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# NOCTURIA AS AN UNDERESTIMATED PUBLIC HEALTH PROBLEM: SLEEP, PSYCHOSOCIAL AND ECONOMIC BURDEN, AND DIGITAL MONITORING

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**ABSTRACT**

Nocturia is prevalent among adults, yet it remains frequently overlooked and underestimated. It is one of the most common lower urinary tract symptoms, but its consequences extend well beyond the urinary tract. This critical narrative review examines nocturia as a public-health problem across sleep, psychological well-being, family and social participation, work, safety, economic burden, and digital monitoring. Targeted backward citation checking was undertaken, with priority given to population studies, systematic reviews, qualitative research, trials with patient-relevant endpoints, guidelines, and large observational datasets. Clinically significant nocturia, commonly operationalized as at least two voids per night, becomes more frequent with age but also affects working-age adults. Objective sleep studies show graded deterioration in sleep continuity as nocturnal voiding increases. Longer time to the first void is associated with longer sleep, and improvements in the first uninterrupted sleep period track with better perceived sleep quality. Nocturia is also associated with a broad range of psychological difficulties, although causal direction remains uncertain. Qualitative, workplace, and claims studies show that burden is transferred across households, employers, and health systems; falls add a safety concern in older adults. Electronic bladder diaries and wearables can improve longitudinal characterization, but direct evidence that monitoring itself improves nocturia-specific outcomes remains limited. A holistic approach to nocturia as a public-health problem is therefore needed. Episode count remains necessary and important, but it should be interpreted alongside sleep continuity, bother, and next-day function.

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**KEYWORDS**

Nocturia, Sleep Disruption, Quality of Life, Work Productivity, Social Participation, Digital Health

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**1. Introduction**

The International Continence Society defines nocturia as the number of times urine is passed during the main sleep period; the individual wakes to void and each episode is followed by sleep or the intention to sleep [17]. This wording is more than a semantic detail. It anchors nocturia to the sleep-wake cycle and separates the symptom from nocturnal urine production alone. A patient may produce a large nocturnal urine volume without waking, while another may wake repeatedly and void small volumes. Only the latter pattern constitutes nocturia in the symptom-based sense relevant to sleep and daytime function.

Nocturia is multifactorial. Nocturnal polyuria, reduced functional bladder capacity, global polyuria, incomplete emptying, sleep disorders, medication effects, and cardiovascular or metabolic disease may contribute in different combinations. Current primary-care guidance pairs the history and urinalysis with validated questionnaires and a frequency-volume chart rather than treating episode count as a diagnosis [13]. Two patients who both report two nightly voids may still differ markedly in the timing of the first awakening, ability to return to sleep, fall risk, work schedule, and perceived bother.

The population-based FINNO study showed that bother rises materially from two nocturnal voids and becomes more pronounced at three or more episodes, supporting the common threshold of at least two voids for clinically significant nocturia [32]. European and Asian surveys show the same age gradient and a persistent treatment gap [11,29]. Reviews consistently connect nocturia with poor sleep, depression, falls, and reduced quality of life, but causal evidence is uneven across those outcomes [7]. Prevalence alone describes only part of the problem.

Its consequences are dispersed across literatures that rarely meet. Urological studies emphasize frequency, volume, and storage; sleep studies examine awakenings and continuity; workplace research measures presenteeism; economic studies count healthcare use and modeled costs; qualitative work describes adaptation, relationship strain, and restricted participation. Read together, they describe a nighttime symptom whose effects continue into the following day.

A recent IJITSS review addressed lifestyle, behavioral, social, and digital determinants of lower urinary tract symptoms broadly [31]. The present article takes a narrower route: it follows nocturia from the urinary event through sleep, next-day function, household and occupational burden, safety, and cost. Technology is considered only where it can improve nocturia-specific measurement or longitudinal management.

The central proposition is that nocturia can be understood as a disturbance of nocturnal recovery. This is an assumption, not a claim that every nocturnal void causes daytime impairment. The review asks four questions: how common and under-treated is nocturia; how does it relate to sleep, mental health, participation, work, and falls; where do its costs fall; and what can digital monitoring currently measure without overstating clinical benefit

## **2. Methodology**

This article presents a structured critical narrative review with a clinical and public-health orientation. This design was chosen because the question crosses evidence that cannot be reduced to one pooled estimate, including population surveys, objective sleep studies, qualitative research, occupational and economic analyses, guidelines, trials with sleep or quality-of-life endpoints, and digital-health feasibility studies. The review was guided by SANRA domains, including a stated aim, a described search, appropriate referencing, evidence-level interpretation, and use of relevant endpoint data [3].

PubMed/MEDLINE was the primary bibliographic source, and searches were updated through August 2026. Search concepts combined nocturia or nighttime voiding with sleep continuity, first uninterrupted sleep period, mental health, quality of life, family and social participation, work productivity, healthcare use, economic burden, falls, frequency-volume charts, electronic diaries, mobile applications, telemedicine, wearables, and digital monitoring. Reference lists of major reviews, consensus papers, and key studies were checked, and targeted journal searches were used to identify recent IJITSS work with overlapping clinical-social or digital-health scope.

Adult peer-reviewed studies were retained when they informed at least one prespecified domain of burden or measurement. Priority was given to population-based studies, systematic reviews and meta-analyses, qualitative studies reporting lived experience, controlled trials with patient-relevant sleep or quality-of-life endpoints, professional guidance, and large observational datasets. Broader lower urinary tract studies were used only when their methods were transferable to nocturia assessment, and that indirectness is stated. Evidence was interpreted according to design: cross-sectional associations were not treated as causal, objective and self-reported sleep outcomes were separated, and observed resource use was distinguished from modeled cost. No formal risk-of-bias instrument or meta-analysis was undertaken; commercial support was considered when interpreting pharmacological, economic, and app-based studies.

## **3. Results**

### **3.1. Epidemiology and Prevalence of Nocturia**

The reported prevalence of nocturia depends strongly on the threshold used. One nocturnal void is common in adults and may have little clinical consequence, whereas at least two episodes are more consistently associated with bother and functional impairment. The FINNO population study demonstrated that most individuals began to report meaningful bother at two voids, with moderate or major bother more common at three or more [32]. For this reason, studies using a threshold of at least two episodes are especially informative when estimating public-health burden.

Population estimates vary across countries, but the age gradient is remarkably consistent. In a Swedish community survey, at least two nocturnal voids were reported by 15.6% of men and 16.5% of women, with prevalence increasing substantially with age [2]. In Poland, a nationally representative survey of 6,000 adults aged at least 40 years found that 73.7% reported at least one nocturnal void and 36.1% reported at least two. Women were affected more often than men, and frequency increased with age [29]. These data are particularly relevant to a Central European readership because they show that nocturia is not a marginal specialist symptom in the region.

The LUTS Asia study provides a large multinational comparison. Among 8,284 adults aged 40 years or older in China, Taiwan, and South Korea, at least two nightly voids were reported by 35% of men and 37% of women. Increasing frequency was accompanied by progressively poorer quality of life, higher anxiety and depression scores, and greater work limitation [11]. The convergence between the Polish and Asian estimates

is notable, although direct numerical comparison remains constrained by survey mode, age composition, and cultural differences in symptom reporting.

Nocturia also matters below traditional geriatric age thresholds. The NOCTURNE study analyzed wearable-derived sleep information in 9,446 Japanese adults aged 18–65 years and demonstrated a graded relationship between nocturnal voiding and objective sleep continuity [33]. Workplace data involving more than 92,000 observations similarly identified clinically significant nocturia in approximately one in ten working adults and linked it to poorer engagement and productivity [16]. These findings challenge the tendency to frame nocturia solely as a problem of advanced age.

Age remains important because multiple mechanisms accumulate across the life course: sleep becomes more fragmented, nocturnal urine production may increase, bladder capacity can decline, mobility may worsen, and cardiovascular, metabolic, neurological, and sleep disorders become more prevalent. The epidemiological age gradient therefore reflects convergence of mechanisms rather than a single aging process.

The treatment-seeking gap is as important as prevalence. In Poland, only approximately 22.2–29.2% of respondents with nocturia sought treatment despite substantial bother, and bother rose significantly with frequency [29]. In LUTS Asia, up to 30% of participants with at least three nocturnal voids did not seek care [11]. Administrative healthcare data therefore underestimate population burden because many affected people normalize the symptom as part of aging or simply adapt their behavior around it.

**Table 1. Representative epidemiological and burden studies. Estimates are not pooled because symptom thresholds, sampling frames, and ascertainment methods differ.**

| Study | Population/ design                         | Operational definition            | Key result                                                                | Interpretive note                                     |
|-------|--------------------------------------------|-----------------------------------|---------------------------------------------------------------------------|-------------------------------------------------------|
| [2]   | Community survey, Sweden                   | $\geq 2$ voids/night              | 15.6% men; 16.5% women; strong age gradient                               | Cross-sectional; older dataset                        |
| [32]  | Population-based FINNO study               | Frequency categories              | Bother becomes common at 2; moderate/major bother more common at $\geq 3$ | Supports clinical significance of frequency threshold |
| [29]  | 6,000 Polish adults $\geq 40$ years        | $\geq 1$ and $\geq 2$ voids/night | 73.7% $\geq 1$ ; 36.1% $\geq 2$ ; low treatment seeking                   | Representative national survey; self-report           |
| [11]  | 8,284 adults $\geq 40$ years, East Asia    | $\geq 2$ voids/night              | 35% men; 37% women; burden increased with frequency                       | Cross-sectional internet survey                       |
| [33]  | 9,446 Japanese wearable users, 18–65 years | Nocturnal voiding frequency       | Greater frequency associated with shorter uninterrupted sleep             | Selected wearable users; retrospective dataset        |
| [16]  | 92,129 workplace observations              | $\geq 2$ voids/night              | ~10% prevalence in working sample; productivity association               | Self-reported nocturia; occupational selection        |

### 3.2. Impact of Nocturia on Sleep and Daily Functioning

#### Sleep continuity and the quality of nocturnal recovery

Sleep is the most plausible bridge between a nocturnal void and next-day impairment, but the sequence is not uniform. Bladder sensation may wake the patient, or an awakening caused by insomnia, obstructive sleep apnea, pain, or the environment may be followed by a precautionary void [6,7]. A frequency-volume chart can describe what was voided and when; it cannot by itself establish what triggered the awakening.

Objective data support a dose-response relationship between nocturnal voiding and fragmented sleep. In the HEIJO-KYO cohort of 1,086 community-dwelling older adults, actigraphy showed progressively lower sleep efficiency across groups with 0, 1, 2, and at least 3 nocturnal voids (86.3%, 84.8%, 83.6%, and 81.2%, respectively). Wake after sleep onset increased in parallel from 42.6 to 66.1 minutes, while Pittsburgh Sleep Quality Index scores also worsened [26]. Because the study was cross-sectional, these data do not establish that voiding caused the awakenings; they do show that more frequent nocturnal voiding travels with objectively poorer sleep continuity.

The NOCTURNE study extends this finding to 9,446 wearable users aged 18–65 years: the first uninterrupted sleep period fell from approximately 334 minutes in participants without nocturnal voiding to approximately 173 minutes at the highest frequency, while total sleep time also declined [33]. A separate secondary analysis of 757 adults followed for up to five months found that each additional hour before the first void increased the odds of reaching at least 6, 6.5, and 7 hours of total sleep (OR 1.43, 1.30, and 1.24, respectively) [5]. Timing adds clinically relevant information that the nightly count misses.

Patient-reported outcomes point in the same direction. In a post hoc analysis of 580–606 trial participants with complete data, a 72-minute increase in the first uninterrupted sleep period was associated with a 1.8-point improvement in the global Pittsburgh Sleep Quality Index and improvement in six of seven subscales [4]. Two small intervention studies provide additional, cautious signals. A two-week randomized trial in 60 women older than 55 years linked melatonin with fewer nightly voids, a one-hour gain in the first uninterrupted sleep period, and better nocturia-related quality of life [22]. A 12-week pilot in overactive bladder reported concurrent improvement in nocturia and selected sleep measures [10]. These studies show that sleep endpoints are responsive; they do not establish a universal treatment effect or direction of causation.

Sleep pathology may also generate or amplify nocturia. A systematic review and consensus project identified obstructive sleep apnea as the sleep disorder with the most developed evidence base and emphasized that sleep disorders are frequently overlooked during nocturia assessment [27]. Easy arousability, altered sleep architecture, and mechanisms that increase nocturnal urine production can all contribute. This strengthens the argument against assuming that every nocturnal void is primarily a bladder event.

In practice, assessment should record three things separately: voiding frequency, the timing and context of each awakening, and the effect on subsequent sleep and daytime function. A reduction of one void may be highly meaningful if it restores a long initial sleep block, and trivial if wakefulness persists for another reason.

### 3.3. Mental health: association, shared mechanisms, and limits of causal inference

The association between nocturia and depression is repeatedly observed, but causality remains uncertain. In the Swedish population study, major depression was independently associated with at least two nocturnal voids, with adjusted odds ratios of 6.5 in men and 2.8 in women after adjustment for age and self-rated health [2]. The size of these estimates makes the relationship difficult to dismiss, but the cross-sectional design leaves several causal pathways open.

A systematic review of nocturia, depression, and anxiety found a strong association between nocturia and depression in cross-sectional evidence, whereas the relationship with anxiety was less consistent [9]. The review considered bidirectionality plausible. Depression can alter sleep architecture, health behavior, medication exposure, and symptom perception; nocturia can repeatedly fragment sleep and contribute to fatigue and reduced resilience. Comorbid chronic disease can influence both.

The LUTS Asia study reinforces the severity gradient: higher nocturia frequency was accompanied by worse anxiety and depression scores and poorer general quality of life [11]. These data are most appropriately interpreted as evidence that psychological burden clusters with nocturia severity, not as proof that nocturia independently produces a depressive disorder.

For clinical and public-health purposes, the distinction between association and causation is constructive. Frequent nocturia should prompt questions about sleep quality, mood, anxiety, and daytime function, especially when the patient reports substantial bother. It should not be used as a psychiatric screening test in isolation, nor should treatment success be inferred from a reduction in void count if the patient remains exhausted or distressed.

### **3.4. Family life, relationships, and social participation**

Direct evidence on family life and social participation is less abundant than evidence on sleep or work because much of the nocturia literature embeds social effects within generic quality-of-life scores. Qualitative studies provide a stronger basis for interpreting this domain. A qualitative interview study involving 32 community-dwelling older adults with at least two nocturnal voids found that participants experienced nocturia as debilitating, frustrating, distressing, and unpredictable; it altered sleep, affected personal relationships, increased fear of falling, and restricted participation [8]. Many participants did not prioritize the symptom for healthcare and relied on self-management.

A separate qualitative study examined the lived experience of 20 adults with nocturia using interviews structured around the evening, the night, and the following day [34]. This temporal framework is useful because it shows that burden begins before sleep - through planning and anticipatory behaviors - continues through repeated awakenings, and persists as next-day fatigue or reduced functioning. The study also highlights heterogeneity: the same number of episodes can be experienced very differently depending on work, caring responsibilities, sleep habits, and perceived control.

Partner burden has been studied more often in the broader male LUTS literature than in isolated nocturia cohorts. In a study of 130 female partners of men with LUTS and more than one nocturnal void, 77% reported sleep disturbance, 62% fatigue, and 13% moderate or severe social limitations; nocturia frequency correlated with several partner-burden domains [21]. Because the population had broader LUTS, these figures should not be attributed to nocturia alone. They nonetheless demonstrate that nighttime urinary symptoms can become a household rather than an individual exposure.

The most important conclusion from this domain is therefore methodological. Family and social participation should be measured directly. Partner sleep, caregiver time, restrictions on travel or overnight stays, activity avoidance, and participation are not interchangeable with a generic quality-of-life score. The relatively sparse evidence is a research gap, not a reason to substitute plausible assumptions for measured outcomes.

### **3.5. Occupational functioning: presenteeism is the dominant signal**

The workplace literature offers some of the clearest evidence that the burden of nocturia extends into daytime social functioning. The mechanism is intuitive but should not be reduced to absenteeism. People with nocturia may continue to attend work while functioning below their usual capacity because of sleep fragmentation, fatigue, or impaired concentration.

An analysis of 92,129 workplace observations from adults aged 18–70 years found that approximately 10% reported at least two nocturnal voids and that nocturia remained associated with poorer subjective well-being, lower work engagement, and productivity impairment after adjustment for sleep duration, sleep quality, and multiple confounders [16]. The study's scale and multivariable approach strengthen the association, although both nocturia and several outcomes were self-reported.

A comparative review of nocturia and other common chronic conditions found that overall work productivity impairment across evaluable nocturia studies ranged from 14% to 39% [24]. The literature was heterogeneous and partly industry-linked, so the range should not be treated as a universal estimate. Its value lies in showing that a symptom often dismissed as an inconvenience can produce impairment on the same order as conditions more readily recognized as workplace health problems.

Claims-linked survey data provide a complementary perspective. Adults reporting at least two nightly voids had adjusted presenteeism and overall work impairment of 20%, compared with 10% among those with fewer than two voids, and also reported greater activity impairment [12]. The study population was older and had more comorbidity in the higher-frequency group, and the study was commercially sponsored; residual confounding remains possible. Even with those limitations, the consistency with independent workplace research makes presenteeism a credible component of nocturia burden.

This distinction matters economically and clinically. Sick-leave records can substantially underestimate impact when the dominant loss occurs while the person remains at work. Future studies should therefore pair absenteeism with validated measures of presenteeism, work limitations, fatigue, and safety-sensitive performance.

### 3.6. Falls and nighttime safety

Nocturia also exposes patients to repeated nighttime ambulation, creating a plausible link with falls in older adults. The association is unlikely to be simple: gait instability, sedating medication, poor vision, orthostatic symptoms, frailty, and sleep disorders can increase both nocturia burden and fall risk.

A systematic review and meta-analysis of nine longitudinal observational studies reported an adjusted pooled risk ratio for falls of 1.20 (95% CI 1.05–1.37), corresponding to an estimated annual risk difference of 7.5% among older adults; the pooled estimate for fractures was 1.32 (95% CI 0.99–1.76). Evidence for nocturia as a prognostic factor for falls was rated moderate, whereas causal evidence was rated very low [28]. This distinction is essential: nocturia identifies a higher-risk group but may also act as a marker of underlying multimorbidity or frailty.

Recent studies have attempted to refine the association. An adjusted secondary analysis examined nocturia and falls while accounting for factors including arthritis, gait instability, and obstructive sleep apnea [1]. In 491 older adults undergoing surgery for hip fracture, a retrospective study reported nighttime-fall frequencies of 20.4% without nocturia, 37.3% with one nocturnal void, and 40.6% with at least two; severe nocturia remained associated with nighttime falls after multivariable adjustment [36]. These findings support attention to nighttime safety while still falling short of proving that treatment of nocturia itself will prevent falls.

**Table 2. Critical synthesis of functional and social outcomes. Strength of interpretation refers to confidence in the association, not proof of causation.**

| Domain                      | Quantitative/ direct signal                                                                                                                                | Highest-value evidence | Strength of interpretation                                     | Main caveat                                                                               |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|----------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| Sleep continuity            | Graded loss of sleep efficiency and first uninterrupted sleep; each 1-hour delay to first void associated with greater odds of reaching 6–7 hours of sleep | [4,5,22,26,33]         | Strong association with objective and patient-reported support | Direction can be bidirectional; treatment studies are selected and partly industry-linked |
| Depression                  | Large cross-sectional associations; severity gradient                                                                                                      | [2,9,11]               | Consistent association                                         | Causality and common causes unresolved                                                    |
| Family/social participation | Relationship strain, unpredictability, participation restriction                                                                                           | [8,21,34]              | Direct qualitative evidence, limited quantification            | Partner study includes broader LUTS                                                       |
| Work                        | Presenteeism and overall work impairment; 14–39% range in review                                                                                           | [12,16,24]             | Consistent occupational signal                                 | Self-report and sponsorship in some studies                                               |
| Falls                       | Pooled adjusted RR 1.20 for falls                                                                                                                          | [1,28,36]              | Moderate prognostic evidence                                   | Very low certainty for causality                                                          |

### 3.7. Economic Burden of Nocturia

The economic burden is better conceptualized as a transfer of costs across stakeholders than as a simple direct-versus-indirect classification. The patient experiences disrupted sleep and reduced function; the employer absorbs presenteeism; the healthcare system absorbs outpatient care and injury-related costs; families may provide informal support. These components rarely appear in the same dataset, which helps explain why the burden remains partially invisible.

### **3.8. Observed healthcare utilization and patient-level costs**

A claims-linked analysis of 899 adults with nocturia found that, compared with participants reporting fewer than two episodes, those with at least two had more adjusted outpatient encounters per patient per month (2.1 vs. 1.6), more office visits (0.9 vs. 0.7), and more prescriptions filled (3.2 vs. 2.2). Adjusted outpatient costs were \$678 versus \$506 per patient per month, and adjusted total healthcare costs were \$1,114 versus \$810; hospitalization and emergency-department differences were not statistically significant [12].

The design makes this study useful because it links symptom frequency to observed resource use rather than relying solely on modeled prevalence. It also has important limitations: the mean age was 71.4 years, the higher-frequency group had more comorbidity, symptom frequency was assessed after the six-month resource-use window, and the study was industry sponsored. The estimates therefore should not be interpreted as a causal price tag for nocturia.

### **3.9. Productivity as a major component of societal burden**

In the same study, at least two nocturnal voids were associated with twice the adjusted presenteeism and overall work impairment (20% vs. 10%). The authors estimated 2.2 additional lost productivity days per patient per month and \$347 greater indirect cost per month, equivalent to \$4,164 per patient per year in the study's economic context [12]. These figures illustrate why a condition can have a substantial societal effect without producing proportional absenteeism or hospital use.

A separate NHANES-based analysis identified 22,300 adults, 24% of whom reported at least two nightly voids. Nocturia was associated with more hospital and outpatient use, fewer weekly work hours, lower employment, and worse self-rated health after adjustment. Using 2017 US cost assumptions, the analysis estimated \$62.9 billion in excess direct healthcare costs and \$151.7 billion in indirect productivity costs, for a total of \$214.5 billion; the highest share of excess costs was attributed to adults aged 45–64 years [19].

These national estimates are useful for scale but not as contemporary universal costs. They are prevalence-based models, depend on unit-cost and wage assumptions, and were sponsored by a pharmaceutical manufacturer. Sensitivity analyses produced a wide range (\$94.0–\$231.1 billion), underscoring the uncertainty inherent in extrapolation. They should be cited as 2017 US model estimates, not as the current global cost of nocturia.

### **3.10. Historical models, falls, and what remains uncounted**

Earlier economic reviews reached the same qualitative conclusion: productivity loss can outweigh direct treatment costs, and nocturia-related falls add another pathway to expenditure [18]. Their monetary values are now dated, but they remain useful for understanding cost structure. A modest increase in fall risk becomes economically relevant when applied to large older populations, even if only a fraction of falls are attributable to nocturnal bathroom trips.

The least visible costs are those borne within households. Partner sleep disturbance, informal assistance during the night, reduced participation, and adaptation of daily routines are rarely monetized. Nor do claims databases capture people who are substantially bothered but do not seek care. The low treatment-seeking rates reported in Poland and East Asia therefore imply that utilization-based analyses describe only part of the societal burden [11,29].

### **3.11. Implications for future economic research**

Economic studies should report nocturia frequency and bother separately, distinguish observed resource use from modeled expenditure, and stratify costs by age and social role. The relevant burden for a 45-year-old shift worker is likely to be dominated by sleep and productivity, whereas an 82-year-old with mobility impairment may generate relatively little employment cost but substantial fall, caregiver, and healthcare burden. A single average cost per patient can obscure these different profiles.

### **3.12. Modern Technologies for Monitoring Nocturia**

The strongest rationale for technology in nocturia is measurement. The symptom unfolds across nights, and a clinic visit provides only a brief retrospective snapshot. Digital tools can potentially increase temporal resolution, reduce transcription, and connect urinary events with sleep and next-day outcomes. Their value should therefore be judged by whether they improve data quality or clinical decisions, not by novelty alone.

### **3.13. The bladder diary remains the reference framework**

A frequency-volume chart or bladder diary remains the clinical reference because episode count cannot distinguish nocturnal polyuria from reduced storage capacity or other patterns. It records timing and volume and may include fluid intake, urgency, sleep times, and incontinence; recent primary-care guidance continues to recommend it as part of diagnosis [13]. Digitalization is useful only if it preserves these variables and keeps the resulting record interpretable.

Diary data can also reveal within-night physiology that a symptom count conceals. In a retrospective analysis of 130 men with at least two nightly voids and without several major secondary causes, early- and late-night diuresis rates differed among those meeting nocturnal-polyuria criteria, although the single-center veteran sample limits generalization [25]. The study illustrates why timing and urine-production rate matter when moving from symptom description to phenotype.

### **3.14. Electronic diaries and mobile applications: evidence for feasibility and validity**

More mature evidence supports electronic diaries as a practical alternative to paper. A validation study of a three-day smartphone bladder diary in 136 patients with overactive bladder or nocturia found 90% completion of all variables in the first electronic diary, high test-retest reliability (intraclass correlation coefficients 0.73–0.94), good-to-excellent paper-app correlations, and an 88.2% preference for the app in a future diary task [23]. This is directly relevant to nocturia because patients with nocturia were included in the validation population.

A randomized crossover assessment in women with lower urinary tract symptoms found good test-retest reliability for both electronic and paper voiding diaries, although the electronic diary recorded slightly fewer voids and leaks [30]. The finding is instructive: electronic capture is not automatically more accurate. Interface design can alter reporting behavior and therefore must be validated rather than assumed to improve data quality.

A 2022 prospective comparison used an acoustic uroflowmetry-based mobile app in 78 men with LUTS/BPH. More than 85% completed more diary days with the app than on paper, and ratings for convenience and satisfaction favored the app. Correlation between formats was strong for total voids ( $r=0.90$ ) and nocturnal voids ( $r=0.83$ ), although recordings were not concurrent and the population was male and selected [20]. This study is particularly relevant to nocturia monitoring because it directly captured nocturnal urine volume, nocturnal polyuria index, and nighttime voiding frequency.

Accessibility is not synonymous with digitization. A study of a low-literacy frequency-volume method using measuring jars, colored pouches, and pebbles found that 29 of 30 adults recorded day and night voids satisfactorily and that interpreted results did not differ materially from nursing records [35]. The supervised inpatient setting and small sample limit transferability, but the study makes an important design point: an inclusive diary may need a low-tech or assisted option alongside an app.

### **3.15. Apps for longitudinal self-management: promising but mostly indirect for nocturia**

Digital therapeutics have progressed beyond diary replacement. In a randomized trial of 237 men with LUTS, an app-based therapeutic added to usual care improved symptom scores, bother, and health-related quality of life compared with usual care alone [14]. A multicountry pilot of the MyBPHCare application in 157 men likewise found acceptable-to-good user ratings and high willingness to recommend the app, although medication adherence remained incomplete [15].

These studies demonstrate that digital self-management can be feasible and can influence broader LUTS outcomes. They do not establish that a mobile intervention reduces nocturia-specific social or sleep burden. That distinction is important because importing an effective LUTS app into a nocturia review without qualifying indirectness would overstate the evidence.

### **3.16. Telemedicine: an organizational layer with a thin nocturia-specific evidence base**

Telemedicine is frequently proposed for nocturia because electronic diaries can be reviewed remotely and treatment often requires repeated adjustment. Direct nocturia-specific comparative trials of telemedicine, however, are scarce. The evidence currently supports feasibility of remote data transfer more strongly than improved clinical outcomes.

The most defensible model is hybrid care. Remote review can support longitudinal interpretation of diaries, medication timing, fluid behavior, and symptom trajectories, whereas examination, urinalysis, post-void residual measurement, renal or cardiovascular evaluation, and assessment of suspected sleep apnea may still require in-person care. Digital access should also be considered explicitly: older adults carry the highest prevalence of nocturia yet may face visual, motor, cognitive, socioeconomic, or connectivity barriers.

### 3.17. Wearables: linking the urinary event to sleep and nighttime activity

Wearables are distinctive because they can measure the domain most likely to mediate burden: sleep continuity. The HEIJO-KYO cohort used wrist actigraphy to quantify sleep efficiency and wake after sleep onset across nocturia-frequency groups [26]. The NOCTURNE study used a much larger wearable dataset to link increasing nocturnal voiding with shorter first uninterrupted sleep and more awakenings [33]. Together, these studies show how digital measurement can move beyond retrospective statements that a patient 'slept poorly.'

Consumer sleep trackers should nevertheless be interpreted cautiously. Their proprietary algorithms vary, sleep-stage estimates are not equivalent to polysomnography, and an awakening detected by movement does not identify why the patient woke. Wearables are therefore better positioned as longitudinal adjuncts than as stand-alone diagnostic tools.

### 3.18. Toward integrated longitudinal phenotyping

A more useful technological endpoint is integrated longitudinal phenotyping rather than a larger collection of disconnected data. A clinically meaningful system could combine diary-derived urine volumes and timing with sleep continuity, medication timing, evening fluid intake, perceived bother, daytime sleepiness, and selected functional outcomes. The objective would be to distinguish patterns that currently appear identical when reduced to 'two voids per night.'

Before such systems become routine, studies should demonstrate incremental value over a well-completed conventional diary. Relevant outcomes include completion rate, measurement validity, clinician interpretation time, change in diagnostic classification, adherence, patient burden, clinical outcomes, privacy, interoperability, and cost-effectiveness. Technology should earn its place by improving decisions or patient-relevant outcomes, not by digitizing a symptom count.

**Table 3. Technology evidence relevant to nocturia. The table separates demonstrated evidence from proposed clinical value to avoid equating technical feasibility with clinical effectiveness.**

| Technology                | Best current evidence              | Directness for nocturia                                    | Potential value                                                                        | Unresolved issue                                                       |
|---------------------------|------------------------------------|------------------------------------------------------------|----------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| Electronic bladder diary  | [23,30,35]                         | Direct/partly direct; low-literacy access addressed        | Time-stamped frequency/volume data; low-tech or assisted alternatives can widen access | Interface effects, adherence, supervision needs, and digital exclusion |
| Acoustic/mobile diary     | [20]                               | Direct for nocturnal diary variables; male LUTS population | Automatic/semiautomatic volume and nocturnal-frequency capture                         | Nonconcurrent validation; selected users                               |
| App-based self-management | [14,15]                            | Indirect - broader male LUTS                               | Education, reminders, behavior support, longitudinal follow-up                         | Nocturia-specific outcomes not established                             |
| Telemedicine              | Remote diary/monitoring literature | Indirect/limited direct comparative evidence               | Repeated review without travel; care continuity                                        | Diagnostic tasks still require in-person care; equity                  |
| Wearable sleep monitoring | [26,33]                            | Direct for sleep-nocturia association                      | Objective sleep continuity and awakening patterns                                      | Algorithm validity; cannot determine cause of awakening                |

## **4. Discussion**

### **4.1. Episode count is necessary, but it is not a complete severity measure**

The threshold of at least two nightly voids is useful for population estimates, but it is not a universal severity definition. Qualitative studies show that the same count can represent little disruption for one person and prolonged wakefulness, fatigue, or safety risk for another [8,34]. Research and care should therefore describe frequency together with sleep continuity and patient-reported bother or next-day impairment. A change in count without a change in recovery may not be a meaningful benefit.

### **4.2. Nocturnal recovery is a plausible bridge between urology and daytime function, not a universal causal pathway**

The most coherent cross-domain finding is that nocturia travels with disrupted sleep and impaired next-day function. Objective studies establish a graded association; the FUSP analyses show that delaying the first void tracks with longer and better perceived sleep; and small intervention studies show that urinary and sleep outcomes can improve together [4,5,10,22,26,33]. This convergence supports nocturnal recovery as a useful bridge between urology and daytime functioning.

The framework must remain conditional. The patient may wake because of urinary urgency, because of obstructive sleep apnea or insomnia, or for an unrelated reason and then void. Evidence from a systematic review shows how under-recognized sleep disorders can sit upstream of nocturia [27]. The direction of causation may also vary from night to night within the same patient. Thus, the value of the 'nocturnal recovery' framework is integrative: it encourages urologists to ask what happens around the void, rather than declaring sleep disruption to be caused by the bladder in every case.

### **4.3. The burden changes with social role and can be transferred to other people**

Burden is also shaped by social role. A working adult may experience presenteeism and lost concentration; an older adult with impaired mobility may face falls and dependence; a partner may lose sleep without having a urinary symptom. Adaptation and low help-seeking can make these effects disappear from clinical records, while partner and qualitative studies show that they remain present in the household [8,21,34].

### **4.4. The burden is systematically underestimated by healthcare data**

Healthcare data systematically miss burden that produces no consultation, code, or invoice. Most people reporting nocturia in the Polish and East Asian surveys had not sought treatment, while presenteeism, partner sleep disruption, and lost participation are rarely visible to health systems [11,29]. National cost models capture some of that wider scale but depend heavily on prevalence, wage, and attribution assumptions. Claims analyses and models are therefore complementary, not interchangeable.

### **4.5. Digital monitoring should solve a measurement problem before it claims to solve a clinical problem**

Digital evidence is strongest for narrow measurement questions: whether an electronic diary can be completed, agrees with paper, captures nocturnal frequency or volume, and transmits data longitudinally [20,23,30]. Broader LUTS trials suggest that apps can improve symptom scores and quality of life, but nocturia-specific effects on sleep, participation, and cost remain largely untested [14]. Digital tools can currently describe the symptom better; whether that changes outcomes requires prospective testing.

Equity belongs in that evaluation. Older adults carry much of the prevalence but may face visual, motor, cognitive, financial, or connectivity barriers. The successful use of a low-literacy frequency-volume chart in a small supervised study illustrates that innovation may involve simplification, assistance, and a paper or tactile alternative—not only another app [35].

### **4.6. A research agenda centered on patient-relevant endpoints**

Future studies should report the exact nocturia definition and frequency distribution, a continuity metric such as first uninterrupted sleep or wake after sleep onset, patient-reported bother, and next-day function. Working-age studies should add presenteeism; older-adult studies should include nighttime mobility and falls; social research should measure partner sleep, caregiver time, and participation directly.

Longitudinal designs are needed to clarify temporal direction and clinically meaningful within-person change. Pragmatic digital trials should compare integrated monitoring with a high-quality conventional diary, not with no monitoring. Economic studies should stratify by phenotype and social role because identical episode counts can lead to different treatment pathways and preventable costs.

## 5. Strengths and Limitations of the Review

This review integrates epidemiological, objective sleep, qualitative, occupational, safety, economic, and digital-monitoring evidence rather than treating them as separate problems. It distinguishes direct nocturia evidence from broader LUTS technology studies, separates observed resource use from modeled cost, and uses qualitative and partner evidence to examine outcomes that generic quality-of-life scores often conceal.

Its limits follow from the design. PubMed/MEDLINE was the primary database, supplemented by targeted citation checking rather than an exhaustive search of every bibliographic source. Selection and appraisal were not duplicated by independent reviewers, and no formal risk-of-bias instrument or meta-analysis was used. Definitions, age ranges, comorbidity adjustment, and outcome instruments vary; many associations are cross-sectional; and direct evidence on family burden, telemedicine, and nocturia-specific digital outcomes remains sparse. Several detailed economic, pharmacological, and app studies received industry support. These constraints limit causal and policy claims.

## 6. Conclusions

Nocturia is common, frequently untreated, and socially consequential, but the nightly count explains only part of its burden. The strongest evidence links higher frequency with poorer sleep continuity and impaired next-day function; depression, falls, relationship strain, and work loss are important associated outcomes, although causal certainty varies. Costs are distributed across patients, households, employers, and health systems, including people who never seek care.

Digital technology is currently most convincing as a measurement strategy. Electronic diaries can provide valid longitudinal urinary data, and wearables can add sleep context, but neither should be equated with improved clinical outcomes. The practical next step is to test whether integrated measurement of urinary events, sleep continuity, bother, and daytime function changes decisions that matter to patients. The central question is not only how often a person wakes to void, but what those awakenings do to recovery, safety, participation, and the following day.

**Conflicts of interest:** No conflicts of interest to declare

**Data availability:** No new data were created or analyzed. All evidence considered in this review is available in the cited publications.

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