

# **Innovative, Tech-Driven, And Digital Tools For Managing Pediatric Urinary Incontinence: A Scoping Review**

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## Table of Contents

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|                                 |           |
|---------------------------------|-----------|
| <b>Original Manuscript.....</b> | <b>5</b>  |
| <b>Supplementary Files.....</b> | <b>35</b> |
| Figures .....                   | 36        |
| Figure 1.....                   | 37        |
| Figure 2.....                   | 38        |
| Figure 3.....                   | 39        |
| Figure 4.....                   | 40        |
| Multimedia Appendixes .....     | 41        |
| Multimedia Appendix 1.....      | 42        |
| Multimedia Appendix 2.....      | 42        |
| Multimedia Appendix 3.....      | 42        |

# Innovative, Tech-Driven, And Digital Tools For Managing Pediatric Urinary Incontinence: A Scoping Review

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## Abstract

**Background:** Urinary incontinence affects around 7-10% of children during the day and 9-12% during the night. Once anatomical and neurogenic causes are ruled out, treatment mainly involves lifestyle advice and behavioral methods. However, motivation and adherence to these methods, essential for success, are often low. Traditional tools, such as pen-and-paper solutions, may feel outdated to today's 'digital native' children. As healthcare evolves with technology, traditional UI management tools may no longer meet children's needs, potentially affecting their motivation and adherence.

**Objective:** Our objective was to identify innovative, tech-driven and digital tools for managing pediatric urinary incontinence as alternatives to traditional methods and provide an overview of their supporting evidence.

**Methods:** This scoping review followed PRISMA-ScR guidelines, with a search conducted in March 2022 across PubMed, Web of Science, and Cochrane Library, without date limits. The review focused on innovative, tech-driven and digital tools for pediatric urinary incontinence management, covering a wide range of dysfunctions and behavioral methods. Articles involving adults, lacking results, not in English, or missing full texts were excluded. From 2030 articles retrieved, 60 were included after screening, with 6 additional articles identified through cross-references, resulting in a total of 66 included articles.

**Results:** The field of pediatric urinary incontinence demonstrates a considerable level of innovation, as evidenced by the inclusion of 66 studies, with nearly one-third (38%, n=25/66) focusing on nocturnal enuresis. Most studies were randomized controlled trials (n=14) or validation studies (n=13), and over one-third (38%, n=25/66) assessed patient experience outcomes such as satisfaction, motivation, and usability. Our analysis led to the identification and classification of six main categories of tools: (i) mobile health (n=7), (ii) serious games (n=7), (iii) reminder technology (n=6), (iv) educational media (n=12), further divided into video (n=5) and other media (n=7), (v) telehealth and remote patient monitoring (n=13), with subcategories of communication (n=5) and technological advances (n=8), and (vi) enuresis alarm innovations (n=21), further divided into novel configurations (n=8) and pre-void alarms (n=13).

**Conclusions:** Many of the tools identified in this review show great promise as feasible and effective alternatives to traditional methods. They engage children well, improving compliance and leading to high satisfaction and preference, while also having the potential to save time for healthcare providers. However, their superiority over traditional methods remains unclear due to study limitations and conflicting results. Additionally, managing pediatric UI is complex due to its multifaceted nature, requiring accurate diagnosis and tailored interventions that consider clinical signs, child characteristics, and stakeholder involvement. We propose that future tools evolve into holistic, adaptive, and personalized ecosystems that align with stakeholders' needs by integrating diverse strategies for urinary incontinence management. Combining different tool categories identified in this review

may provide a framework for creating these ecosystems.

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## Original Manuscript

## Review

# Innovative, Tech-Driven, And Digital Tools For Managing Pediatric Urinary Incontinence: A Scoping Review

## Abstract

**Background:** Urinary incontinence affects around 7-10% of children during the day and 9-12% during the night. Treatment mainly involves lifestyle advice and behavioral methods, but motivation and adherence are low. Traditional tools, such as pen-and-paper solutions, may feel outdated and no longer meet the needs of today's 'digital native' children. Meanwhile, digital interventions have already shown effectiveness in other pediatric healthcare areas.

**Objective:** This scoping review aimed to identify and map innovative, tech-driven and digital tools for managing pediatric urinary incontinence.

**Methods:** PubMed, Web of Science, and Cochrane Library were searched in March 2022 without date restrictions, complemented by cross-referencing. Studies were eligible if they focused on pediatric patients ( $\leq 18$  years) with bladder and bowel dysfunctions, exploring non-invasive, technology-based interventions such as mHealth, remote monitoring and gamification. Adults, invasive treatments, and conventional methods without tangible tools were excluded. Gray literature was considered, but non-English, inaccessible or result-lacking articles were excluded. A formal critical appraisal was not conducted, as the focus was on mapping existing tools rather than evaluating effectiveness. Data analysis combined descriptive statistics and qualitative content analysis, categorizing tools through iterative coding and team discussions.

**Results:** Sixty-six articles were included, with nearly one-third (38%,  $n=25/66$ ) focusing on nocturnal enuresis. Most studies were randomized controlled trials ( $n=14$ ) or validation studies ( $n=13$ ), and over one-third (38%,  $n=25/66$ ) assessed patient experience outcomes such as satisfaction, motivation, and usability. Our analysis led to the identification and classification of six main categories of tools: (i) mobile health ( $n=7$ ), (ii) serious games ( $n=7$ ), (iii) reminder technology ( $n=6$ ), (iv) educational media ( $n=12$ ), further divided into video ( $n=5$ ) and other media ( $n=7$ ), (v) telehealth and remote patient monitoring ( $n=13$ ), with subcategories of communication ( $n=5$ ) and technological advances ( $n=8$ ), and (vi) enuresis alarm innovations ( $n=21$ ), further divided into novel configurations ( $n=8$ ) and pre-void alarms ( $n=13$ ).

**Conclusions:** The field of pediatric urinary incontinence demonstrates a considerable level of innovation, as evidenced by the inclusion of 66 studies. Many of the tools identified in this review are described as promising and feasible alternatives to traditional methods. These tools are reported to enhance engagement, improve compliance and increase patient satisfaction and preference, while also having the potential to save time for healthcare providers. However, the review also identifies gaps in research, highlighting the need for more rigorous research to better assess their effectiveness and address the complex, multifaceted challenges of pediatric urinary incontinence management. Limitations of this review include restricting the search to three databases, excluding non-English studies, the broad scope that made synthesis challenging, and single-reviewer screening, though frequent team discussions ensured rigor. We propose that future tools should integrate connected, adaptive, and personalized approaches that align with stakeholder need, guided by a multidisciplinary, human-centered framework that combines both qualitative and quantitative insights.

**Keywords:** pediatric urinary incontinence; nocturnal enuresis; behavioral therapy; urotherapy; patient compliance; mobile health; serious games; telehealth; health technology; enuresis alarm

## Introduction

Urinary incontinence (UI) is prevalent among children, affecting around 7-10% of children (aged 5-13 years) during the day [1] and 9-12% (aged 5-15 years) during the night [2–4]. UI often leads to low self-esteem, shame, and stress, negatively impacting the child's psychosocial well-being and overall quality of life [5–9]. The primary treatment approach for pediatric UI, once anatomical and neurogenic causes are excluded, mainly involves lifestyle advice and behavioral methods [10–12]. These methods vary depending on whether the UI occurs during the day or at night.

For daytime urinary incontinence (DUI), the recommended first-line approach is standard urotherapy. It encompasses patient education, keeping track of symptoms through bladder diaries, regulating fluid intake and toilet routines, adhering to scheduled voiding, and providing support and encouragement [13–16]. An important part of this treatment is teaching children appropriate responses to their bladder signals. Standard urotherapy achieves success rates ranging from 40–56% [17–19]. For nighttime UI, also known as nocturnal enuresis (NE), one of the recommended first-line treatments is NE alarm training [20]. This method employs a moisture sensor that triggers an alarm to wake the child upon bedwetting. Through this approach, children are conditioned to recognize and respond to bladder signals, ultimately helping to reduce bedwetting episodes. The success rate of alarm training is between 50–70% [21]. However, motivation and adherence, both crucial for these behavioral methods to be successful [22,23], are low in practice [22,24,25].

There are many factors that influence motivation and adherence [15,24–27], including duration of therapy, required effort, symptom bother, awareness, but also supporting tools' usability and acceptance. The evaluation and management of pediatric UI traditionally rely on pen and paper bladder diaries [28–30], along with verbal and written instructions for behavioral techniques [31], and traditional NE alarms [32]. However, these analog methods may seem outdated by today's 'digital native' children, who are accustomed to using technology and digital tools [33] such as smartphones and interactive computer games [34]. Consequently, traditional approaches to pediatric UI management may no longer meet today's children's needs and expectations, potentially affecting motivation and adherence. Meanwhile, digital interventions have already proven effective as alternatives to traditional methods in other pediatric healthcare areas, such as pain tracking [35], ADHD therapy [36], childhood obesity prevention [37] and asthma management [38].

Therefore, our objective was to identify and map innovative, tech-driven and digital tools for pediatric UI management as alternatives to conventional approaches like pen and paper solutions. Additionally, we aimed to provide an overview of these tools' characteristics, including their features, design drivers and any reported evidence supporting their use.

## Methods

This scoping review followed the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines as outlined by Tricco et al. (2018) [39]; see Multimedia Appendix 1 for the PRISMA-ScR checklist.

## Eligibility criteria

Eligibility criteria were determined based on the PCC framework (Population, Concept, and

Context). The *population* for this review included pediatric patients experiencing bladder and bowel dysfunctions, such as nocturnal enuresis, overactive bladder, underactive bladder, and dysfunctional voiding, as well as neurogenic conditions like Spina Bifida. Articles involving adult populations ( $\geq 18$  years) or unrelated conditions (e.g., cancer or rare diseases) were excluded.

The *concept* focused on innovative, technology-driven, and digital tools for managing pediatric UI and related dysfunctions. Eligible tools included smartphone applications, multimedia resources, and remote monitoring technologies, whereas conventional methods or treatment plans without tangible tools were excluded.

The *context* was limited to studies that addressed non-invasive therapeutic approaches, particularly behavioral methods like urotherapy, bladder training, and alarm training. Invasive approaches, including surgeries and their associated tools, were excluded.

All types of literature were considered, including gray literature (e.g., conference proceedings, preprints, and technical reports), to provide a broad range of available literature and reduce publication bias. However, articles not presenting results or findings, not written in English, or lacking full-text availability were excluded.

## Search strategy

The search (see Multimedia Appendix 2 for full search strategy) was conducted in March 2022 across three databases, Pubmed, Web of Science and Cochrane Library, with no limitations on publication dates. The PCC framework guided the selection of search terms.

Key search terms for the *population* included "children," "adolescents," "pediatric," "bladder bowel dysfunction" and "enuresis." For the *concept*, terms like "digital," "mHealth," "gamification," "multimedia," and "remote monitoring" were used. *Context*-related search terms included "urotherapy," "bladder training," "alarm therapy," "self-monitoring," and "behavior management."

## Study selection

The study selection process was conducted by the first author (LB) with consultation and supervision provided by the team of authors. After removing duplicates, potential studies underwent screening based on their titles and abstracts in line with the eligibility criteria, with any uncertainties discussed with the author team.

Subsequently, LB read and assessed the full-text articles, periodically consulting with the team to ensure consistency and rigor. To reduce selection bias from database choice, we conducted cross-referencing, scanning reference lists of the included articles to identify additional relevant studies.

The selected studies underwent final review and confirmation by the entire author team. A formal critical appraisal or methodological quality assessment was not conducted, as the aim of this scoping review was to identify and map the available evidence on innovative, technology-driven, and digital tools rather than to draw formal conclusions on their effectiveness.

## Data extraction

Data were extracted and charted using Microsoft Excel according to four main heading groups: (i) article information, (ii) participant characteristics (population), (iii) tool description (concept), and (iv) research methods and results (context). Article information encompassed details such as article title, authors, journal, publication year, country, and database source. Participant characteristics included sample size, age range, sex distribution, and dysfunction indication. Tool description covered intended therapy type, tool design details, and its design drivers. Finally, research methods and results comprised study design, intervention group(s), study outcomes, and conclusions.

## Data analysis

A combination of descriptive statistics and basic qualitative content analysis was employed for data

analysis. Descriptive statistics were used to analyze study characteristics, providing frequency counts and proportions for extraction items such as study design and dysfunction indication. Basic qualitative content analysis was used to identify and classify innovative, tech-driven, and digital tools into distinct categories. The process began with multiple readings of the extraction items related to the tool description to familiarize ourselves with the data. Following an inductive approach, initial notes were made to generate codes, and coding was manually conducted in Microsoft Excel, where relevant terms were highlighted and grouped into emerging patterns. Through iterative refinement and team discussions, codes were merged, removed, or redefined to eliminate overlap and ensure sufficient distinction. The final set of codes was organized into six broad categories, three of which were further subdivided to capture more specific aspects. LB conducted the preliminary analysis, and to ensure consistency and reliability, the coding process was reviewed and refined collaboratively by the coauthors at multiple stages. Any disagreements in categorization were addressed through discussions to achieve consensus.

## Results

### Retrieval of studies

The search retrieved a total of 2030 articles (Pubmed, n=951; Web of Science, n=760; Cochrane, n=319). After removing duplicates (n=372), a total of 1658 studies were included in the title and abstract screening. Following title and abstract screening, 1575 articles were excluded, leaving 83 for full-text evaluation. Finally, 60 articles were included in the data extraction process, with an additional 6 identified through cross-references, resulting in a total of 66 included articles. Figure 1 illustrates the flowchart of the screening and selection process.

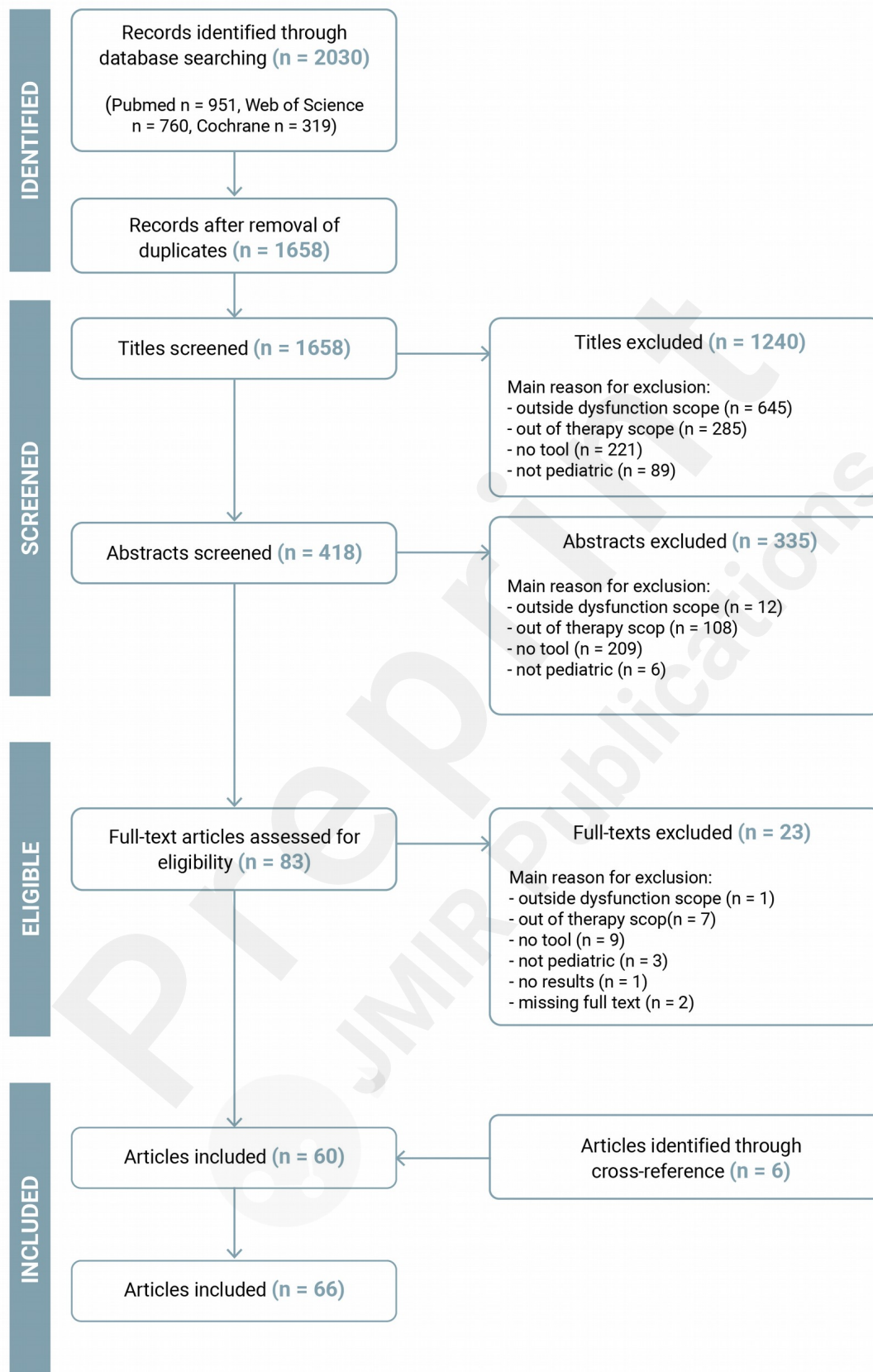


Figure 1. PRISMA flowchart of the literature screening and selection process

## General analysis to describe study characteristics

Among the studies included (n=66), the majority were randomized controlled trials (RCT) (n=14)

and validation studies (n=13), followed by quasi-experiments (n=10), prospective studies with no control group (n=7), and qualitative or mixed methods study designs (n=8) as depicted in Table 1. Nearly one-third (32%, n=21/66) of the identified tools targeted children with NE, followed by dysfunctional voiding (DV) (n=9), BBD (n=7), and DUI (n=7). More than one-third (38%, n=25/66) of studies evaluated outcomes related to patient experience, such as satisfaction, motivation, and usability. A mean sample size of 82 subjects with a standard deviation of 83 (range 14-353) was found for the RCTs, quasi-experiments, and experimental studies (no control), indicating a large variation in sample size.

Table 1. Summary of study characteristics (N = 66)

| Study characteristics  |                               | Studies, n (%) |
|------------------------|-------------------------------|----------------|
| Study design           |                               |                |
|                        | RCT                           | 14 (21.2)      |
|                        | Feasibility / validation      | 13 (19.7)      |
|                        | Quasi-experiment              | 10 (15.2)      |
|                        | Prospective n.c.              | 7 (10.6)       |
|                        | Review                        | 6 (9.1)        |
|                        | Mixed methods                 | 5 (7.6)        |
|                        | Retrospective study           | 4 (6.1)        |
|                        | Qualitative                   | 3 (4.5)        |
|                        | Modelling                     | 2 (3.0)        |
|                        | Case study                    | 1 (1.5)        |
|                        | Design-based research         | 1 (1.5)        |
| Dysfunction indication |                               |                |
|                        | NE                            | 21 (31.8)      |
|                        | DV                            | 9 (13.6)       |
|                        | BBD                           | 7 (10.6)       |
|                        | DUI                           | 7 (10.6)       |
|                        | Daytime and/or nighttime UI   | 5 (7.6)        |
|                        | Neurogenic                    | 5 (7.6)        |
|                        | UTI                           | 4 (6.1)        |
|                        | (Neuro)developmental disorder | 3 (4.5)        |
|                        | OAB                           | 2 (3.0)        |
|                        | UAB                           | 1 (1.5)        |
|                        | Bowel dysfunction             | 1 (1.5)        |
|                        | Anatomical                    | 1 (1.5)        |

We identified and established a total of six primary categories of innovative, tech-driven and digital tools (Figure 2): (i) mobile health (n=7), (ii) serious games (n=7), (iii) reminder technology (n=6), (iv) educational media (n=12), (v) telehealth and remote patient monitoring (RPM) (n=13), and (vi) enuresis alarm innovations (n=21). Further sub-categories were identified within educational media, including video (n=5) and other media (n=7); within telehealth and RPM, including communication (n=5) and technological advances (n=8); and within enuresis alarm innovations, including novel configurations (n=8) and pre-void alarms (n=13).



Figure 2. Overview of the six categories and sub-categories of innovative, tech-driven and digital tools

Overall, we found that the distribution of dysfunction types was generally well balanced across the different tool categories. Mobile health demonstrates a diverse distribution, addressing a range of dysfunctions from umbrella terms like BBD (14%,  $n=1/7$ ) and daytime and/or nighttime UI (14%,  $n=1/7$ ) to neurogenic disorders (29%,  $n=2/7$ ). Serious games are predominantly used for DV (71%,  $n=5/7$ ). Reminder technology is used for timed voiding in cases of DUI and OAB (50%,  $n=3/6$ ), as well as for self-management of neurogenic and (neuro)developmental disorders (50%,  $n=3/6$ ). Educational media is used across a range of dysfunctions, with slightly more usage for NE (33%,  $n=4/12$ ) and urinary tract infections (UTI) (25%,  $n=3/12$ ). Telehealth is primarily used for umbrella terms such as BBD (31%,  $n=4/13$ ) and daytime and/or nighttime UI (31%,  $n=4/13$ ), with additional usage also observed for DV (23%,  $n=3/13$ ). Finally, enuresis alarm innovations are predominantly associated with NE (76%,  $n=16/21$ ), as expected, though not exclusively. They are also applied for other conditions such as DUI (10%,  $n=2/21$ ) and (neuro)developmental disorders (10%,  $n=2/21$ ).

## Categories of innovative, tech-driven and digital tools

### 1. Mobile health ( $n = 7$ )

*Category overview and key drivers:* Mobile health interventions involve the use of smartphones, tablets, and computers for medical and healthcare purposes. These digital devices have become increasingly prevalent in our society, especially among children and adolescents [40]. Therefore, they offer a practical and accessible medium with a range of possibilities, such as enhancing patient engagement and improving access, availability, and continuity of care [40,41].

*Tools within this category:* This review identified seven studies on mobile health interventions, with extended details available in Multimedia Appendix 3 (Table A1). These included electronic bladder diary applications [42,43], which serve as digital alternatives for traditional paper versions to improve patient compliance. Additionally, three self-management applications with training programs were included, targeting conditions like DUI (smartphone application) [44], bowel dysfunctions (internet application) [45], and Spina Bifida (smartphone application) [46,47]. These self-management applications incorporate features such as weekly modules with exercises, daily goals, self-monitoring of parameters like fluid intake, toilet visits, medication, and mood status, as well as reminders, progress tracking, personalized feedback, and rewards such as in-app trophies and stars. Furthermore, a parent software portal [48] was identified, enabling parents to monitor their child's symptoms, such as UTIs, to aid clinical decision-making.

*Study results and conclusions:* The studies on mobile health interventions report feasibility, acceptability, ease of use, and patient/parent satisfaction [42–48]. Furthermore, they describe improvements in patient compliance, as seen in both the bowel dysfunction self-management program and the parent software portal, with high completion rates and low dropouts [45,48]. However, the parent software portal was described as facing challenges in effectively delivering information to healthcare professionals, lacking integration into their busy clinical practice [48]. Despite many promising aspects, the studies often reported limitations in providing robust evidence of effectiveness. For example, the electronic bladder diary format was described as offering data quality advantages for certain patients but was not found to be superior to the paper-based bladder diary [42]. The sole RCT investigating the self-management program for bowel dysfunctions reported greater improvements in patients' quality of life and reducing overall symptom severity. However, this was in comparison to a non-equivalent control group of children on a wait-list who were not receiving any treatment [45].

## 2. Serious games (n = 7)

*Category overview and key drivers:* Serious games are interactive applications designed as games but intended for educational or therapeutic purposes. By blending elements of fun and seriousness, serious games offer a playful way for children to learn about complex topics like bladder and bowel health. This approach can be particularly effective for engaging children, who have limited attention spans and may struggle with processing information. Moreover, the entertainment aspect of serious games is crucial for motivating and engaging children, as they strive for success within the game [43,49,50].

*Tools within this category:* Table A2 in Multimedia Appendix 3 shows that serious games are mainly used for pelvic floor biofeedback training through biogames (86%, n=6/7) [51–56]. In these biogames, the game action is controlled by the appropriate muscular contractions and relaxations detected by pelvic floor electromyography patches worn by the child. Various animated scenarios are available, such as golfing, flying spaceships, riding an elephant, playing basketball, and swimming with dolphins or fish. Additionally, one serious game was found for standard urotherapy, which is played on a smartphone [57]. In this game, the child is rewarded for maintaining a daily bladder diary and voiding adequately during the 3-month training program, with additional rewards for staying dry.

*Study results and conclusions:* Overall, studies describe positive effects of biogames for pelvic floor biofeedback training on health outcomes, particularly for children with DV [51–54,56] and, in one

study, for those with UAB [55]. However, understanding the precise impact of adding a game to the therapy is challenging, as the studies report limitations such as retrospective designs [53], lack of control groups [51], and non-equivalent therapy comparisons [52,54,55].

Findings varied across studies: one study reported similar results in half the time with biogames (mean of 3.6 sessions) compared to without (mean of 7.6 sessions) [53], while another study reported a relatively high number of treatment sessions with biogames (mean of 9.6 sessions) [54]. In the sole RCT comparing equivalent therapies [56], no differences were observed in terms of clinical success, cooperation, and motivation between pelvic floor biofeedback training with or without biogames. Nevertheless, subjective observations suggested that using biogames effectively captured children's attention and prevented boredom during the sessions, particularly among younger children [56].

Similarly, in the comparison of standard urotherapy with or without a serious game, no significant differences were reported in training results, quality of life or motivation [57]. However, children expressed a clear preference for the game. They provided valuable suggestions for its improvement, such as introducing more dynamic gameplay with changing storylines and evolving game types, along with features like regular updates on training progress and detailed information about their bladder problem.

### 3. *Reminder technology (n = 6)*

*Category overview and key drivers:* Reminder technology use programmable timers to activate alarms aimed at assisting children in adhering to therapy or self-management schedules, without requiring constant prompting from parents. This approach supports children's independence, as parental reminders may sometimes contribute to resistance, with children preferring autonomy in adhering to their schedules [58].

*Tools within this category:* Six studies were categorized under reminder technology, see Table A3 in Multimedia Appendix 3. Half of these studies evaluate timer watches, which are used in standard urotherapy to assist with timed voiding (50%, n=3/6) [59–61]. The timer watch can be programmed to automatically alarm at specified intervals, such as every two hours, helping children maintain a consistent voiding schedule.

The other half of the studies focus on self-management reminders for children with neurogenic or (neuro)developmental disorders (50%, n=3/6) [62–64]. A laptop calendar program assists children with prospective memory disabilities in completing and logging daily schedules, such as self-catheterization and medication, through visual and auditory reminders [64]. A smartwatch with built-in fitness tracker displays visual icons to prompt children with Spina Bifida to engage in various daily activities from self-care to playtime, and rewarding timely completion with stars [63]. Lastly, “Potty Monkey” an interactive toy prompts children with special needs to void at set times, providing reminders, modeling techniques, and positive reinforcement for time-based toilet training [62].

*Study results and conclusions:* Reminder technology for timed voiding using a timer watch was reported to be superior in treating severe DUI in children with OAB compared to standard urotherapy without it, with improved adherence to the voiding schedule playing a key factor [60,61]. Additionally, another study described reminder technology to be an equally effective but simpler alternative to enuresis alarms (using moisture sensors) in treating DUI, also reporting good adherence rates [59].

For self-management in children with neurogenic or (neuro)developmental disorders, reminder technology was reported as feasible, though findings were based on small sample sizes [62–64]. The tools were described as alleviating anxiety for caregivers and patients by providing a log of tasks [64] and fostering child independence through clear routines [63]. However, patient acceptance

varied, with the smartwatch being highly accepted [63] and the interactive toy receiving lower acceptance [62], with aesthetics and flexibility playing a key role.

## 4. Educational media (n = 12)

### 4.1 Video (n = 5)

*Category overview and key drivers:* Videos, as educational media, offer a visually engaging and interactive format for explaining complex concepts and techniques to patients and parents. They provide a convenient and 24/7 available alternative or supplement to in-person visits. Moreover, videos offer anonymity, which can be beneficial for individuals who feel embarrassed or hesitant to seek medical advice in person. As a result, the internet and video-sharing platforms have become popular sources of health-related information [33].

*Tools within this category:* In our review, five studies were categorized under the subcategory of video in educational media, see Table A4 in Multimedia Appendix 3. These videos covered a range of topics. Some supported behavioral therapy, such as an animated bladder training video [65,66] and an abundance of YouTube videos on NE therapy [67,68]. Another video focused on preparing children for surgical interventions, featuring actual hospital staff and using role-play modelling techniques to demonstrate the anesthesia process [69].

*Study results and conclusions:* Multiple studies describe videos as effective educational media for patients, offering alternatives to in-person strategies [65,66,69]. In a non-inferiority RCT, the animated bladder training video was found to be equivalent to standard urotherapy in reducing bladder and bowel symptoms [65] and improving quality of life scores [66]. Similarly, the pre-surgery video was reported to effectively reduce preoperative anxiety and resulted in less postoperative maladaptive behavior [69].

While videos are described as effective tools for educating patients and families, caution is recommended when relying on video-sharing platforms, like YouTube, that lack robust systems to ensure the accuracy, completeness and quality of information [67,68]. The studies indicate a need for a balance between adherence to evidence-based guidelines and the creation of engaging content that captures and maintains viewer attention.

### 4.2 Other media (n = 7)

*Category overview and key drivers:* Effective information delivery is crucial for raising awareness, setting expectations, promoting patient adherence, and ensuring data quality. Unfortunately, verbal explanations by doctors may be poorly understood due to time constraints and complexity, while written information may not always be suitable or desirable for children, resulting in limited child participation. Thus, employing other types of educational media tailored and engaging for children may help ensure effective information delivery to pediatric patients.

*Tools within this category:* Seven studies were classified under other types of educational media (Table A5 in Multimedia Appendix 3). This category included two homework books for UI: one that uses coloring activities to log the severity of incontinence [70] and another that features practical exercises for standard urotherapy [71]. Additionally, [70,71] a multimedia program for NE was identified, which combines text, drawings, cartoons and sound to educate children on bedwetting [72,73]. Lastly, educational materials on UTIs included educational urine kits for clean-catch urine collection [74–76] and a low-cost origami-based microscope that utilizes a mobile phone camera to

raise awareness of genital hygiene and UTIs in schools [76].

*Study results and conclusions:* The UI homework books were reported to be feasible, usable, and well-received, with good compliance [70,71]. Additionally, the homework book for standard urotherapy was associated with increased fluid intake and hold time [71].

The multimedia program for NE was noted to show promise in holding children's attention and improving their knowledge, especially for younger children with low literacy levels [72]. However, results from the RCT indicated that while the multimedia program was not more effective than traditional verbal and written information, it can help save healthcare professionals time in patient education [73].

Similarly, urine kits with educational pamphlets for clean-catch urine collection did not demonstrate a significant reduction in contamination rates but may help streamline patient education [74,75]. However, "Foldscope" was described as a promising educational tool for promoting health awareness by detecting UTI-positive urine samples reasonably well [76].

## 5. Telehealth and RPM (n = 13)

### 5.1. Communication (n = 5)

*Category overview and key drivers:* Telehealth and RPM enable remote communication and data exchange between patients and clinicians. Although face-to-face communication has been shown to improve treatment adherence [27,77,78], constraints such as time, cost and travel can lead to extended intervals between consultations, potentially affecting patient motivation [79]. Telehealth may address some of these issues by offering consistent follow-up visits and motivational support without the need for physical visits.

*Tools within this category:* Five studies were categorized within the subcategory of communication in telehealth and RPM, see Table A6 in Multimedia Appendix 3. One study explored video conferencing for remote patient visits [80], while another study evaluated a UTI home monitoring system [81]. This system facilitates communication between parents of children with neurogenic bladder and urology nursing staff to alert them of potential UTI signs. It comprises a portable urinalysis device, Bluetooth weight scale, thermometer, electronic bladder diary, and a mobile communication device. Additionally, an embodied conversational agent, 'Dr. Evie,' was identified, offering personalized lifestyle advice and empathetic coaching for UI self-management while generating reports for GPs [82–84].

*Study results and conclusions:* The studies report high patient and parent satisfaction with telehealth, citing reduced stress and increased convenience, especially for rural families, due to decreased travel time [80–84]. Additionally, the UI self-management program, featuring an embodied conversational agent, was reported to improve patients' adherence rates from 50% to 76% on average and alleviate symptoms [82–84]. Advice from non-family members and a sense of alliance with Dr. Evie were noted to enhance program engagement.

Healthcare providers expressed mixed feelings about telehealth, acknowledging improved access to care but reporting technical barriers in conducting physical examinations and establishing rapport, particularly with pediatric patients [80]. Integrating RPM systems, such as the UTI monitoring system, may mitigate these technical barriers by providing valuable data for remote support and enhancing patient and parent self-efficacy [81]. However, patients' selective use of certain products, mainly the urinalysis device, was noted to create data gaps that hinder clinical evaluation. Additionally, technical issues contributed to increased workload for clinical teams, emphasizing the importance of careful consideration of all stakeholders' diverse needs and preferences to facilitate

successful integration into clinical practice.

## 5.2 Technological advances (n = 8)

*Category overview and key drivers:* Technological advances enabling telehealth and RPM aim to overcome limitations of in-clinic procedures, including the psychological stress children often experience in hospital settings [85,86]. These procedures can also be inconvenient and time-consuming, as seen with non-invasive uroflowmetry, which requires voiding with a full bladder [87]. Similarly, therapies like EMG biofeedback demand significant time and financial resources due to poor compliance and the need for multiple visits [86]. Meanwhile invasive studies carry health risks and are often discouraged, especially for young patients [88,89].

*Tools within this category:* Eight studies were categorized in the telehealth and RPM subcategory (Table A7 in Multimedia Appendix 3), focusing on technological advances. These ranged from a machine learning algorithm to predict enuresis in children [90] to a non-invasive alternative to traditional invasive urodynamics using near-infrared spectrometry (NIRS) [91].

Advances in uroflowmetry beyond traditional gravimetric methods were also reviewed [87]. These included basic volumetric, mechanical and electrical methods like capacitance sensors. Unconventional approaches were also discussed, including image processing for drop patterns, ultrasound Doppler effect, vibration sensors on the penis, and acoustic technology using a smartphone app to record urine sound [87,92].

Several studies explored adapting existing technologies for home use. These included uroflowmetry for home use [86,92] and its application in therapy settings to provide biofeedback during voiding [86,93]. Another study introduced home pelvic floor biofeedback through a wearable EMG device, featuring a watch-like design with a light scale to indicate muscle activity strength [94]. Additionally, transcutaneous electrical nerve stimulation (TENS) was evaluated as a user-friendly substitute for in-clinic percutaneous tibial nerve stimulation (PTNS) to enhance continence, enabling self-administration at home without invasive needle insertion [95].

*Study results and conclusions:* Overall, the studies describe promising advances in technology. The machine learning technology was described as having promising accuracy in screening for enuresis, with older age at toilet training initiation identified as a significant predictor [90]. Both uroflowmetry and EMG biofeedback were described as effective in reducing symptoms in patients with DV [93,94], with home uroflowmetry biofeedback showing promise and patient preference [86]. TENS was reported to show efficacy in reducing NE episodes, providing a safe and non-invasive at-home treatment option [95].

However, some novel technologies, like NIRS, were described as promising and well-accepted by patients but were also noted to lack standardized benchmarks and face challenges in ensuring consistent and reliable data that align with established norms and guidelines [91]. Similarly, while various uroflowmetry methods exist, gravimetric uroflowmeters were favored due to their simplicity and reliability [87]. For example, sound-based uroflowmetry, despite showing strong correlations with conventional uroflowmetry, was reported to have wide limits of agreement, with its accuracy influenced by variables like smartphone type and toilet settings [92].

## 6. Enuresis alarm innovations (n = 21)

### 6.1 Novel configurations (n = 8)

*Category overview and key drivers:* Enuresis alarms function by detecting urine on two conducting strips, causing a voltage change and triggering an alarm [96–98]. Alarms with rigid wires may cause

discomfort or psychological effects for the child, while fragile sensors can lead to missed alarms due to unintentional or deliberate deactivation. Conversely, overly sensitive alarms may trigger false alarms, which can be discouraging for patients [97]. These design shortcomings related to comfort, durability, and reliability in traditional enuresis alarms are the reason for novel configurations.

*Tools within this category:* We encountered eight studies featuring various configurations of enuresis alarms (Table A8 in Multimedia Appendix 3), spanning from pad-and-bell to body-worn alarms, and from wired to wireless. The pad-and-bell alarm uses a bed-mat with conductive strips, while the body-worn alarm has a sensor attached to underwear [97–99]. Wireless versions transmit signals to an alarm positioned further away, requiring the child to leave the bed to deactivate it [97]. Smart textile sensors integrate conductive threads into underwear or disposable urine pads [96], with recent innovations incorporating wireless transmitters and smartphone apps for notifications and reinforcement strategies [100].

Configurations of the alarm signal itself range from loud acoustic alarms to subtler options such as lights, vibrating alarms, or personalized recorded messages [97]. For instance, one study evaluated a code-word alarm with a digital voice recorder for parents to record personalized code words, rewarding children for recalling it the following morning [101]. Lastly, another, more unconventional, approach involves electrical impulses via surface electrode pads to activate the external urethral sphincter to interrupt micturition instead of relying on audible alarms [102,103].

*Study results and conclusions:* Comparative studies on bell-and-pad versus body-worn alarms reported mixed results [98,99]. While one study reported better outcomes with the bell-and-pad alarm [99], another found both equally effective but noted high dropout rates due to embarrassment [98]. Variations in false alarm rates and missed alarms were observed, suggesting that individual device features may have influenced performance more than the alarm type itself.

A review [97] highlighted the potential of smart textiles to enhance comfort and detection efficiency, with studies reporting positive performance and safety during daytime training [96,100]. One of these studies specifically found that a smart textile alarm with an app delivered similar outcomes in less time, with high patient and parent satisfaction, compared to standard behavioral therapy for toilet training children with autism spectrum disorder [100].

Using a pre-recorded code-word was reported to improve arousal response and training attitude, reducing dropouts by 10%, though it only affected treatment outcomes in a subgroup with monosymptomatic NE [101]. Electrical impulses were reported as effective with perineal placement [102], though based on a small sample, while suprapubic placement showed no significant effect [103]. Reported benefits included potentially reducing fully wet beds, boosting self-confidence and family motivation, but drawbacks such as higher cost, complexity, and potential fear of electrical currents were also noted.

## 6.2. Pre-void alarms (n = 13)

*Category overview and key drivers:* Traditional enuresis alarms provide a warning after an enuretic incident has occurred. Consequently, both the child and the parent still experience the inconvenience and consequences of wet pants or sheets during treatment, requiring a substantial level of motivation [104,105]. Moreover, the child must establish an indirect link between the full bladder sensation and the alarm as it sounds after the bladder has emptied. These limitations have driven the development of pre-void enuresis alarms, designed to anticipate enuretic incidents by predicting when they might occur and provide a warning in advance.

*Tools within this category:* Thirteen studies were found on pre-void alarms (Table A9 in Multimedia

Appendix 3), of which the majority (n=12, 92%) used ultrasound technology to trigger an alarm when bladder volume reaches a predefined threshold. Basic ultrasound technology detects the posterior bladder wall rising above the symphysis pubis [104,106], while advanced systems estimate bladder volume using an array of transducers to locate both anterior and posterior bladder walls through ultrasound echoes [105,107–115].

Various specialized measures have been implemented to enhance the reliability of pre-void alarms. This includes employing intelligent software and machine learning to customize for factors like body morphology, age, and sex [106,109–115]. Furthermore, to mitigate sensitivity to ultrasound probe movement, solutions such as tailored belts [104,106,115], elastic garments [105,109–111], adhesive materials [112–114], and even synchronizing measurements with the child's respiratory rhythm [106] have been explored.

One pre-void alarm system estimates bladder volume using wearables and deep learning instead of ultrasound, tracking impedance with a waist belt sensor, heart rate and sleep stage with a smartwatch, and limb movement using fabric foot bands [116].

*Study results and conclusions:* The studies on pre-void enuresis alarms were primarily validation and feasibility studies reporting on the technological feasibility of these alarms, with detection rates varying from below 50% to 90% [104,106–109,113,115,116]. However, sample sizes were small (1 to 41 patients) or relied on artificial bladder models.

Patient acceptance, influenced by the need for a comfortable, discrete, and non-stigmatizing design, was evaluated for MyPad [110,111] and SENS-U [112,114], both of which were well-accepted. SENS-U was also reported feasible for both daytime bladder training [112] and nighttime monitoring [114].

Despite feasibility, several challenges were noted, including sensor positioning sensitivity, bladder shape changes due to an enlarged rectum or posture, and compatibility issues with different body types, particularly in obese children [104,105,109,111–115]. Additionally, daytime observations of SENS-U showed that 23% of children experienced urgency or leakage before reaching the predefined volume-based threshold [112].

Finally, only one study compared the pre-void alarm with the traditional alarm, reporting comparable cure rates, but a treatment duration approximately three times longer [105]. The study suggested that awakening to wet sheets may constitute a classic conditioning negative reinforcement, potentially essential for the cure process.

## Discussion

### Principal findings

In this scoping review, we identified and mapped innovative, tech-driven and digital tools for managing pediatric UI. The field of pediatric UI demonstrates a considerable level of innovation, as evidenced by the inclusion of 66 articles, with nearly one-third focusing on nocturnal enuresis. Our analysis led to the identification and classification of six primary categories of tools, three of which were divided into sub-categories.

1. *Mobile health interventions* leverage the widespread use of smartphones, tablets, and computers, offering a convenient and accessible medium for health-related purposes, such as electronic bladder diaries [42,43] and self-management apps or portals [44–48].
2. *Serious games* engage children through playful interactions, such as games for pelvic floor biofeedback training [51–56] and standard urotherapy [57].
3. *Reminder technology* aims to enhance therapy adherence without constant parental prompting,

such as timer watches [59–61] and self-management reminder tools [62–64].

4. *Educational media* for delivering health-related information to patients is subdivided into videos and other types of educational media.
  - 4.1. Videos offer visually engaging, 24/7 accessible, and anonymous dissemination of health information on topics, ranging from behavioral therapy like bladder training and NE therapy [65–68] to preparing for surgical interventions [69].
  - 4.2. A variety of other materials were found that provide child-friendly and engaging patient education, such as UI homework books [70,71], a NE multimedia program [72,73], and educational materials for UTIs [74–76].
5. *Telehealth and RPM* for remote health information exchange is subdivided into communication and technological advances.
  - 5.1. Remote communication between patients and healthcare professionals, through video conferencing [80], home monitoring systems [81] and an embodied conversational agent [82–84], can lead to time, cost, and travel savings.
  - 5.2. Technological advances, such as machine learning algorithms [90], new technologies [87,91,92] and new applications enabling home use [86,87,91–95], aim to surpass limitations of in-clinic procedures.
6. *Enuresis alarm innovations* is subdivided into novel configurations of traditional enuresis alarms and pre-void alarms.
  - 6.1. Enuresis alarm configurations span from pad-and-bell to body-worn alarms [97–99], wired to wireless systems [97], smart textiles [96,100], and a variety of alarm signals [97,101–103].
  - 6.2. Pre-void alarms aim to predict enuretic incidents and provide warnings in advance [104–116], with the majority using bladder ultrasound technology [104–115].

Many of the tools identified in this review are described as promising alternatives to traditional methods, with studies reporting their feasibility [42–48,62–64,70,71,104,106–109,113,115,116], potential to improve outcomes [45,51–57,65,66,69,82–84,93–95,101], and ability to save time for healthcare providers [53,65,66,69,73–75]. Additionally, these tools are described as engaging for children, improving patient compliance [45,48,56,59–61,71,72,82–84] and leading to high levels of patient satisfaction and preference [42–48,57,63,80–84,86,100,111,112,114].

However, the current body of evidence is limited by methodological limitations, including retrospective designs [53,60,93,94], absence of control groups [51,62,83,84,95,105,112,114], and small sample sizes with almost one quarter of studies (24%,  $n=16/66$ ) having a sample size smaller or equal to 15 participants [47,63,64,81,83,94,96,102,107,109–112,114–116]. While 21% ( $n = 14/66$ ) of the included articles were RCTs [45,54–56,61,65,66,69,73,86,99–101,103], some did not compare equivalent therapies [45,54,55]. Furthermore, the findings varied, with some studies demonstrating differences in outcomes between the novel tools and traditional methods [53,60,61,82–84,99–101,105], while others reported similar outcomes [42,54,65,73–75,86,98,103]. These observations highlight the need for more rigorous research to better establish the effectiveness of these tools.

## Understanding the challenges of managing pediatric UI

The variability in reported findings and gaps in robust evidence may also reflect the complexity of managing pediatric UI. This review highlights the multifaceted and multifactorial influences on pediatric UI management.

*Multifaceted:* Pediatric UI management encompasses various aspects such as patient education, diagnosis-informed behavior modifications, and providing support and encouragement (Figure 3).

- *Patient education:* Studies included in this review highlight various educational activities such as raising awareness [74–76], explaining complex concepts [69], setting expectations [72,73], providing lifestyle advice [65–68,83,84] and promoting adherence [57,70,71,82].
- *Diagnosis-informed behavior modifications:* Management typically begins with a thorough diagnostic process, as described by several included studies [42,70,80,82–84,87,91,92]. By accurately identifying contributing factors and underlying causes, appropriate therapeutic interventions can be selected. Interventions described in the reviewed studies, include providing instructions and reminders to establish healthy bladder and bowel habits [59–64]. Monitoring these habits through the collection of data on fluid intake, voiding patterns and bowel movements [42,43,57], as well as quality of life indicators [44–47], is reported to help identify patterns and track progress over time [44–48,57,81].
- *Support and encouragement:* The included studies emphasize that support, encouragement and feedback can help reinforce positive behaviors and maintain therapy consistency, whether in-clinic [51–56], at home [44–47,80,82–84,86,95], or in a group setting [93].

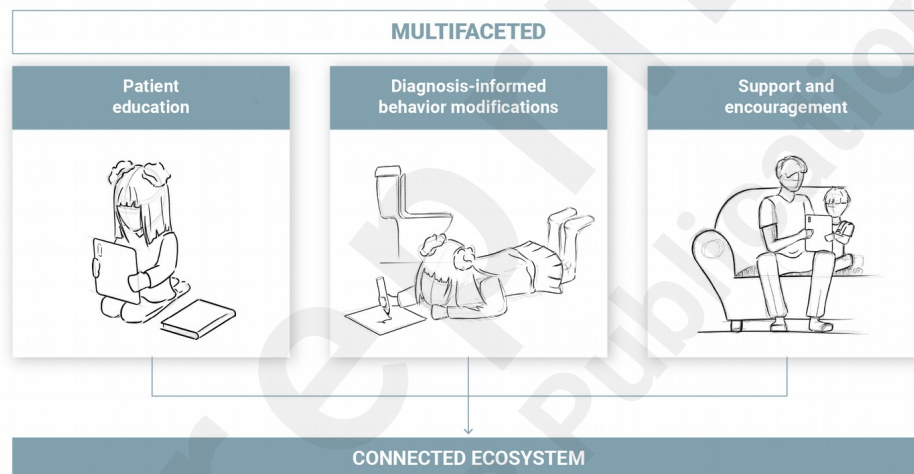


Figure 3. Pediatric UI management is multifaceted, including patient education, diagnosis-informed behavior modifications, and support and encouragement. Integrating these aspects into a connected ecosystem might be an ideal way to address this multifaceted nature.

Despite this multifaceted nature, many tools discussed in this review offer stand-alone solutions that address specific aspects. Examples include mobile health apps for keeping electronic bladder diaries [42,43], biogames for pelvic floor biofeedback [51–56], timer watches for timed voiding [59–61], educational videos covering specific concepts [65–69], and enuresis alarm innovations for alarm training [96–115]. While these stand-alone solutions address particular aspects of pediatric UI management, they do so in isolation, potentially missing opportunities to create synergies and links between different aspects of UI management. This review leads us to wonder whether integrating these various aspects into a connected ecosystem could better address the multifaceted nature of UI management.

*Multifactorial:* Pediatric UI management is influenced by a range of factors such as clinical signs, child characteristics, and the involvement of multiple stakeholders (Figure 4).

- *Clinical signs:* The management of pediatric UI depends on the specific types and severity of symptoms children experience. These can include multiple symptoms related to the bladder and bowel [42,65,66,80,87,91,92], occurring during the day and/or night [43,82–84,90]. Each child's therapy journey is therefore unique, with varying underlying causes, progress rates and potential setbacks. Accurate differentiation during the diagnostic phase, along with continuous monitoring of therapy progress, as described in some studies [44–47,57,82–84,86,93,94], can support tailoring management plans to the child's specific condition and adapting them as needed. We propose that tools be adaptive to meet the evolving needs of children during therapy and to help maintain their motivation. For instance, feedback from children using the urotherapy serious game indicated a desire for more dynamic gameplay that adapts to their training progress [57].
- *Child characteristics:* The management of UI depends not only to the child's clinical signs and physiological needs but also on their psychological and emotional needs. As described in the studies, these needs include the child's motivation [49,56,57,104,105], attitude toward training [45,48,60,61,70,71,82,101], level of maturation and attention span [56,72]. Emotional factors such as self-image, embarrassment, fear, and stress were also described as key influences [64,69,98,102]. These child-specific characteristics can influence outcomes. For instance, varying findings from comparative studies on different enuresis alarm configurations [98,99] suggest that certain configurations may be more effective for some children than others. Additionally, one study reported that reminder technology was an equally effective but simpler alternative to enuresis alarms in treating DUI [59]. We propose that personalizing or selecting tools based on the child's preferences may enhance acceptance, satisfaction, and potentially lead to better outcomes.
- *Multiple stakeholders:* Each stakeholder involved in pediatric UI management has distinct needs. Studies indicate that parental motivation often depends on constraints such as time, cost and travel, prioritizing convenience and self-efficacy [22,25,42,43,48,80–84,87,100,102,104,105]. Healthcare professionals, on the other hand, are described as managing time constraints in busy clinical practices, aiming for efficiency and high-quality data [42,48,53,65,66,69,87,91] while also maintaining empathy and establishing a therapeutic alliance [80,83]. Aligning these diverse needs can be challenging, as described by the UTI remote monitoring system [81]. Although the system comprised a set of products, most parents primarily used the urinalysis device because it met their needs for self-efficacy and reassurance. The other products were underutilized, leading to frustration among healthcare providers, who faced added workload for setting up the system without improved data quality. These findings underscore the importance of designing tools that balance the needs of all stakeholders, improving quality of life for patients and families while optimizing time and efficiency for healthcare professionals.

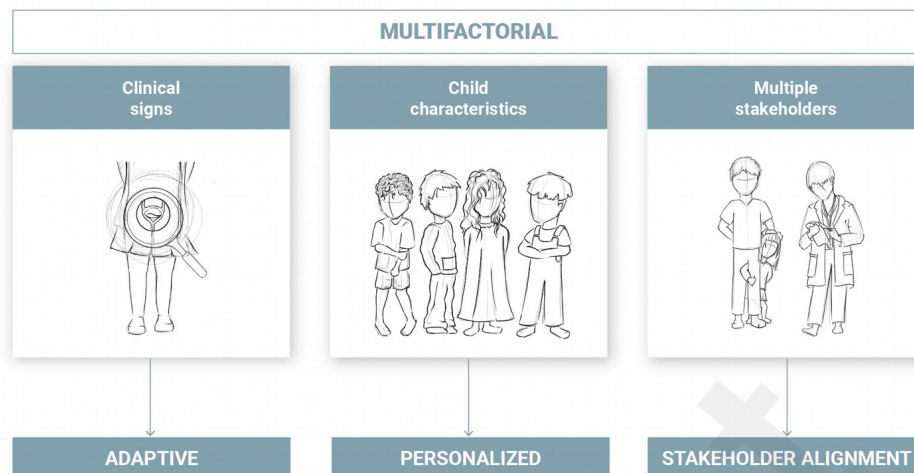


Figure 4. Pediatric UI management is multifactorial, influenced by a range of factors such as (i) clinical signs that progress over time requiring adaptive interventions, (ii) child characteristics that demand a personalized approach, and (iii) the involvement of multiple stakeholders whose needs must be aligned.

## Transforming healthcare with connected ecosystems

Given the multifaceted and multifactorial nature of pediatric UI management, we propose that novel tools should be designed as healthcare ecosystems that are (i) connected, (ii) adaptive, (iii) personalized, and (iv) aligned with the needs of all stakeholders.

The concept of healthcare ecosystems for managing pediatric UI is rooted in a broader transformation of the healthcare industry driven by innovation [117]. Advances such as electronic health records, networked computer systems, and telehealth have revolutionized healthcare delivery, shifting from a model centered on face-to-face interactions with individual clinicians to a smart, interconnected healthcare community emphasizing shared decision-making [118]. The COVID-19 pandemic further accelerated this transition, highlighting the critical role of digital technologies in maintaining access to healthcare [119]. Furthermore, recent breakthroughs in computational power and artificial intelligence promise to expand the capabilities of healthcare systems even further [118]. A fair part of the currently available medical devices already has the ability to connect and communicate with other devices or systems. This connectivity transforms previously isolated tools into collaborative systems that operate within closed feedback loops, tailoring outputs to the individual [120]. For example, in glucose monitoring, sensors measure blood glucose levels, which then inform insulin delivery systems to maintain optimal glucose control [121]. Similarly, smart pillboxes improve medication adherence by tracking remaining doses, providing reminders through a connected alarm device [122].

While many of these systems have been tested primarily in contexts such as monitoring elderly patients at home [123]—where they support independence and reduce healthcare burdens—pediatric urology presents a significant opportunity for similar innovations. For example, a recently published article on the Minze Homeflow system demonstrates how a connected ecosystem can enhance pediatric UI management [124]. It integrates physical products (uroflowmeter and accessories) with digital tools (Minze App and Clinician Portal) for remote monitoring of uroflowmetry and bladder diary data. By shifting diagnostics to the home environment, the Homeflow system minimizes stress for pediatric patients, while providing more reliable data compared to in-clinic measurements. Such a system demonstrates the feasibility and benefits of connected healthcare ecosystems in addressing specific challenges in pediatric urology.

Another study [125] demonstrated how the Homeflow ecosystem could be further expanded by

connecting additional products to the system, such as a smart drinking bottle and reminder technology, to personalize urotherapy [125]. The smart drinking bottle and home uroflowmeter monitored fluid intake and urinary output, while a reminder watch linked these devices, offering personalized voiding prompts based on the child's bladder capacity and fluid intake. This demonstrates the potential of connected ecosystems to adapt and align with the individual care needs of pediatric patients.

## Overcoming challenges in healthcare innovation

The successful implementation of healthcare innovation and ecosystems requires addressing important challenges, such as regulatory and privacy concerns, equitable access, screen time considerations, and keeping healthcare human-centered. Thoughtful strategies are needed to overcome these challenges and maximize benefits.

*Regulatory and privacy concerns:* Ensuring patient privacy and data security remains a critical challenge for digital healthcare innovation [126]. As these tools handle sensitive patient data, robust regulatory frameworks must be established to protect patient data. However, balancing innovation with regulation remains a challenge, especially considering the rapid pace of technological advancements. Current regulations may struggle to keep up, potentially delaying the adoption of transformative tools. A balanced approach is required to ensure safety and trust without hampering innovation that can improve patient care.

*Equity in access:* Ensuring equitable access is another challenge for healthcare innovation, especially in low-resource settings. Individuals in such settings must not be left behind, as they are often the ones who stand to benefit the most from these advancements [117]. However, barriers such as limited infrastructure, potentially high entry costs, and digital literacy disparities can hinder adoption [118]. Nevertheless, innovation also has the potential to improve equity by decentralizing care. Shifting diagnostics and therapies from clinics to homes or communities can reduce costs and improve accessibility. Additionally, customizable solutions tailored to varying resource levels, aligned with reimbursement models, or supported through public health initiatives can support the equitable implementation of innovation.

*Screen time considerations:* The use of digital tools raises concerns about screen time and its potential impact on children's health. A 2019 systematic review [127] identified associations between excessive screen time and health risks, including adiposity, unhealthy diet, depressive symptoms, and reduced quality of life. However, the review did not consider the influence of content or context on these outcomes. Research indicates that well-designed, age-appropriate content, especially when curated by engaged adults [128], can positively impact learning and behavior [129]. For example, screen time can calm distressed children during medical procedures [130] or support language learning [131]. Moreover, active video games or nature-exploration apps, can encourage physical activity and imaginative play by connecting on- and off-screen experiences [132].

Nevertheless, certain screen use patterns present clear risks. Screen time before bedtime is strongly associated with sleep disturbances [133]. The mere presence of electronic devices in bedrooms has been linked to shorter sleep duration, partly due to melatonin suppression [134]—an essential consideration for tools addressing nocturnal enuresis. A 2024 systematic review [135] reinforced these findings, showing that greater use of mobile devices, particularly at bedtime or in patterns of device dependence, can harm mental health in children and adolescents. At the same time, it emphasized technology's dual impact: while social media often correlates with negative effects, other communication tools can enhance psychological well-being by strengthening social connections and providing access to support. These effects vary across individuals, highlighting the need to identify

those most vulnerable to adverse effects.

In summary, the impact of screen time is shaped by multiple factors. To maximize benefits, digital tools should be thoughtfully designed to deliver engaging, age-appropriate content, promote balanced screen habits, integrate on- and off-screen interactions, and avoid bedtime use and over-reliance on devices.

*Keeping healthcare human-centered:* Digital technology presents significant opportunities to enhance efficiency and accuracy in healthcare. However, human interaction remains fundamental to preserving empathy, trust, and nuanced clinical decision-making. For example, a study in this review reported that healthcare providers experienced difficulties building rapport with pediatric patients due to technical barriers [80]. This underscores the importance of designing tools that augment healthcare professionals' capabilities, ensuring that technology supports rather than depersonalizes patient care. Therefore, a human-centered approach to technology is needed to actively incorporate the perspectives and needs of patients, caregivers, and healthcare providers, placing them at the center of smart and connected healthcare, both in research and practice [118].

Such an approach values not only objective evidence but also subjective patient and stakeholder experiences, combining quantitative and qualitative methods. However, in our review, only 12% (n=8/66) of studies employed qualitative [44,80,110] or mixed methods [42,46,63,72,81] designs. Despite this, more than one-third (38%, n=25/66) of studies evaluated outcomes related to patient experience, such as satisfaction, motivation, and usability [44–47,56,57,62,63,71,72,76,80,81,83,84,93,99–101,105,109–112,114]. This indicates a growing recognition of the importance of patient-centered outcomes but also underscores the need for more qualitative approaches to capture deeper insights.

To incorporate a human-centered approach, we conducted a separate qualitative study alongside this scoping review to explore children's perspectives, experiences, and expectations regarding urotherapy-supporting tools. To facilitate this, we developed a focus group discussion toolkit specifically tailored to pediatric UI [136]. The toolkit incorporated creative tasks involving imagination and play, enabling children to express their thoughts and experiences in a child-friendly and engaging manner. By combining insights from this scoping review with the findings from the focus groups, we aim to provide a comprehensive perspective that blends existing evidence with the desires and needs of the target population. This integrated approach can guide the development of more effective and user-centered tools for pediatric UI management.

## Limitations

This scoping review has certain methodological limitations that should be considered when interpreting its result. Firstly, the search was limited to three electronic databases, and only English-language papers were included. Secondly, only one reviewer screened the entire set of search results. However, the team engaged in frequent and extensive discussions throughout the study selection process to ensure rigorous screening. Thirdly, our search had an extensive scope due to our broad criteria for defining innovative, tech-driven and digital tools, as well as the absence of time limits. This broad field and the potential abundance of relevant tools made it challenging to provide a concise overview of all information. Consequently, the review encompassed a broad range of studies and a wide variety of innovative, tech-driven and digital tools.

## Conclusions

This scoping review offers valuable insights into various categories of innovative, tech-driven and digital tools for managing pediatric UI and their supporting evidence. The inclusion of 66 articles highlights a considerable level of innovation in the field.

We identified six main categories of tools: mobile health, serious games, reminder technology,

educational media, telehealth and RPM, and enuresis alarm innovations. Further sub-categories were found within these, such as video and other media within educational media, communication and technological advances within telehealth and RPM, and novel configurations and pre-void alarms within enuresis alarm innovations.

Many of these tools are described as promising alternatives to traditional methods, with studies reporting feasibility, effectiveness in improving outcomes, and potential time savings for healthcare providers. Additionally, these tools are described as engaging children effectively, potentially enhancing patient compliance and contributing to high patient satisfaction and preference. However, the review identifies gaps in research, highlighting the need for more rigorous research to better assess the effectiveness of these tools and address the complex, multifaceted challenges of pediatric UI management. We propose the development of connected, adaptive, and personalized healthcare ecosystems that integrate diverse strategies for UI management, including education, diagnosis, therapy, monitoring, and feedback. By enabling synergies and links between these different strategies, such ecosystems could create a closed-loop system that enhances the alignment and efficiency of care.

We suggest that future research and development in this field adopt a human-centered and multidisciplinary approach, combining quantitative and qualitative methods to incorporate user perspectives and involve all stakeholders from the start. This mixed-methods approach may help ensure that both objective evidence and subjective experiences are equally valued, supporting impactful innovations in this complex field of pediatric UI management.

## Acknowledgements

The conceptualization of this scoping review, including the formulation of the research question, search strategy, and eligibility criteria, was a collaborative effort involving the entire team of authors. LB took the lead in the study selection process and data analysis, which included screening titles and abstracts, assessing full-text articles, charting the data, and conducting categorization of the identified tools. Throughout these processes, LB consulted with the team to ensure consistency, rigor, and consensus. GDW and AV provided expertise on pediatric UI management, while LVC and JV contributed insights on product design and categorization of the tools. All authors offered guidance throughout the research project, including interpretation and critical review. LB drafted the manuscript and finalized the version presented here. The generative AI tool ChatGPT by OpenAI was used to improve language and readability. The tool provided inspiration on how to rephrase parts of the manuscript, but final edits and decisions were made by the authors. The final manuscript was critically reviewed and approved by all authors.

## Data availability

No primary data were generated or analyzed for this review. The data used for this scoping review are based on published literature and studies, all of which are cited in the manuscript. In case additional data or information are requested, please contact the corresponding author.

## Conflicts of Interest

None declared

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## Abbreviations

BBD: bladder and bowel dysfunction  
DV: dysfunctional voiding  
DUI: daytime urinary incontinence  
NE: nocturnal enuresis  
NIRS: near-infrared spectrometry  
OAB: overactive bladder  
PTNS: percutaneous tibial nerve stimulation  
RCT: randomized controlled trial  
RPM: remote patient monitoring  
TENS: transcutaneous electrical nerve stimulation  
UAB: underactive bladder  
UI: urinary incontinence  
UTI: urinary tract infection

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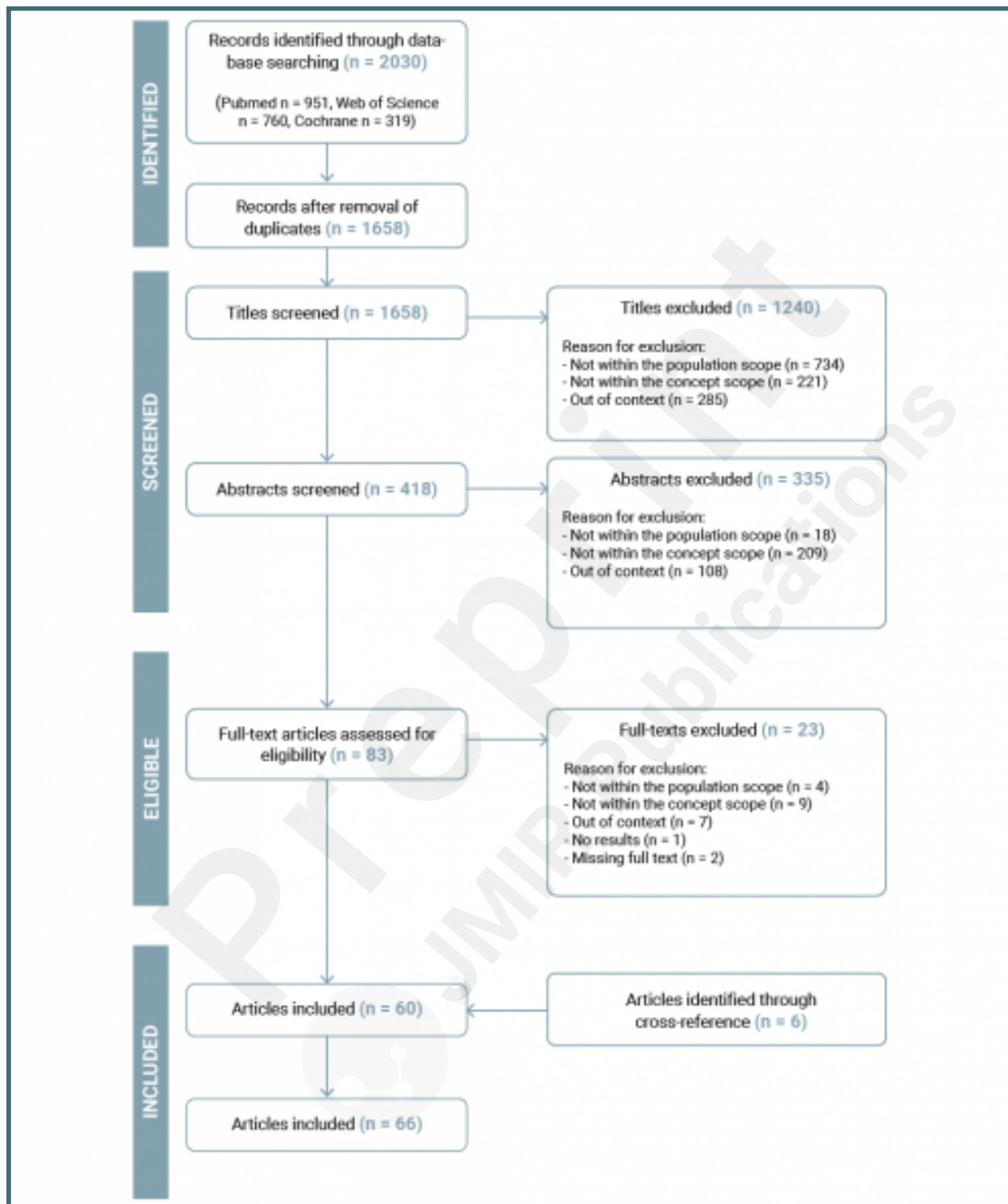
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## Supplementary Files

## Figures

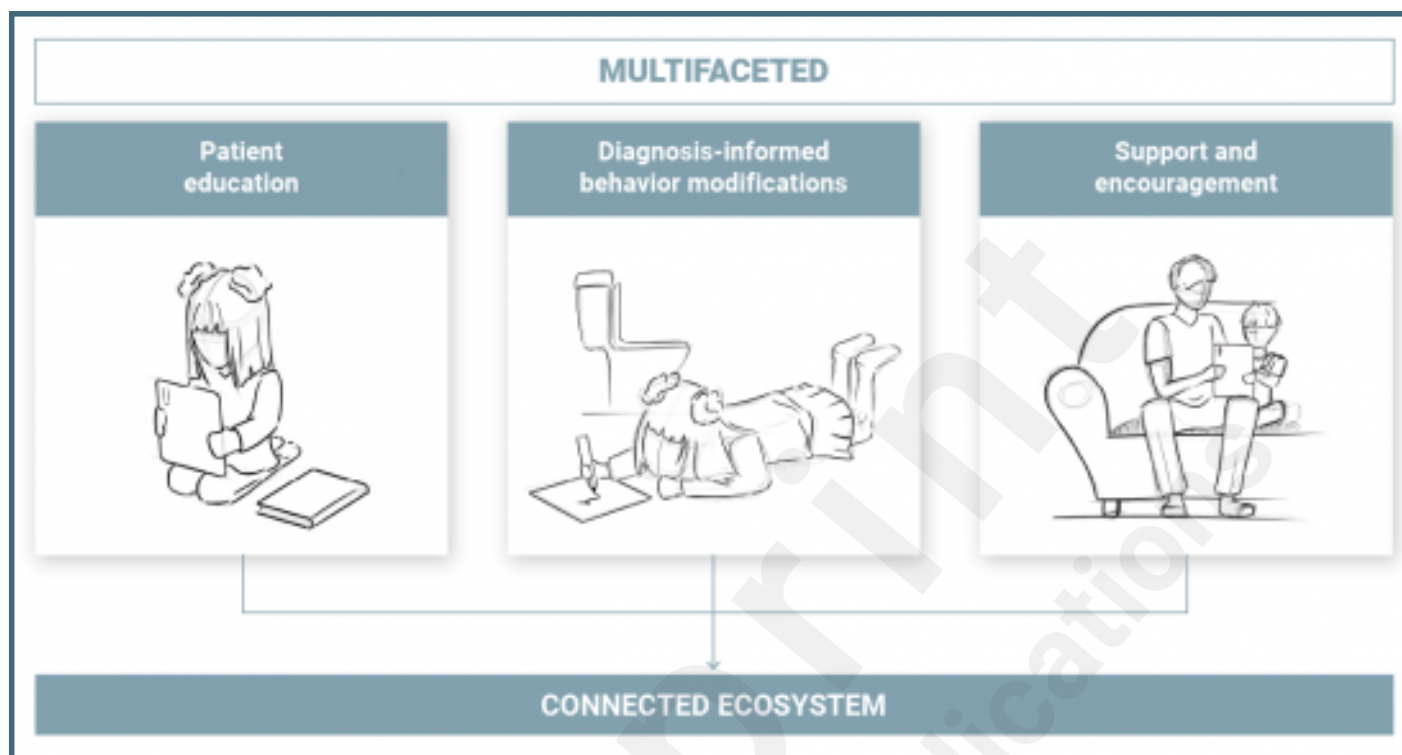
PRISMA flowchart of the literature screening and selection process.



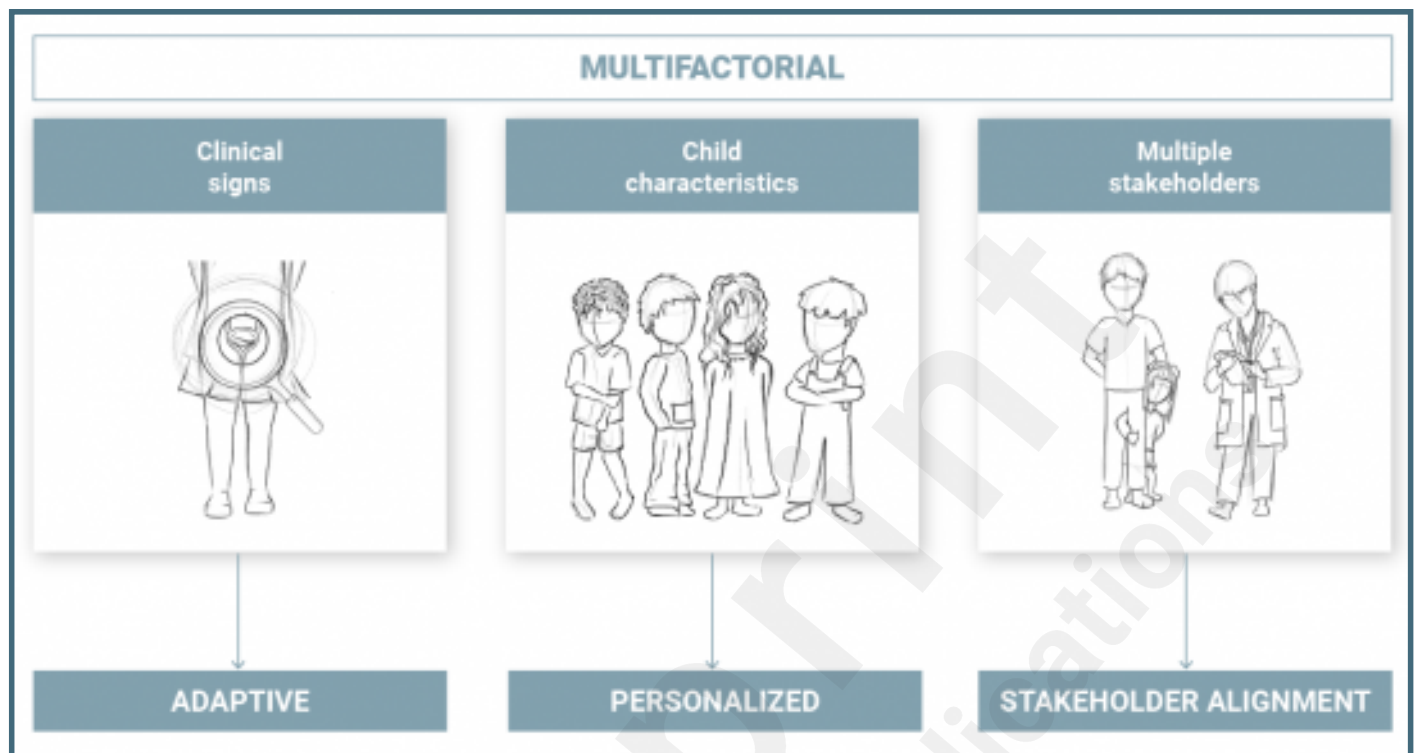
Overview of the six categories and sub-categories of innovative, tech-driven and digital tools.



Pediatric UI management is multifaceted, including patient education, diagnosis-informed behavior modifications, and support and encouragement. Integrating these aspects into a connected ecosystem might be an ideal way to address this multifaceted nature.



Pediatric UI management is multifactorial, influenced by a range of factors such as (i) clinical signs that progress over time requiring adaptive interventions, (ii) child characteristics that demand a personalized approach, and (iii) the involvement of multiple stakeholders whose needs must be aligned.



## **Multimedia Appendixes**

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist.

URL: <http://asset.jmir.pub/assets/1d0bf18e82a8f3488c056ebef4d0970a.docx>

Full search strategy.

URL: <http://asset.jmir.pub/assets/23851433f7506b0b43339d85e1e7c86f.docx>

Overview of included studies by tool category.

URL: <http://asset.jmir.pub/assets/8ba746e7d006668f058768056aec4803.docx>

