Review

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Urinary Incontinence Management Using Sensor-Based Technologies: A Systematic Review with Narrative Synthesis

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Abstract

Background. Urinary incontinence (UI) is prevalent in older populations. UI is associated with reduced quality of life, skin complications, and increased caregiver burden. Sensor-based UI technologies have been introduced to support timely and individualized care beyond routine check-and-change practices, but their effectiveness remains unclear.
Objectives: To examine the sensor-based technologies used in UI care and to synthesize evidence regarding their effects on patient and caregiver outcomes.
Methods. A search was conducted in December 2025 using five databases (PubMed, CINAHL, EMBASE, the Cochrane Library, and IEEE Xplore) in accordance with the PRISMA guidelines. Search terms included "urinary incontinence," "smart diaper," "smart pad," "sensor," "wearable sensor," and "continence monitoring," combined using Boolean operators (AND, OR) and controlled vocabulary (e.g., MeSH, EMTREE). Studies included if they applied sensor-based UI technologies embedded in pads or diapers, and reported clinical outcomes related to UI care.
Results. Eight studies were included. Sensor-based UI technologies ranged from systems that detected voiding, leakage, saturation, or urine volume and provided alerts to advanced systems using sensor-derived data for voiding pattern analysis and individualized care planning. Technical performance and care-process outcomes were mixed, although some studies reported improvements in pad checking, leakage,

body had no role in the design of the study.

absorbent product use, and adherence to individualized care plans. Patient outcomes showed limited improvements, with some benefits in skin condition, continence-related outcomes, and sleep interruptions. Caregiver outcomes generally indicated favorable usability, perceived usefulness, and support for decision-making, although controlled studies did not demonstrate improvements in caregiver burden, work engagement, or organizational headroom. Evidence regarding informal caregivers remained limited.

Conclusion. Sensor-based UI technologies may support more timely and individualized UI care by improving care processes and caregiver decision-making. Given the important role of informal caregivers in UI care, future research should evaluate the effects on informal caregiver outcomes.

Keywords: Urinary Incontinence, Sensors, Adult Diapers, Wearable Electronic Devices, Nursing Care, Systematic Review

Introduction

Urinary incontinence (UI) is defined as any involuntary leakage of urine (Haylen et al., 2010) and represents a significant global public health concern (Gröning et al., 2024). The prevalence of UI is estimated to be approximately 25–45% among adults worldwide, with substantially higher rates reported among women and older populations (Bishop et al., 2025; Patel et al., 2022). Given the rapid growth of the aging population, the burden associated with UI is expected to increase substantially in the coming decades (Milsom & Gyhagen, 2019; Patel et al., 2022).

Beyond bladder dysfunction, UI exerts negative consequences across multiple dimensions of individual health. UI has been associated with urinary tract infections, sleep disturbances, falls, and skin damage caused by exposure to moisture (Gröning et al., 2024; Soysal et al., 2023). Inadequate management of UI increases the risk of incontinence-associated dermatitis (IAD), pressure injuries, secondary infections, and sepsis (Kottner & Dissemond, 2025). In addition to these physical consequences, UI can negatively affect psychological and social well-being, contributing to reduced quality of life, depression, anxiety, social isolation, and stigma (Pizzol et al., 2021; Soysal et al., 2023).

Effective UI care requires individualized continence management based on each person's voiding patterns, care needs, and functional abilities (Department of Veterans' Affairs, 2020; van Cooten et al., 2025). Its implementation, however, is often limited in hospitals and long-term care settings by staffing shortages, workload demands, rigid routines, and insufficient organizational support (Marcu et al., 2024; Skotnes et al., 2013). UI care often relies on routine check-and-change practices using absorbent products, which are performed according to predetermined schedules rather than individual voiding patterns (Wagg et al., 2025). Repeated manual checks of absorbent products may compromise privacy and dignity (Department of Veterans' Affairs, 2020). Premature pad replacement can result in unnecessary product waste, whereas delayed replacement may increase the risk of leakage, skin damage, and IAD (Rajabali et al., 2023; Wagg et al., 2025). These challenges may be particularly pronounced among individuals with cognitive impairment who are unable to communicate their toileting needs effectively.

To address these challenges, various digital technologies have recently been introduced into UI care. Examples include smartphone applications, telemonitoring systems, wearable devices, and sensor-based absorbent products (Weinstein et al., 2022; Zhu et al., 2025). Among these, sensor-based UI technologies have received particular attention for their potential to enable real-time detection of voiding events or pad saturation, thereby supporting timely and individualized UI care (Cho et al., 2021; Rajabali et al., 2023). Such technologies have been reported to reduce unnecessary pad checks and changes, lower the risk of complications such as

IAD, and preserve residents' sleep quality and dignity (Rajabali et al., 2023; Wagg et al., 2025).

Despite this growing interest, the existing evidence base remains fragmented. Prior reviews have examined broad digital and technological approaches to UI management, including telemonitoring, app-based interventions, and ultrasound (Gröning et al., 2024; Omotunde & Wagg, 2023). Other reviews have focused on non-invasive bladder urine volume estimation using electrical impedance-based methods (Noyori et al., 2022) or sensor-based products without synthesizing clinical outcomes (Jeong & Park, 2019). Evidence regarding their clinical effectiveness across patient and caregiver outcomes remains limited and has not been systematically synthesized.

This systematic review aimed to examine the characteristics of sensor-based technologies used in UI care and to synthesize evidence regarding their effects on patient and caregiver outcomes. This review provides evidence on the current utilization and effectiveness of these technologies and informs their future application.

Methods

This study was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The key terms and research question were structured according to the population, intervention, comparison, outcomes, and study design (PICOs) framework as follows: (1) population: people with UI or people requiring UI care; (2) intervention: sensor-based UI technologies embedded in or attached to absorbent products or wearable continence devices to detect voiding-related events; (3) comparison: standard care, alternative intervention, or no intervention; (4) outcomes: all outcomes related to UI management; and (5) study design: randomized controlled trials, non-equivalent control group experimental designs, and single-group pre-post studies (pre-experimental designs). This review was registered in the PROSPERO database (registration number: CRD420261384275).

Search strategy

A literature search was conducted in PubMed, CINAHL, EMBASE, the Cochrane Library, and IEEE Xplore databases without restrictions on the publication period. The final search was conducted on December 14, 2025. Search terms included "urinary incontinence," "smart diaper," "smart pad," "sensor," "wearable sensor," and "continence monitoring," combined using Boolean operators (AND, OR) and controlled vocabulary (e.g., MeSH, EMTREE). The search strategies were reviewed by an academic librarian. The complete search strategies for each database are provided in Supplementary Material A.

Eligibility criteria

Studies were included in this review if they met the following criteria: (1) studies conducted with people with UI or people requiring UI care; (2) studies using sensor-based technologies as an intervention for continence management; (3) studies employing intervention-based research designs; (4) studies published in English.

Studies were excluded if they met the following criteria: (1) studies not involving people with UI or people requiring UI care; (2) studies not incorporating sensor-based technology; (3) non-intervention studies, such as reviews, qualitative studies, or technology development studies; (4) grey literature, including dissertations and research reports; (5) studies without accessible full texts; and (6) studies published in languages other than English.

Study selection and data extraction

All retrieved records were managed using EndNote 21 reference management software. After duplicate records were removed, two independent reviewers (DL and KK) screened the titles and abstracts of the identified studies. Studies that appeared potentially eligible were then subjected to full-text review to confirm final inclusion. Any disagreements arising during the screening process were resolved through discussion among the reviewers (JL, DL, and KK) during research meetings.

Three reviewers discussed and established the data extraction items during a research meeting prior to the review process. The extracted data included the author, publication year, country, study design, setting/sample, age, technology

type, intervention, and duration/evaluation (Table 1), as well as study outcomes (Table 2). Two reviewers (DL and KK) independently extracted the data, and the extracted information was subsequently verified against the full texts by another reviewer (JL).

Data synthesis

Substantial heterogeneity was observed across intervention characteristics and outcome measures. The findings were synthesized using a narrative approach without meta-analysis. The classification framework was developed after data extraction based on the review aim and the extracted data. The characteristics of sensor-based UI technologies and the outcomes associated with their use were synthesized separately. The functional characteristics of the technologies were classified into three components: sensing functions, notification systems, and pattern monitoring with individualized UI care planning. Outcomes were classified into three domains: technical performance, patient outcomes, and caregiver outcomes. Technical performance included detection and measurement performance as well as operational measures related to continence care. Patient outcomes included clinical, functional, psychosocial, and quality-of-life outcomes. Caregiver outcomes included device usability, perceived usefulness, and adherence among caregivers or healthcare workers who used the devices. The findings were tabulated and narratively compared within each category. Outcomes were retained in their originally reported formats.

Quality appraisal

Two independent reviewers (DL and KK) conducted quality assessments of the included studies. For randomized controlled trials, the Joanna Briggs Institute (JBI) Checklist for Randomized Controlled Trials was utilized (Barker et al., 2023), while the JBI Checklist for Quasi-Experimental Studies was applied to non-randomized experimental studies (Barker et al., 2024). Discrepancies between the reviewers were resolved through consensus discussions during research meetings (JL, DL, and KK).

Results

The study selection process is presented in Figure 1. The database search yielded 3,930 records. After removing 2,133 duplicates, 1,797 records were screened by title and abstract, of which 1,744 were excluded. Of the 53 full-text articles assessed for eligibility, 45 were excluded because they did not meet the inclusion criteria. Specifically, 28 studies evaluated non–sensor-based interventions, 12 focused solely on device development, three did not include clinical evaluation, one was classified as gray literature, and one was published in a language other than English. Finally, eight studies met the inclusion criteria and were included in the final synthesis.

The methodological quality of all included studies was assessed using the JBI Critical Appraisal Tools. Three studies employing a randomized controlled trial design were evaluated using the JBI Checklist for Randomized Controlled Trials (Barker et al., 2023). The remaining five studies were evaluated using the JBI Checklist for Quasi-Experimental Studies (Barker et al., 2024). In accordance with the revised JBI Critical Appraisal Tools, item-level judgments were reported descriptively, and studies were not excluded based on a total appraisal score. Although several studies had methodological limitations, all studies were retained for synthesis after discussion and consensus among the reviewers. Detailed results of the critical appraisal are presented in Supplementary material B.

Characteristics of the included studies

The characteristics of the included studies are presented in Table 1. A total of eight studies published between 2004 and 2025 were included in this review. The studies were conducted in Australia (n = 2), Canada (n = 2), Poland (n = 1), Korea (n = 1), United Kingdom (n = 1), and the Netherlands (n = 1), with one study conducted across Canada and Germany. The included studies comprised three randomized controlled trials, two quasi-experimental studies, and three single-group intervention studies. Across all studies, a total of 539 participants were included, with sample sizes ranging from 30 to 156 participants. Four studies were conducted in nursing homes or residential care facilities, two in acute care hospitals, one in a home

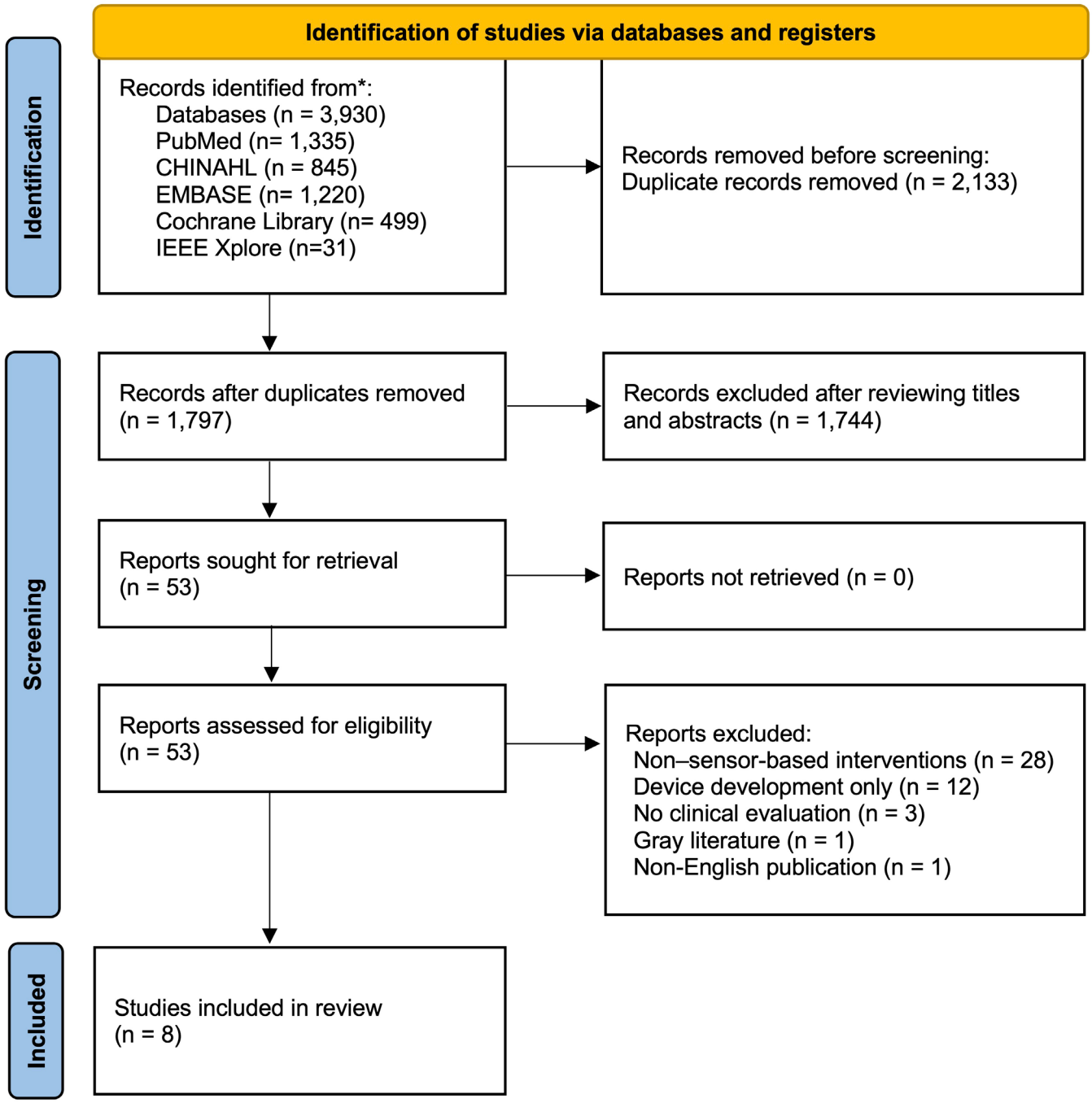


Figure 1. PRISMA Flowchart of the study

care setting, and one across community-based settings. Most participants were people with UI, and two studies included people with UI who were unable to communicate their UI care needs (van Cooten et al., 2025; Wagg et al., 2025). The mean or median age of participants ranged from 45.4 to 88.5 years, and the proportion of female participants ranged from 43.0% to 100%.

Characteristics of sensor-based UI technologies

The sensor-based UI technologies were categorized into three key functional components: sensing functions, notification systems, and pattern monitoring with individualized UI care planning.

Sensing functions

Sensing functions varied across technologies, including voiding detection, urine volume estimation, saturation sensing, and leakage detection. Voiding detection identifies the occurrence of a urination event. Nikoletti et al.

care setting, and one across community-based settings. Most participants were people with UI, and two studies included people with UI who were unable to communicate their UI care needs (van Cooten et al., 2025; Wagg et al., 2025). The mean or median age of participants ranged from 45.4 to 88.5 years, and the proportion of female participants ranged from 43.0% to 100%.

Notification systems

Six of the eight included studies incorporated caregiver notification functionalities. The predominant delivery method involved smartphone- or mobile device–based applications, through which sensor-derived wetness or saturation data were transmitted via Bluetooth or wireless communication systems to support timely UI care. Long et al. (2015) used wearable smart underwear that provided lower-abdominal vibration alerts when urine reached the embedded sensor threads.

Pattern monitoring and individualized UI care planning

Four studies incorporated pattern-monitoring functions that utilized continence data to identify individual voiding patterns and inform individualized UI care planning. Three studies relied on manual interpretation of sensor-collected data by healthcare professionals to develop individualized toileting schedules and care plans (Nikoletti et al., 2004; van Cooten et al., 2025; Yu et al., 2014). In contrast, Rajabali et al. (2023) employed an automated pattern-analysis system that compiled voiding data transmitted to a secure remote server and generated structured continence assessment reports to support individualized care planning.

Outcome

Outcomes associated with device use were grouped into three domains: technical performance, patient outcomes, and caregiver outcomes. Detailed findings are presented in Table 2.

Technical performance

Technical performance outcomes were classified as direct device performance and derived outcomes. Direct outcomes included detection accuracy and false alarms, while derived outcomes included pad checking behavior, product use, care time, and costs. Direct device performance was evaluated in two studies. Cho et al. (2021) compared sensor-estimated urine volume with manually measured urine volume and reported high agreement between the two measures, while Long et al. (2015) reported pad leakage alerts in 86% of leakage events and timely alerts in 82% of events. Outcomes derived from technology use were reported in four studies. Rajabali et al. (2023) reported significant reductions in night pad absorbency and total 24-hour pad absorbency, although no significant differences were observed for day pad absorbency or the number of pads used. Similarly, Wagg et al. (2025) found a significant reduction in daily total pad absorbency. Pad-checking behavior was assessed in three studies. Agholme et al. (2023) reported a reduction in daily pad checks, whereas the other two studies found no significant between-group differences in wet checks or pad checks (Rajabali et al., 2023; Wagg et al., 2025). Leakage frequency was assessed in three studies and showed inconsistent findings. Significant reductions in leakage episodes were reported in two studies (Agholme et al., 2023; Rajabali et al., 2023), whereas van Cooten et al. (2025) reported greater reductions in the waiting-list group than in the intervention group. In contrast, findings related to pad change frequency were mixed, with only one study reporting a reduction in incontinence material changes (van Cooten et al., 2025), while others found no significant differences (Agholme et al., 2023; Wagg et al., 2025). Time spent on UI care was assessed in three studies, none of which reported a significant reduction following the intervention (Rajabali et al., 2023; van Cooten et al., 2025; Wagg et al., 2025). Wagg et al. (2025) further reported no significant between-group differences in toilet visits, clothing changes, linen changes, or the time between pad saturation notification and pad change. Agholme et al. (2023) reported no device-related adverse events, and no significant changes were observed in fecal incidences.

Patient outcomes

All studies reported patient outcomes. Skin-related outcomes were assessed in three studies. Two studies reported improvements in skin conditions, including resolution of skin redness or irritation and improvement of existing IAD or pressure injuries (Agholme et al., 2023; Cho et al., 2021). In contrast, Wagg et al. (2025) found no significant between-group differences in skin health outcomes, although non-inferiority of the intervention was demonstrated. Continence-related outcomes were assessed in three studies. Long et al. (2015) reported no change in UI symptom severity, while Nikoletti et al. (2004) reported only a within-group improvement in UI severity. In contrast, Yu et al. (2014) demonstrated significant improvements in several continence-related outcomes. Quality of life and well-being outcomes were assessed in four studies. No significant between-group improvements were observed in quality of life or well-being outcome (Rajabali et al., 2023; van Cooten et al., 2025; Wagg et al., 2025), although Rajabali et al. (2023) reported significant within-group improvements. Long et al. (2015) also found no significant overall improvement in lower urinary tract symptom-related quality of life, except for a significant improvement in the travel restriction item. Long et al. (2015) also assessed the psychosocial impact of the device after use and reported positive scores across competence, adaptability, and self-esteem domains. Sleep-related outcomes were assessed in one study, which demonstrated a significant reduction in daily sleep interruptions following the intervention, whereas no significant differences were observed in responsive behavior scores (Wagg et al., 2025). Cognitive impairment and ADL outcomes were evaluated in one and two studies, respectively, with no significant improvements reported (Nikoletti et al., 2004; Rajabali et al., 2023).

Caregiver outcomes

Seven studies reported caregiver outcomes. Only one study reported outcomes related to informal caregivers (Cho et al., 2021). Descriptive caregiver experience findings were generally favorable. Agholme et al. (2023) reported high usability and perceived usefulness, whereas Cho et al. (2021) found that 59% of caregivers were willing to purchase the system despite implementation difficulties reported by 41% of caregivers. Adherence-related outcomes were reported in three studies, with generally favorable adherence to individualized UI care plans (Nikoletti et al., 2004; Rajabali et al., 2023; Yu et al., 2014). In contrast, controlled studies found no clear effects on caregivers' physical burden, work engagement, or organizational headroom (van Cooten et al., 2025; Wagg et al., 2025). Qualitative findings from two studies identified both perceived benefits and implementation barriers, including improved resource utilization and quality of UI care, as well as device malfunction, lack of time, resistance to practice change, and limited organizational support (Nikoletti et al., 2004; Rajabali et al., 2023).

Discussion

This systematic review synthesized evidence on sensor-based technologies for UI management across technical performance, patient outcomes, and caregiver outcomes. The evidence suggests that these technologies have the potential to support continence care and caregiver decision-making.

This review identified changes over time in the functional use of sensor-based UI technologies. In earlier studies, sensor-derived voiding patterns were used to develop individualized toileting plans (Yu et al., 2014), whereas more recent systems incorporated real-time notification functions or automated pattern analysis to support caregiver decision-making (Cho et al., 2021; Rajabali et al., 2023). This finding is consistent with previous literature indicating that sensor-based UI care products are evolving beyond moisture detection to support care timing, continence assessment, and care delivery (Jeong & Park, 2019; Omotunde & Wagg, 2023). Real-time urine detection and change notifications are intended to support more timely UI care than fixed schedule-based care. Nevertheless, controlled evidence demonstrating improved response timing remains limited. For example, Wagg et al. (2025) found no significant between-group difference in the time between pad saturation notification and pad change. These notification-based systems remain reactive because they prompt a response after wetness, leakage, or saturation. Pattern monitoring combined with individualized

Table 1. Characteristics of studies included.

1st Author, year	Country	Study Design	Setting /Sample N (E/C)	Age / Sex (M%/F%)	Technology Type	Intervention (E / C)	Duration/ Evaluation
Agholme, 2023	Poland	Single-arm clinical trial	Home environment; older adults with UI receiving home care; N=35	74.0y (M:20.0%, F:80.0%)	Saturation sensing + notification	E: TENA SmartCare Change Indicator (reusable sensor on outside of pad + transmitter + smartphone app)E: TENA SmartCare Change Indicator (reusable sensor on outside of pad + transmitter + smartphone app)	3 weeks; T0: baseline, T1: learning week, T2: investigational week using device
Cho, 2021	Korea	Prospective single-arm pilot study	Acute care hospital; patients aged ≥50 years wearing diapers due to UI; N=30	80.8y (M:30.0%, F:70.0%)	Voiding detection + volume estimation system + notification	E: Smart diaper system (conductor-embedded diaper + sensing device + smartphone app); *Reference measurement: wet diaper weight recorded on FVCs	3–5 days; T0: baseline, T1: End of monitoring
Long, 2015	United Kingdom	Prototype product evaluation study	Outpatient clinics, general practice surgeries, community continence services, charities, and networks; women aged ≥18 years regularly using continence pads and experiencing pad leakage; N=55	67 y (M:0%, F:100%)	Pad leakage detection + notification	E: TACT3 Smart UnderWear (washable fixation pants + sewn-in conductive threads + removable signaling unit) *Reference measurement: leakage event diary during the first 7 days	2 weeks; T0: baseline, T1: week 2
Nikoletti, 2004	Australia	RCT with qualitative component	Acute care rehabilitation wards; elderly incontinent patients aged ≥65 years; N= 41(22/19) (only 6 completed CMC)	E: 82 y (M: 59%, F: 41%); C: 85 y (M: 37%, F: 63%)	Voiding detection + notification + pattern monitoring + individualized toileting plan	E: Habit training with electronic monitoring (sensor in pad, portable monitoring device) → individualized toileting plan C: Standard habit training → individualized toileting plan	72hr monitoring; T0: baseline, T1: 1 month after
Rajabali, 2023	Canada	Quasi-experimental mixed-methods study	Nursing home; residents aged >65 years requiring UI care; N= 89(43/46)	E=85.6y (M:18.6%, F: 81.4%); C= 88.5y (M:32.6%, F:67.4%)	Voiding detection + volume estimation system + automated pattern monitoring + individualized toileting plan	E: TENA Identifi (sensor-woven pads + transmitter logger + remote secure server) → Individualized toileting plan C: Usual care ("ask, check, and change")	72-h assessment; T0: baseline, T1: week 8, T2: week 16
van Cooten, 2025	Netherlands	Cluster RCT	Residential care facilities; people with PIMD and unable to communicate IM change need; N=156 (82/74)	E: 51.7 y (M 57%, F 43%); C: 45.4 y (M 53%, F 47%)	Saturation sensing + notification + pattern monitoring + individualized toileting plan	E: Abena Nova (urine sensors pad+ reusable clip + receivers + mobile app/online platform) C: Regular care	12 weeks; T0: baseline, T1: weeks 6, T2: week 12
Wagg, 2025	Canada, Germany	Cluster RCT	NH residents ≥65 y with UI, unable to consistently communicate toileting needs; check-and-change regimen; N= 102 (53/49)	E: Median age 87; C: Median age 87 y; Overall male 21.5% (detailed M/F by group not reported)	Saturation sensing + notification	E: TENA SmartCare Change Indicator (reusable sensor on outside of pad + transmitter + smartphone app) C: Usual check-and-change regimen	6 weeks; T0: baseline, T1: week 2, T2: week 6
Yu, 2014	Australia	Quasi-experimental study	NH; older residents with UI; N=31	81 y (F 78%)	Voiding detection + volume estimation system + pattern monitoring + individualized toileting plan	E: SIM telemonitoring system (sensor in pad + smartphone app + desktop computer)	12 weeks; T0: baseline, T1: week 2

Note. E = experimental group; C = control group; M = male; F = female; y = years; UI = urinary incontinence; NH = nursing home; PIMD = profound intellectual and multiple disabilities; IM = incontinence material; RCT = randomized controlled trial; FVC = frequency volume chart; CMC = continence monitoring chart; T0 = baseline; T1 = first follow-up; T2 = second follow-up

Table 2. Outcomes of Included Studies (Part 1).

1st Author, year	Technology Type	Outcomes	
Agholme, 2023	Saturation sensing + notification	Technical performance	▲ Checks per day (4.3→3.5, −16%, p=.001) ▲ Leakages per day (0.33→0.20, −40%, p=.005) △ Changes the absorbing products (3.3→3.0, NS) △ Fecal incidences per day (0.066→0.059, NS) – Safety: no serious device-related adverse events reported
		Patient outcome	- Skin redness / irritation: all 5 cases resolved by end of trial
		Caregiver outcome	- Usability: 83% rated device "very easy"; 89% overall usefulness "good"/"very good"; 89% would recommend – Caregiver perception: 71% reported reduced concern regarding patient comfort; 86% reported facilitated decision-making for diaper changes
Cho, 2021	Voiding detection + volume estimation system + notification	Technical performance	- Voiding detection rate: 32.8%; lower than expected - Urine volume measurement accuracy: mean difference −4.2 mL; 95% limits of agreement −96.7 to 88.3 mL; R^2=0.88 (p<.001)
		Patient outcome	- IAD and bed sore: no new occurrence; 1 case improved
		Caregiver outcome	- Caregiver experience: 59% willing to purchase; 41% reported system difficulties
Long, 2015	Pad leakage detection + notification	Technical performance	- Proportion of occasions alerted to pad leakage: 86% (95% CI: 79%–94%) - Proportion of occasions unaware of leakage prior to alert: 59% - Proportion alerted in time to change before leakage onto clothing/furnishings: 82% (95% CI: 76%–88%) - False alarms per day: mean 1.73 (95% CI: 0.79–2.66), median 0.5
		Patient outcome	△ ICIQ-UI Short Form: no change (prescore 15.0; postscore 15.0) △ ICIQ-LUTSqol: no significant change overall ▲ Effect on ability to travel: significant improvement (p<.05) - PIADS competence/ adaptability/ self-esteem: +0.44/ +1.1/ +0.93 - Overall impression: 92% good/OK (63% good, 29% OK) - Confidence levels: 92% would/might feel more confident (62% would, 30% might) - Willingness to purchase: 46% yes, 31% maybe - Comfort: >80% comfortable - Ease of washing: 93% easy to wash - Instructions for use: 98% good/OK - Design issues: press stud mechanism, bulky signaling unit, visibility under tight-fitting clothes, false alarms possibly triggered by perspiration
		Caregiver outcome	N/R
Nikoletti, 2004	Voiding detection + notification + pattern monitoring + individualized toileting plan	Technical performance	N/R
		Patient outcome	□ Cognitive impairment: at T0 (p=0.91), T1 (p=.82); △ both within-groups □ ADL: at T0 (p=.32), T1 (p=.81); △ both within-groups □ Frequency of incontinence: at T0 (p=0.96), T1 (p=.74); △ both within-groups □ Severity of incontinence: at T0 (p=.075), T1 (p=.686); △ in C, ▲in E↓ (p=.025) - Continence outcome by CMC (n=6): both groups improved; statistical analysis not conducted
		Caregiver outcome	- Compliance: case-study data only (C: 14–55%, E: 39–59%) - Nurses' perceptions (qualitative): device malfunction, lack of time, resistance to practice change, and inadequate support identified as key barriers
Rajabali, 2023	Voiding detection + volume estimation system + automated pattern monitoring + individualized toileting plan	Technical performance	■ Reduction in 24-h pad absorbency (50.6% vs 39.1%, p=.034) □ Number of day pads used ↓(p=.263); △ both within-groups □ Number of night pads used ↓(p=.499); △ both within-groups □ Absorbency of day pads used ↓ (p=.779); △ both within-groups ■ Absorbency of night pads used ↑ (p=.0001); △ in C, ▲in E↓ (p=.010) ■ Total absorbency of pads used in 24 h ↓ (p=.011); △ in C, ▲ in E↓ (p=.013) □ Total cost of day pads↓ (p=.275); △ both within-groups ■ Total cost of night pads ↓ (p=.048); △ in C, ▲ in E ↓ (p=.009) □ Number of pad leakages/24 h ↓ (p=.057); △ in C, ▲ in E ↓ (p=.016) □ Number of wet checks↓ (p=.193); △ both within-groups □ Reported time spent in continence care↓(p=.055); △ both within-groups
		Patient outcome	□ ADL↑ (p=.364); △ both within-groups □ Fluid intake ↓ (p=.861); △ both within-groups □ Reported QoL-AD↓ (p=.595); ▲ both within-groups (p=.049) □ Observed QoL-AD↑ (p=.387)
		Caregiver outcome	- Adherence to the continence care plan derived (week 16): 68.3% - Caregiver (Nurses, CAs, managers) (qualitative): Resource use/ Quality of continence care/ System utility and limitations

Table 2. Outcomes of Included Studies (Part 2).

1st Author, year	Technology Type	Outcomes	
van Cooten, 2025	Saturation sensing + notification + pattern monitoring + individualized toileting plan	Technical performance	■ Leakages per week: significantly decrease in C compared with E at T2 (p=.01) ■ IM changes per week: significantly reduced in E compared with C at T1 (p=.004) and T2 (p=.003) □ Duration for continence care per week: no significant difference at T1 (p=.89) and T2 (p=.84)
		Patient outcome	□ Subjective well-being (MIPQ): no significant difference at T2 (p=.66) □ Objective well-being (QOL-PMD): no significant difference at T2 (p=.08)
		Caregiver outcome	□ Caregivers' physical burden: no significant difference (p=.09)
Wagg, 2025	Saturation sensing + notification	Technical performance	□ Daily number of pad checks (p=.589) □ Daily number of pad changes (p=.070) □ Daily number of toilet visits (p=.506) □ Daily number of clothing changes (p=.134) □ Daily number of linen changes (p=.703) □ Care efficiency score: reduced more in E (−16 vs −30 min/day) ■ Daily total absorbency: significantly reduced in E (p=.034) □ Time between notification of pad saturation and pad change (p=.346) □ Number of unnecessary checks/changes per 24 hours (p=.218)
		Patient outcome	□ Skin health (p=.209); non-inferiority demonstrated (p<.001) □ Intermittent skin score (p=.209) □ EQ-5D VAS (p=.236) □ QoL-AD score (p=.403) □ Daily responsive behavior score (p=.444) ■ Daily number of sleep interruptions: significantly reduced in E (p=.018)
		Caregiver outcome	□ UWES total score (p=.930) □ Organizational headroom: no significant difference
Yu, 2014	Voiding detection + volume estimation system + pattern monitoring + individualized toileting plan	Technical performance	N/R
		Patient outcome	▲ Volume of urine voided into continence aids ↓ (p=.015) ▲ No. of prescribed toileting events ↓ (median 18→15/72h, p=.015) ▲ No. of actual toileting events (median 6→16/72h, p<.001) ▲ No. of successful toileting events (median 3→8/72h, p=.011) △ % of successful toileting events (50%→50%, unchanged)
		Caregiver outcome	▲ Compliance with care plan prescription (33.3→106.7%, p=.033)

Note.

■ = statistically significant difference between groups

□ = no statistically significant difference between groups

▲ = statistically significant change from baseline (pre–post within-group change)

△ = no statistically significant change from baseline

ADL = activities of daily living; C = control group; CAs = care aides; CI = confidence interval; CMC = Continence Monitoring Chart; E = experimental group; EQ-5D VAS = EuroQol 5-Dimension Visual Analog Scale; IAD = incontinence-associated dermatitis; ICIQ-LUTSqol = International Consultation on Incontinence Questionnaire–Lower Urinary Tract Symptoms Quality of Life; ICIQ-UI Short Form = International Consultation on Incontinence Questionnaire–Urinary Incontinence Short Form; IM = incontinence material; MIPQ = Mood, Interest and Pleasure Questionnaire; N/R = not reported; NS = not significant; PIADS = Psychosocial Impact of Assistive Devices Scale; QOL-PMD = Quality of Life of Persons with Profound Multiple Disabilities; QoL-AD = Quality of Life in Alzheimer's Disease; T0 = baseline; T1 = first follow-up; T2 = second follow-up; UI = urinary incontinence; UWES = Utrecht Work Engagement Scale.

care planning offers a conceptually different approach by using accumulated voiding data to inform toileting schedules, product selection, and care timing. Studies incorporating this approach suggest potential to support proactive care planning (Rajabali et al., 2023; van Cooten et al., 2025; Yu et al., 2014), although the evidence remains limited. Further research is therefore needed to determine whether this approach can reduce reliance on uniform fixed schedules and align UI care with recommendations for individualized management (Nambiar et al., 2022; Newman et al., 2019).

Regarding technical performance, the included studies evaluated both direct device performance and outcomes derived from technology use. Direct device performance showed mixed findings. This variability may reflect differences in sensing mechanisms and real-world conditions, as sensor measurements can be affected by movement, body position, and pressure changes (Kim et al., 2024). Performance assessment was also limited because one study analyzed only a subset of all recorded voiding events (Cho et al., 2021) and reliance on participant-completed diaries in another (Long et al., 2015). Accordingly, the available evidence is insufficient to draw firm conclusions about the accuracy and reliability of these devices. Among outcomes derived from technology use, positive changes were reported in selected measures of pad checking, leakage, absorbent product use, and costs (Agholme et al., 2023; Rajabali et al., 2023; Wagg et al., 2025). For example, Rajabali et al. (2023) reported a significant reduction in nighttime pad costs, suggesting that sensor-derived information may help caregivers select absorbent products more appropriately and reduce unnecessary product use. This is clinically relevant because appropriate product use and timely pad changing may reduce waste while also helping to prevent prolonged moisture exposure and related skin problems (Kottner & Dissemond, 2025). Given the need for long-term UI management, studies evaluating both clinical and economic outcomes over extended periods are needed to determine the feasibility of implementing these technologies in real-world care settings.

For patient outcomes, positive findings were reported for skin condition, continence-related outcomes, and sleep interruptions. Their interpretation is limited because the skin findings were largely descriptive (Agholme et al., 2023; Cho et al., 2021), continence-related improvements were primarily based on within-group changes (Nikoletti et al., 2004; Yu et al., 2014), and reduced sleep interruptions were reported in only one study (Wagg et al., 2025). Regarding the patient psychosocial outcomes, favorable findings were reported only by Long et al. (2015), including perceived benefits for confidence and a reduced impact of UI on travel. This difference may reflect population and setting heterogeneity. Long et al. (2015) included community-dwelling women who could operate the device and respond directly to alerts, whereas most other studies involved care-dependent individuals who relied on caregivers for UI care (Rajabali et al., 2023; van Cooten et al., 2025; Wagg et al., 2025). Although UI has consistently been associated with reduced quality of life and increased psychosocial burden (Pizzol et al., 2021), the included studies showed limited evidence of improvement in these outcomes. The intervention periods may have been insufficient to capture measurable patient-level changes, particularly among care-dependent populations. Long-term intervention studies that account for the characteristics of the target population are needed to evaluate the effects of sensor-based UI management on quality of life and psychosocial well-being (Gröning et al., 2024; van den Bosch et al., 2025).

For caregiver outcomes, positive findings were reported regarding device usability. Consistent improvements were not observed in caregiver burden, work engagement, or organizational headroom (van Cooten et al., 2025; Wagg et al., 2025). Qualitative findings also indicated implementation barriers, including device malfunction, lack of time, resistance to practice change, and limited organizational support (Nikoletti et al., 2004; Rajabali et al., 2023). Meaningful improvements in caregiver outcomes may require integration into existing workflows, clear staff roles, adequate training, and organizational support (Freeman et al., 2025; Gröning et al., 2024; Walzer et al., 2025). Caregiver outcomes in the included studies were assessed mainly among formal caregivers, including care aides, nurses, and frontline care staff. Evidence regarding informal caregivers remains limited, despite their important role in UI care in community and home settings. This gap carries clinical relevance. UI is associated with broad health consequences and substantial socioeconomic costs across care settings (Bishop

et al., 2025; Soysal et al., 2023). Caregiving related to UI management may place physical, emotional, and time-related burdens on informal caregivers (Akpinar et al., 2023; Bishop et al., 2025). Future studies should evaluate sensor-based UI technologies in home-based care and include outcomes such as caregiving burden, sleep, psychological well-being, and quality of life.

One notable finding of this review was that patient perspectives on usability and satisfaction were insufficiently examined. The only study that collected direct patient feedback was Long et al. (2015), which included community-dwelling women who could operate the device independently and respond directly to its alerts. There is a lack of comprehensive evaluation of patients' usability, satisfaction, or acceptability among patients receiving caregiver-assisted continence care. This gap may limit understanding of how these technologies are experienced by the individuals most directly affected by their use. Patient perspectives on comfort, bodily privacy, dignity, perceived usefulness, and willingness to continue use are essential for determining their clinical relevance. Future studies should conduct patient-centered evaluations among individuals who receive caregiver-assisted continence care but can communicate their experiences, while using adapted methods for those with cognitive or communication impairments.

Limitation

This study is significant in that it integrated the functional characteristics, clinical effects, and caregiver experiences of sensor-based UI technologies and demonstrated that these technologies may serve not merely as urine detection devices, but as tools that support UI care processes and caregivers' decision-making. However, this review has several limitations. First, substantial heterogeneity in the functional components of the interventions and outcome measures across the included studies precluded meta-analysis and required reliance on narrative synthesis, which may limit the integrated interpretation of the evidence. Second, because this review excluded device development and technical validation studies, it may not fully reflect the diversity of technologies in the early development stage or recent advances in sensor-based UI care technologies. Third, this review included only studies published in English, which may have introduced language bias. Fourth, considering the methodological limitations identified in the risk-of-bias assessment and the predominance of pilot/feasibility studies and single-arm designs, confidence in the overall evidence remains limited. Finally, some included studies evaluated commercially developed technologies and involved manufacturers in study funding or conduct, which may have introduced potential conflicts of interest.

Conclusion

This systematic review synthesized evidence on sensor-based UI technologies across technical, patient, and caregiver domains. These technologies are evolving from simple wetness detection toward systems that integrate real-time notification, voiding pattern analysis, and automatic individualized care planning. Technical performance remained inconsistent, and improvements in patient outcomes were limited. Evidence of potential benefit was more apparent for care-process outcomes and support for UI care decision-making than for broader patient outcomes. Individuals requiring diaper-based UI care represent a highly dependent population, and improvements in care processes may have substantial clinical significance even when measurable changes in broader patient outcomes are not observed.

Future research should prioritize standardized outcome measurement, longer follow-up periods, adequate sample sizes, and the inclusion of informal caregivers as a stakeholder group. The cost implications of these technologies, including absorbent product use, staff time, device costs, and sustainability in routine care, should also be evaluated. Rigorous assessment of implementation processes will be important to determine whether these technologies can produce sustained improvements in clinical and long-term care practice.

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