM825 (Courage & Khazaka GmbH Germany).	DESIGN-R subscale[42] & Transparent disc method for assessing erythema.	Torso and control (Healed PU sites included the sacrum, coccyx, trochanter, or scapula areas)	Every 2 weeks for 8 weeks until either development of recurrent PU or inability to assess the patient.	✗ $P = 0.30$
Bubun[28]	Skin moisture checker	No detail of assessment	Specific areas assessed unknown	Skin moisture measured every 2 days until day 13.	✗ $P = 0.52$
Choi[29]	Skin moisture meter (Daom-609, Daom Networks, Seoul, Korea). Uncoated paper (315 mm × 340 mm, WYPALL™, Yuhan Kimberly, Seoul, Korea)	Revised pressure injury staging system of the NPUAP[43]	Sacrum	Skin moisture measured 2 hours following study commencement/uncoated paper application, and at days 1, 3 and 5 (including PU incidence assessments).	✗ $P = 0.37$
He[30]	CM825 corneometer (Courage & Khazaka GmbH Germany).	NPUAP (2007).	Scapula, sacrum, hip, and heel (Moisture content of each site reported separately)	Daily assessments of skin barrier factors, from ICU admission until discharge, or until PU development.	✓ $P < 0.001$ Lower SC hydration (Sacrum and hip)
Kohara[31]	CM825 corneometer (Courage & Khazaka GmbH Germany).	NPUAP (2014), only PU's grade ≥2 was reported	Sacrum and both heels (SC hydration of each site reported separately)	Medical records assessed 1 month after SC hydration measurement obtained.	✗ $P = 0.61$
Sanada[32]	Moisture checker (MY707s, Scalar America, Scalar Kabushiki Company, Tokyo, Japan).	NPUAP scale. Heel PU's reported	Sacrum	Daily assessments of skin moisture from 24 hours of ICU admission until PU development or ICU discharge.	✓ $P = 0.002$ Higher SC hydration
Schnelle[33]	NOVA DPM 9003 dermal phase meter (NOVA Technology Corporation, 75 Congress St., Portmouth, NH).	PU categories and skin condition definitions listed within the study appendix (no document of specific reference)	Four perineal regions and control	Every 3 weeks for a minimum of 60 days.	✗ No P value reported
Shibata[34]	Derma Unit SSC3 with corneometer CM825 attachment (Courage & Khazaka electronic GMbH, Inc., Cologne, Germany.)	DESIGN-R subscale[42]	Torso and control (Healed PU sites included the sacrum, coccyx, trochanter, and other)	Two-weekly over a period of 6 weeks.	✓ $P = 0.01$ Lower SC hydration

TABLE 1 (Continued)

Study author	Skin hydration assessment	PU assessment	Anatomical location(s) assessed	Follow-up	Association between skin hydration and PU development
Yusuf[35]	Corneometer CM 825 (Courage & Khazaka GmbH, Koln, Germany)	PU assessment based on the EPUAP grading systems and grading of superficial skin changes performed by a panel of wound experts.	Sacrum and control	Skin hydration assessed every 3 days for 15 days or until a PU or superficial skin change was observed. Skin assessed daily for skin changes.	☒ $P = 0.62$

Note: ☑, Yes; ☒, No.
Abbreviations: EPUAP, European Pressure Ulcer Advisory Panel; NPUAP, National Pressure Ulcer Advisory Panel.

Bubun[28] investigated the relationship between skin moisture and medical device related pressure injury (MDRPI). A total of 50 participants with medical devices fixed within the first 24 h of ICU admission had skin moisture assessed every 2 days until the thirteenth day. The skin moisture status between no MDRPI and the presence of MDRPI was analysed using an independent *t*-test. The independent *t*-test was also applied for the intervention devices and diagnostic devices. Results indicated that there was no difference in skin moisture between the no MDRPI group (moisture range: 28.81 ± 2.68 to 32.38 ± 5.44) and the presence of MDRPI group (moisture range: 27.67 ± 2.02 to 31.93 ± 2.21) for those with intervention devices ($P > 0.05$). Similarly, among those with diagnostic devices, there was no statistical difference in skin moisture between the no MDRPI group (moisture range: 27.06 ± 4.33 to 40.53 ± 32.53) and the presence of MDRPI group (moisture range: 27.50 ± 1.51 to 34.79 ± 12.58) ($P > 0.05$).

The third study was an RCT evaluating sacral uncoated paper application for its moisture-absorbing properties in an experimental group receiving usual care, and its effect on skin moisture and PU incidence was compared with a control group receiving only usual care (ie, repositioning and air mattress).[29] A total of 135 ICU participants (n = 68 experimental, n = 67 control) were followed up for 5 days, with measures of skin moisture undertaken at baseline and on days 1, 3, and 5. Despite a significant difference between groups regarding endpoint skin moisture ($t = -16.17$, $P < 0.001$) and subsequent PU risk score ($t = 6.96$, $P < 0.001$), there was no significant difference between groups in relation to the incidence of PU development (X^2 1.06[a], $P = 0.37$). One patient (1.5%) from the experimental group developed a grade 1 PU on day 5, whereas three patients (4.5%) from the control group developed PU's on days 3 and 5, two of which were grade 1 and one was a grade 2.

He[30] examined SC hydration and its association with the incidence of PUs in 102 ICU participants. SC hydration was assessed daily until discharge, or PU development, across multiple soft tissue compression sites. There was a 31.4% (n = 32) incidence of PU development of which a lower SC hydration showed statistically significantly different results at the lower sacrum and hip ($P < 0.001$) when compared with patients that did not develop a PU. Of those who developed a PU, 56.2% (N = 18) had suspected deep tissue injury, 34.4% (n = 11) had developed a stage 1 PU, and 9.4% (n = 3) had stage 2 PU. The mean SC hydration (AU) at the sacrum was 17.7 ± 3.78 for patients who developed a PU, versus 20.0 ± 3.92 for patients who did not develop a PU. Last, the mean SC hydration at the hip was 18.6 (SD 4.48) for patients who developed a PU versus 22.4 (SD 4.92) for

patients who did not develop a PU. No significant difference was observed in scapular ($P = 0.053$) or heel ($P = 0.057$) moisture levels.

Kohara[31] investigated the relationship between physiological indices of the skin and PU development in 55 elderly participants. Measures of SC hydration were obtained at the sacrum and heels, and medical records were reviewed 1 month later to determine those who developed PU's ≥ grade 2. Results were reported as median (IQR) and showed no statistically significant differences in SC hydration (AU) between observations from those that developed a PU grade 2 (n = 5), versus observations from those that did not develop a PU (18.4: 10.5-37.2; 17.9: 10.2-27.3; respectively, $P = 0.61$). Of these, two patients developed a PU on the sacrum, the median SC hydration (AU) was 37.2 (range; 36.2-38.2) versus 29.6 (range; 6.1-71.8) for patients that had no sacral PU. Two patients developed three PU's on the heels, SC hydration (AU) was a median of 13.1 (range; 8.0-18.4) versus 12.7 (range; 2.2-46.7) for observations with no heel PU. All patients that developed a PU were incontinent (7.3%, n = 4). The authors reported difficulty categorising grade 1 PU's, however, skin discolouration was present at the time of measurement on all sites that developed a PU grade 2.

Sanada[32] examined risk factors associated with PU development, whereby skin moisture measurements were obtained daily at the sacral sites of 105 ICU participants. A PU stage 1 to 2 developed in 33.3% (n = 35) of participants, and multivariate analysis identified that skin moisture was a statistically significant risk factor for PU development (OR 8.2, 95%CI 2.2-30.9, $P = 0.002$). Of those who developed a PU, skin moisture was >34 in 60% (n = 21) of cases compared with 21.4% (n = 15) of cases in patients who did not develop a PU (OR 5.5, CI 2.3-13.3, $P = 0.0001$). Therefore, the authors concluded that higher skin moisture was associated with PU development. Skin moisture was measured at the sacrum, however, 13.2% (n = 5) of PU's had developed on the heels.

Schnelle[33] collected skin moisture data in 100 incontinent residents across four nursing homes, with the aim of predicting PUs and skin conditions. A total of 10 readings were obtained across four perineal regions of the body, every 3 weeks for a minimum of 60 days. A total of 21% developed a PU stage 1 or 2 and areas with the highest level of wetness were the areas most affected by skin conditions. Measures of urinary incontinence (wet skin) statistically significantly correlated with blanchable erythema ($r = 0.28$, $P = 0.01$), however, skin moisture was not predictive of PU stages 1 and 2. Blanchable erythema severity was the only variable predictive of PU stages 1 and 2 ($r = 0.32$, $P = 0.001$). Despite these findings, grade 1 PU were included at baseline and two observation criteria meant that a PU was not counted unless it was present on both observations, conducted 3 weeks apart.

Shibata[34] explored factors associated with recurrent PU's after conservative treatment, which involved measuring SC hydration twice a week over a 6-week period in 30 participants with healed PU's. A recurrent PU developed in 26.7% (n = 8) and the median SC hydration (AU) was significantly lower on the site of the recurrent PU when compared with non-recurrent PU's (8.4; IQR 6.9-10.7; 28.4; IQR 10.2-41.9, respectively, $P = 0.01$).

Yusuf[35] measured SC hydration on the sacrum of 71 participants every 3 days for 15 days and evaluated its relationship with the development of PU and superficial skin changes. A total of 28% developed a PU or superficial skin changes (n = 20), 55% (n = 11) of which had developed a grade 1 (25%, n = 5) or grade 2 PU (30%, n = 6). Results were reported as mean (SD), and no statistically significant difference in SC hydration (AU) between groups with skin changes and no skin changes was observed (6.9 ± 18.1; 4.3 ± 19.0 respectively, $P = 0.62$). SC hydration results were reported with all skin changes including blanchable erythema, maceration, and dermatitis, therefore the relationship between SC hydration and PU development is not independently reported.

5 | DISCUSSION

This goal of this SR was to determine the association between skin hydration and PU development. Three studies showed statistically significant associations between skin hydration and PU development[30,32,34] however, only two were considered valid during quality appraisal.[30,32] On the other hand, 66.7% (n = 6) of studies did not show statistically significant associations between skin hydration and PU development.

Lower skin hydration was associated with PU development in two studies,[30,34] whereas higher skin hydration was associated with PU development in one study.[32] On the sacrum, both a lower[30] and higher[32] skin hydration was associated with PU development. Similar results were observed in an observational study whereby a higher skin hydration was correlated with PU risk at the sacrum using the Norton risk assessment scale ($r = -0.53$, $P < 0.01$).[19] Supporting this, Kottner[36] discussed the influence of the external microclimate, whereby its direct effect on the SC can increase and decrease hydration.[36] The influence of the external microclimate can lead to a reduction in skin tolerance,[37] affecting its susceptibility to loads of external pressure, friction, or shear involved in PU development.[38]

The influence of the external microclimate on SC hydration supports the variation of both higher and lower results associated with PU development throughout studies. Secondly, it's important to highlight that this variability of skin hydration may have influenced statistical conclusions, as both higher and lower SC hydration measurements can be associated with PU development.

The skin's tissue structure is considered to play a key role in PU development; however, multiple factors increase an individual's risk of developing a PU. Therefore, measuring skin hydration is a singular approach to assessing PU development among a complex interplay of competing factors. Gefen[2] has highlighted that PUs can develop from two distinct pathways, one is superficial which can directly impact the SC and the second pathway initiates at deeper tissue structures. Most PUs however, develop as a result of deep tissue injury and thus PUs that appear clinically superficial such as those graded as stage 1 or 2, are commonly associated with deeper injury.[39] Therefore, if a PU has developed internally within deeper tissue prior to the migration of injury on the visible skin surface, assessing the skin hydration may not be a reliable assessment method. This may explain the variability of results within this systematic review and account for the high percentage of studies that did not show a statistically significant association between SC hydration and PU development (66.7%, n = 6). Ultimately, PUs are not influenced by one factor alone but a complex interplay of multiple factors is at play during PU development.

The EBL outcomes have reduced the validity of reported findings in this review, as only 33.3% of studies were considered valid. Paying a particular focus on robust methodologies for measuring skin hydration and visual skin assessment, combined with an appropriate follow-up timeframe is vital to capture reliable outcomes. Potential bias surrounding visual skin assessment was high (77.8%, n = 7). Skin assessment is subjective and validating outcomes with a second trained researcher and using validated PU grading instruments can enhance internal validity. Similarly, follow-up was identified as a potential limitation for capturing reliable outcomes in a high percentage of studies (77.8%, n = 7). Only two studies conducted daily SC hydration measurements.[30,32] An appropriate follow-up is vital to enhance the reliability of outcomes for both SC hydration and visual skin assessment for the detection of PU development. All studies measured skin hydration objectively, with 55.6% (n = 5) using the corneometer CM825. Similarly, to the corneometer, the moisture meter can measure the degree of hydration in the superficial layers of the SC, which results in a percentage that reflects hydration.[40] The Nova DPM device used by Schnelle,[33] has been shown to correlate well with the CM825 ($r = 0.82$, $P = 0.00$), however, both devices have a varied depth of measurement within the SC.[41]

6 | LIMITATIONS

A number of important limitations need to be considered. First, the diverse range of participants and anatomical sites assessed, combined with the diversity of methodologies further limits the homogeneity of evidence from these studies. This heterogeneity meant that a meta-analysis was considered inappropriate. Second, 33.3% (n = 3) of included studies had either unclear reporting of baseline skin status or included participants with skin discoloration or grade 1 PUs. Two studies examined participants with a PU that had healed within 1 to 2 months. Further, SC hydration can vary over different anatomical sites, however, some studies reported the collective skin hydration across multiple anatomical sites which may have influenced the overall results. Finally, a high proportion of studies were of low methodological quality (66.7%, n = 6), which further impacts the results of this review.

7 | CONCLUSION

Within the included studies, lower skin hydration was associated with PU development in two studies, whereas higher skin hydration was associated with PU development in one study. On the sacrum, both lower and higher skin hydration was associated with PU development. The quality of included studies, variation of methodologies, and reported results has reduced the homogeneity of outcomes. This review highlights the requirement for future research evidence, to ascertain the role of skin hydration in PU development.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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