

Extended reality digital technologies in nephrology and dialysis: a scoping review

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ABSTRACT

Introduction: Extended reality (XR), an umbrella term encompassing virtual reality, augmented reality, and mixed reality, is increasingly being explored to address educational, procedural, and psychosocial challenges in nephrology and dialysis. However, the breadth, maturity, and clinical focus of XR applications in this field have not been comprehensively mapped. The aim was to map and characterize the extent, nature, and focus of the evidence on XR in nephrology and dialysis, to identify application domains, and to highlight gaps that may inform future research and implementation.

Methods: We conducted a scoping review in accordance with PRISMA-ScR guidance. We searched 5 databases for English-language sources published within the last 10 years. Eligible sources included full-text empirical studies, systematic reviews, case reports, cohort studies, surveys, case-control studies, and clinical trials addressing XR in nephrology and dialysis.

Results: Eighteen studies met the inclusion criteria. The evidence clustered into 3 domains: (1) chairside and intradialytic symptom management using immersive VR; (2) dialysis training and self-management support, including VR-assisted peritoneal dialysis exchange learning and implementation workflows; and (3) education, procedural planning, and training in kidney-related anatomy and interventions using XR. Most studies were small, single-country investigations and were heterogeneous in XR modality, content, and outcome measures.

Conclusions: XR in nephrology and dialysis has progressed from proof of concept toward early clinical and educational evaluation, with the strongest near-term signal in symptom management during hemodialysis and task-based learning for peritoneal dialysis. Standardized outcomes, implementation research, equity-focused design, and pragmatic trials are needed before widespread adoption can be considered.

Keywords: Augmented reality, Education, Extended reality, Hemodialysis, Mixed reality, Nephrology, Peritoneal dialysis, Simulation, Virtual reality

Introduction

Extended reality (XR) describes technologies that blend physical and digital environments along a continuum that includes virtual reality (VR), augmented reality (AR), and mixed reality (MR) (1). In health care, XR is increasingly being adopted to support patient education, professional training, procedural rehearsal, rehabilitation, and behavioral interventions (2). In nephrology and dialysis, this context presents a distinctive opportunity because patients receiving hemodialysis spend several hours each week in a fixed clinical environment and

often experience repetitive procedural discomfort, anxiety, boredom, and symptoms that can be difficult to manage pharmacologically. At the same time, clinicians and trainees must master cognitively demanding physiology, communication-intensive counseling, and technically challenging procedures such as vascular access management, kidney biopsy, and surgical planning for kidney tumors and transplantation (1,2).

Over the past decade, consumer-grade head-mounted displays have lowered barriers to the delivery of immersive VR, while AR and MR devices have enabled hands-free, spatially anchored visualization of three-dimensional anatomy and workflows. At the same time, interest in immersive platforms for education and patient engagement, including in nephrology, has increased. Conceptual discussions in nephrology have highlighted potential use cases such as interactive patient education, collaborative care planning, and immersive learning environments, while also emphasizing that routine clinical integration remains at an early stage (3).

Received: February 18, 2026

Accepted: April 15, 2026

Published online: May 4, 2026

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In-home dialysis, AR-enabled real-time training and remote support may reduce educational and logistical barriers that limit uptake and long-term sustainability (4). Although these conceptual discussions suggest considerable potential, they do not clarify which XR approaches have been tested empirically, in which populations, or for which outcomes.

We conducted a scoping review of XR in nephrology and dialysis, focusing on the last decade of evidence as the field has moved from early prototyping toward broader clinical experimentation. This review aimed to (1) map XR application domains in nephrology and dialysis; (2) characterize study designs, populations, and XR modalities; (3) summarize outcomes assessed and signals of benefit or feasibility; and (4) identify research and implementation gaps that should be prioritized (5-8).

Nephrology also faces workforce and training challenges. The specialty must communicate complex physiology to learners while sustaining procedural competence and patient-centered counseling. Digital tools that improve engagement may influence recruitment into, and retention within, nephrology training programs. XR has been proposed as one such tool because it can transform abstract concepts, such as countercurrent multiplication, diuretic sites of action, and electrolyte transport, into manipulable three-dimensional experiences. When aligned with educational theory, XR may support dual coding, embodied cognition, and spatial learning. However, XR may also increase cognitive load if poorly designed, and its novelty may inflate short-term satisfaction without producing durable learning. These tensions further justify a structured mapping of the current evidence (9).

In parallel, dialysis care increasingly emphasizes shared decision-making and home-based therapies. Patient education is crucial but time-constrained, and it often relies on printed materials or brief demonstrations that may not match patients' learning preferences. AR and VR may provide a more experiential form of education by visualizing how kidney injury occurs, rehearsing sterile technique, and allowing patients to practice troubleshooting in a safe environment. Whether such approaches translate into greater self-efficacy, fewer errors, or improved clinical outcomes remains uncertain (1).

Given the rapid commercialization of XR products and the diversity of proposed use cases across kidney care, mapping the evidence base is important both to avoid premature adoption and to identify high-value areas in which innovation should be accelerated.

Methods

We followed the PRISMA extension for scoping reviews (PRISMA-ScR) checklist and explanation to guide reporting (5). Methodological decisions were informed by foundational and updated scoping review guidance, including the Arksey and O'Malley framework, later refinements, and current recommendations (6-8).

Review Questions

1. What XR applications have been evaluated in nephrology and dialysis since 2016?

2. Which populations (patients, clinicians, and students) and settings (in-center hemodialysis, home dialysis, education, and procedural planning) have been targeted?
3. Which outcomes have been assessed (clinical, psychosocial, physiological, educational, and implementation-related), and what directions of effect have been reported?
4. What evidence gaps and priorities emerge for future research and practice? (10)

Eligibility Criteria

We included English-language sources published between January 2016 and January 2026. Eligible publication types were empirical studies (quantitative or qualitative), systematic reviews, case reports, cohort studies, surveys, case-control studies, and clinical trials. Only full-text articles were included. The concept of interest was XR technology, including AR and MR, as well as immersive, semi-immersive, and non-immersive implementations applied to nephrology or dialysis. The context included adult and pediatric kidney care settings, dialysis units, home dialysis training, nephrology education, and kidney-related procedural training and planning. We excluded conference abstracts without full text, non-English sources, and studies that used only conventional two-dimensional video or non-immersive screen-based education without an XR component (10).

Information Sources

We searched PubMed/MEDLINE, Scopus, Web of Science Core Collection, PsycINFO, and the Cochrane Library. Searches were conducted in February 2026 and were limited to the prespecified date range. We also hand-searched the reference lists of included sources.

Search Strategy

The search strings combined controlled vocabulary, where available, and free-text keywords related to XR with kidney- and dialysis-related concepts. Table 1 presents the database-specific search strategies. Searches were adapted to the syntax and field structure of each platform.

Selection of Sources of Evidence

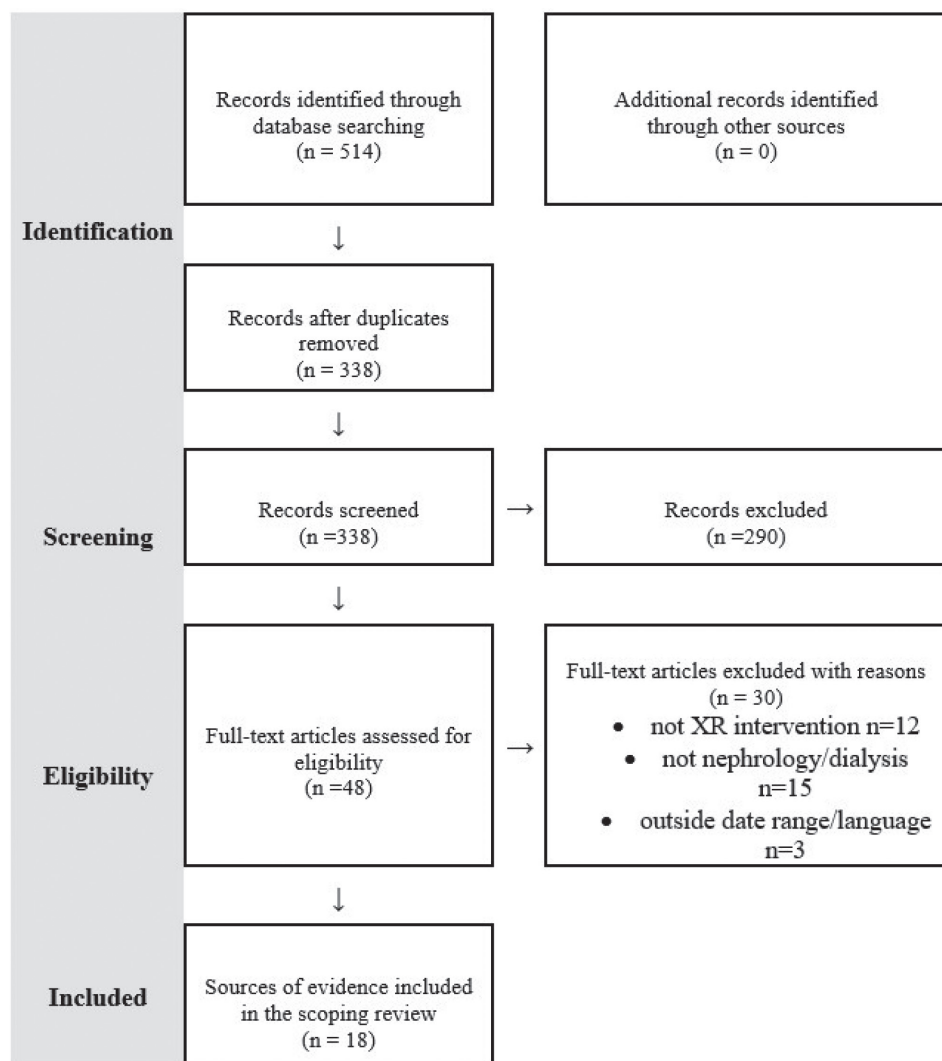
All retrieved records were exported to a reference manager and de-duplicated. Two reviewers independently screened titles and abstracts, followed by full-text assessment of potentially eligible reports. Discrepancies were resolved through discussion among the authors.

Data Charting Process and Data Items

The wording in the Data charting process and data items subsection has been clarified to state that the standardized charting form was pilot-tested on a sample of included studies before full data extraction. Data charting was conducted independently by 2 reviewers using this standardized form. Extracted data were cross-checked for consistency, and disagreements were resolved through discussion among the

TABLE 1 - Search strategy

Database	Search strategy
PubMed/MEDLINE	((“virtual reality”[Title/Abstract] OR “augmented reality”[Title/Abstract] OR “mixed reality”[Title/Abstract] OR “extended reality”[Title/Abstract] OR “immersive technolog*”[Title/Abstract] OR “metaverse”[Title/Abstract]) OR (“Virtual Reality”[MeSH Terms])) AND (nephrolog*[Title/Abstract] OR kidney[Title/Abstract] OR renal[Title/Abstract] OR hemodialysis[Title/Abstract] OR haemodialysis[Title/Abstract] OR “peritoneal dialysis”[Title/Abstract] OR dialysis[Title/Abstract])
Scopus	TITLE-ABS-KEY ((“extended reality” OR “virtual reality” OR “augmented reality” OR “mixed reality” OR metaverse OR “immersive technolog*”) AND (nephrolog* OR kidney OR renal OR hemodialysis OR haemodialysis OR “peritoneal dialysis” OR dialysis))
Web of Science Core Collection	TS= ((“extended reality” OR “virtual reality” OR “augmented reality” OR “mixed reality” OR metaverse OR “immersive technolog*”) AND (nephrolog* OR kidney OR renal OR hemodialysis OR haemodialysis OR “peritoneal dialysis” OR dialysis))
PsycINFO	((DE “Virtual Reality” OR “virtual reality” OR “augmented reality” OR “mixed reality” OR “extended reality”) AND (kidney OR renal OR nephrology OR hemodialysis OR haemodialysis OR “peritoneal dialysis” OR dialysis))
Cochrane Library	(“virtual reality” OR “augmented reality” OR “mixed reality” OR “extended reality”) in Title Abstract Keyword AND (kidney OR renal OR nephrology OR hemodialysis OR haemodialysis OR “peritoneal dialysis” OR dialysis)

**FIGURE 1** - PRISMA-ScR flow diagram.

authors until consensus was reached. The Data charting process and data items subsection have been revised accordingly. No formal protocol for this scoping review was prospectively registered. Extracted items included publication year, country, setting, participant type and sample size, study design, XR modality (VR/AR/MR), hardware and software (when reported), target task or intervention, comparator (if any), outcomes such as clinical symptoms, physiological measures, educational outcomes, feasibility, usability, and key findings. For review articles, we charted the scope and the number of included studies.

Synthesis of Results

We used a descriptive synthesis to summarize the evidence by application domain and XR modality. Because this was a scoping review, we did not perform a formal risk-of-bias assessment or meta-analysis, consistent with common scoping review practice and guidance⁸. We reported the study selection process using a PRISMA-ScR flow diagram.

Results

Selection of Sources of Evidence

Database searches yielded 514 records. After removal of 176 duplicates, 338 records underwent title and abstract

screening, of which 290 were excluded. Forty-eight full-text reports were assessed for eligibility, and 30 were excluded for the reasons summarized in Figure 1. Eighteen sources met the inclusion criteria and were included in the synthesis.

Characteristics of Included Studies

Included sources comprised 15 empirical studies and 2 evidence syntheses (1 systematic review and 1 systematic review with meta-analysis). A narrative review on immersive environments in nephrology was retained only as contextual background and was not included in the evidence synthesis. Publication years ranged from 2019 to 2026, with most studies published after 2023. Clinical studies predominantly enrolled patients receiving in-center hemodialysis, whereas educational and procedural studies targeted medical students, residents, and practicing surgeons. Table 2 summarizes the characteristics of the included studies.

Thematic synthesis

Domain 1: Symptom management and psychological support during hemodialysis

Seven empirical studies evaluated chairside or intra-dialytic VR for symptom relief, stress reduction, or psychological well-being. A recurring use case was distraction or

TABLE 2 - Characteristics of included studies

Study	Country & Setting	Design & Sample	XR modality & content	Main outcomes & key findings
Namazinia et al., 2025	Iran HD Center	RCT n = 60	Immersive VR headset (Shinecon) during AVF cannulation	Reduced cannulation pain vs routine care
Elzeky et al., 2024	Egypt HD unit	RCT n = 96	VR distraction during AVF puncture	Lower pain and anxiety Improved satisfaction Lower SBP/HR vs control
Güler et al., 2026	Turkey HD ward	RCT n = 80	Video streaming through VR glasses during AVF needle insertion	Lower pain and anxiety vs control
de Galvis et al., 2025	Spain Multicenter HD	Prospective non-randomized crossover pilot n = 73	Immersive VR headset around puncture and disconnection	Improved pain/anxiety mainly among high-baseline patients Mixed effects among low-baseline patients High acceptability variability
Arezoomand et al., 2025	Iran HD centers	Pre-post single-group n = 32	VR film via headset	Large reductions in DASS-21 anxiety and stress
Russ et al., 2025	Germany 12 dialysis centers	Pre-post single-group n=148 enrolled (143 completed)	Personalized immersive 360° VR (20-min session; choice of experiences)	Improved well-being; ~50% pain reduction among those with pain Transient reductions in BP and HR
Turoń-Skrzypińska et al., 2023	Poland HD clinic	RCT n = 85 analyzed	Low-intensity VR-enhanced cycling during HD (NefroVR prototype)	Reduced depressive symptoms and anxiety over 3 months vs control trend
Lee et al., 2023	Hong Kong (SAR China) Two-center PD program	RCT n = 23	Non-immersive VR with Leap Motion hand tracking for PD exchange learning	Improved PD exchange step performance 89% satisfaction; strong preference for VR aid

Study	Country & Setting	Design & Sample	XR modality & content	Main outcomes & key findings
Lonati et al., 2024	Germany Dialysis centers	Qualitative assessment among healthcare professionals N = 7	Commercial VR PD training tool (stay•safe MyTraining VR)	Proposed 5-step implementation workflow Perceived improvements in training efficiency and efficacy
Kang et al., 2025	International Multiple countries	Systematic review & meta-analysis 12 studies N = 625	VR training/exergaming across HD and PD	Improved 6MWT Reduced depression/anxiety, improved social functioning and self-efficacy Heterogeneity high.
Mecerli et al., 2025	France Multiple settings	Systematic review 6 studies N = NR	Immersive and non-immersive VR (including exergaming)	VR may improve anxiety and depressive symptoms Evidence is limited by small samples
Nakhoul et al., 2024	USA Residency education	Randomized educational evaluation n = 117	3D VR nephron physiology course (DiAL-Neph) plus surveys/focus groups	Higher immediate test scores vs traditional teaching No long-term retention difference High learner acceptability
Gonzalez et al., 2025	Chile Physiology education setting	Educational study (pre/post drawings and perceptions) n = 3 experimental cohorts and 3 control cohorts	AR-based learning sequence for renal physiology	Improved conceptual drawings and positive perceptions of AR learning.
Sonar et al., 2024	USA Outpatient clinic	Questionnaire-based pre/post study n = 67	AR models for NSAID-induced AKI education	Substantial knowledge gains Intent to modify behaviors
Checucci et al., 2021	Italy International Urology Meeting Renal tumor planning	Survey study n = 172 questionnaires	MR holograms from CT (HA3D) viewed with HoloLens for partial nephrectomy planning	High ratings for anatomical accuracy and planning value Many surgeons changed their planned approach
Youssef et al., 2025	USA Resident education	Pilot study n = 34 surgical residents	AR/MR 3D holograms of renal vascular anatomy on HoloLens 2 (Intravision XR)	Improved perceived understanding and applicability for education
Guo et al., 2020	China Simulation lab	Development/validation n = 24	Haptic-enabled holographic VR renal biopsy simulator	Improved puncture accuracy; favorable face/content validity Construct evaluation suggests skill discrimination
Li et al., 2019	China Simulation research	Technical development/validation study n = 27	VR-based renal biopsy with real-time needle force modeling	Enhanced realism of tool-tissue interaction for training Foundational for biopsy simulation

relaxation during arteriovenous fistula (AVF) cannulation. In a randomized clinical trial from Iran (n = 60), Namazinia and colleagues reported lower pain intensity during AVF needle insertion with VR headset distraction compared with routine care (11). Similarly, Elzeky and colleagues conducted a randomized controlled trial evaluating VR distraction during AVF puncture and observed reductions in pain and anxiety, along with improved satisfaction and favorable hemodynamic changes, relative to the control group (12). Another randomized trial using video streaming through VR glasses also suggested reductions in pain and anxiety during AVF needle insertion, further supporting the feasibility of repeated chairside deployment (13). Complementing these findings, de Galvis and colleagues reported a prospective multicenter

crossover pilot in which VR was used around puncture and disconnection for up to 13 sessions. Improvements were most apparent among patients with higher baseline pain and anxiety, whereas those with low baseline symptoms showed smaller benefits or occasional worsening, underscoring the importance of patient selection and titration (14).

Beyond procedure-specific pain and anxiety, immersive VR was also explored as a broader supportive intervention during the hemodialysis session. Arezoomand and colleagues conducted a pre-post interventional study among first-session hemodialysis patients (n = 32) and observed marked reductions in anxiety and stress scores following a VR film delivered through a headset (15). Russ and colleagues evaluated a multicenter personalized immersive VR session in

routine hemodialysis patients (148 enrolled, 143 completed). Participants were selected from multiple 360-degree experiences. Well-being improved, and pain decreased among those reporting pain, alongside transient reductions in blood pressure and heart rate during exposure, without serious adverse events (16). Finally, intradialytic exergaming with low-intensity VR cycling was associated with reductions in depressive symptoms and anxiety over a 3-month program in a randomized study of hemodialysis patients, suggesting a pathway through which XR may support both physical activity and mental health (17).

Across symptom-management studies, outcomes included visual analog scale pain scores, Faces Pain Scale-Revised scores, anxiety and stress measures, satisfaction, and physiological parameters. Comparators ranged from usual care to active controls, and intervention content varied substantially, including nature videos, tailored 360-degree environments, narrative films, and exercise gamification. Nevertheless, the overall signal suggested feasibility and short-term improvements in patient-reported distress. Importantly, heterogeneity and small sample sizes limit inferences regarding durability, cost-effectiveness, and generalizability.

Domain 2: Dialysis Training and Self-Management Support

Evidence for XR-assisted dialysis training was strongest for peritoneal dialysis (PD) exchange learning. Lee and colleagues developed a nonimmersive VR program using Leap Motion hand tracking and tested it in a 2-center, single-blinded randomized controlled trial among incident PD patients ($n = 23$). The VR group received 8 training sessions and demonstrated better performance on the overall PD exchange sequence, particularly on critical steps; satisfaction was high, and patients preferred VR supplementation to standard instruction (18). Lonati and colleagues evaluated a commercial VR training tool (Stay Safe MyTraining VR) and conducted a qualitative assessment among health care professionals, producing a structured implementation workflow that emphasized patient selection, onboarding, supervised sessions, and repetition (19). Together, these studies suggest that XR may add value for skill acquisition and reinforcement in home therapies, where procedural precision and confidence are essential.

At the synthesis level, Kang and colleagues conducted a systematic review and meta-analysis of VR training interventions for dialysis patients (12 studies; 625 participants; searches through December 2023). The meta-analysis reported improvements in walking endurance, reductions in depression and anxiety, and gains in social functioning and self-efficacy, although heterogeneity was high for several outcomes and effects were not consistent across functional measures (20). In parallel, Mecerli and colleagues reviewed VR interventions targeting anxiety and depressive symptoms in hemodialysis patients, identifying 6 quantitative studies published between 2019 and 2024 and concluding that VR shows promise, although the evidence remains limited and sample sizes are small (21). Although these reviews extend beyond nephrology-specific training to broader rehabilitation and psychological interventions, they provide useful context suggesting that XR may act through multiple pathways,

including distraction, relaxation, motivational engagement with exercise, and structured behavioral content.

Domain 3: Education, Procedural Rehearsal, and Kidney-Related Visualization

Several studies evaluated XR as a learning tool for nephrology concepts or kidney-related anatomy and procedures. For renal physiology education, Nakhoul and colleagues evaluated a 3-dimensional VR course (DiAL-Neph) among postgraduate year 1 internal medicine residents ($n = 117$) in a randomized design. Knowledge scores favored VR immediately after the course, but differences were not sustained at 6-12 weeks; qualitative feedback was positive, and most trainees preferred VR as a teaching modality (22). Gonzalez and colleagues tested an AR-based learning sequence for renal physiology and assessed learning through pre-post drawing outcomes and perceptions, supporting AR as a feasible supplement for conceptual visualization (23). At the patient education interface, Sonar and colleagues used AR models to improve knowledge about non-steroidal anti-inflammatory drug-associated acute kidney injury risk in an outpatient setting ($n = 67$), reporting substantial immediate knowledge gains and favorable intentions toward kidney-protective behaviors (24).

For anatomy and procedural planning, MR holograms and AR headsets were used to enhance 3-dimensional understanding. Checcucci and colleagues evaluated surgeons' perceptions of MR holograms for nephron-sparing surgery planning using HoloLens, collecting 172 questionnaires and reporting high ratings for anatomical accuracy and perceived value, with many surgeons changing their planned clamping or resection approaches after MR visualization compared with computed tomography alone (25). Youssef and colleagues conducted a pilot study of HoloLens-based 3-dimensional holograms of renal vascular anatomy derived from donor nephrectomy imaging; residents randomized to hologram review reported improved perceived understanding and applicability for education (26).

XR was also used for biopsy simulation. Guo and colleagues developed and assessed a haptic-enabled holographic surgical simulator for renal biopsy training, reporting improvements in puncture accuracy among medical students and favorable face and content validity assessments (27). Li and colleagues advanced needle-force modeling for a VR-based renal biopsy simulator, addressing a key technical barrier to realistic haptic training in image-guided renal procedures (28). Although these simulator studies were largely conducted in controlled environments rather than nephrology clinics, they suggest a pathway for standardizing procedural competency and reducing patient risk during training.

Summary of Evidence Gaps

Across domains, the included studies were heterogeneous and often early-phase. Few studies reported implementation outcomes beyond immediate feasibility, such as workflow integration, staff burden, infection-control protocols for headset reuse, and longer-term adherence. Equity considerations, including digital literacy, susceptibility to motion sickness, and



access barriers, were rarely addressed. Outcomes were reported inconsistently, limiting cross-study comparison.

Cross-Cutting Patterns in XR Modality and Content

Across the included sources, VR was the dominant XR technology in dialysis-related clinical studies and was typically delivered through commercially available head-mounted displays. Interventions ranged from passive viewing (e.g., nature or calming scenes) to structured psychological programs and interactive exercise. AR and MR were more common in education and surgical planning, where spatial registration and hands-free interaction were central. Few studies provided detailed technical specifications, such as field of view, refresh rate, or latency, and reporting of cybersickness-mitigation strategies was uncommon. Content-development processes were rarely described in depth. When reported, they generally involved either adaptation of existing commercial media (eg, immersive 360-degree films) or custom-built modules targeting kidney physiology or psychological constructs (29).

Outcomes and Measurement Heterogeneity

Patient-facing studies primarily assessed immediate, session-level outcomes. Pain was most often quantified using visual analog scales or faces-based scales, whereas anxiety and stress were assessed using brief visual analog measures or standardized questionnaires such as the DASS-21. Physiological measures, including blood pressure, heart rate, and oxygen saturation, were sometimes recorded before, during, and after VR exposure, but protocols differed with respect to timing and averaging. Few studies assessed broader patient-centered outcomes such as fatigue, sleep, quality of life, or the perceived time burden of dialysis. Likewise, few studies evaluated clinical outcomes that might plausibly change through sustained improvements in mood and engagement, such as interdialytic weight gain, adherence to prescriptions, missed sessions, or hospitalization.

Education

Education-focused studies used a mixture of knowledge tests, self-report satisfaction surveys, focus groups, and, less frequently, objective performance metrics. Notably, the DiAL-Neph evaluation combined short-term and delayed testing with qualitative feedback, offering a useful template for multimethod assessment in nephrology education. However, consistency across studies was limited, and validated instruments for XR-specific learning experiences, such as spatial understanding or cognitive load, were rarely used (30).

Geographic Distribution and Settings

Studies were conducted across multiple regions, including Europe, the Middle East, and North America, reflecting broad interest but also fragmented development. Most clinical dialysis studies were single-center investigations or small multicenter pilots. Where multicenter designs were used, they primarily focused on feasibility and immediate effects rather than longer-term follow-up. Educational studies were often

embedded within residency or medical student curricula and evaluated over short time windows, typically during structured sessions rather than along longitudinal learning pathways.

Adverse Events, Acceptability, and Usability

Most empirical studies reported high acceptability and few serious adverse events. When systematically assessed, common concerns included headset discomfort, visual strain, and occasional dizziness. Infection control procedures for shared devices were not consistently detailed, despite their obvious relevance in dialysis units. Several studies emphasized that patients valued “escaping” the dialysis environment, suggesting that immersion may function both as symptom management and as a meaningfully different experiential environment. Clinicians and trainees generally reported favorable perceptions of XR for understanding kidney anatomy and complex spatial relationships.

Discussion

This scoping review mapped 18 sources of evidence on XR in nephrology and dialysis published between January 2016 and January 2026. Although the evidence base remains small, it is expanding rapidly, with a marked increase in publications after 2023. Three main application domains emerged: (1) intradialytic symptom management and psychological support, particularly for procedural pain, anxiety, and stress reduction; (2) dialysis training and self-management support, especially for peritoneal dialysis exchange learning; and (3) education and kidney-related visualization for trainees and clinicians, including physiology teaching, surgical planning, and biopsy simulation.

Across the symptom-management domain, several studies converged on the feasibility of deploying immersive VR headsets chairside during hemodialysis. Randomized trials focusing on AVF cannulation generally reported reductions in pain and anxiety, and pilot studies suggested possible physiological benefits. These findings are consistent with the broader use of VR as a distraction and relaxation tool in procedural medicine. In hemodialysis, the predictable temporal structure of treatment sessions and the high frequency of repeated procedures create a favorable context for XR interventions that can be delivered without requiring additional clinic visits. However, the heterogeneity of intervention content from passive nature scenes to guided films and interactive exercise indicates that VR should not be considered a single uniform intervention. Future work should therefore specify intervention components such as immersion level, interactivity, narrative, music, and personalization, while also establishing mechanistic hypotheses related to distraction, relaxation response, attentional control, affect regulation, and exercise motivation (31,32). These findings should therefore be interpreted cautiously, because most included studies were designed to assess feasibility or immediate response rather than sustained clinical effectiveness or implementation readiness.

In the dialysis-training domain, VR-assisted PD exchange training appears to be a particularly pragmatic application. PD exchange involves multiple sequential, safety-critical



steps that are well-suited to simulation and repetition. The available evidence suggests that VR may improve procedural accuracy and patient satisfaction, and qualitative work indicates that structured workflows may support implementation within dialysis centers. Nevertheless, scalability is likely to depend on careful patient selection, support for individuals with cognitive or sensory limitations, and alignment with existing training curricula. Importantly, XR should currently be viewed as a complement to, rather than a replacement for, hands-on training, providing opportunities for safe repetition before and between supervised sessions. At this stage, this literature is better understood as proof-of-concept evidence that justifies further testing than as evidence sufficient to support broad operational uptake.

In the education and visualization domain, XR appears most promising when it leverages capabilities that are difficult to reproduce with traditional methods, such as three-dimensional spatial understanding, interactive manipulation of structures, and embodied learning of physiological processes. Existing studies suggest short-term knowledge gains and positive learner perceptions, but evidence for long-term retention remains limited. MR holograms may influence clinical reasoning by enabling a deeper understanding of tumor complexity and vascular relationships, although much of the available evidence remains perception-based. More rigorous educational research should incorporate validated assessments, retention testing, and comparisons with high-quality conventional 3-dimensional visualization. Translating XR into routine nephrology practice will also require attention to infection prevention, device cleaning, user comfort, and workflow integration. Hemodialysis units may face practical constraints related to space, staff time, and device maintenance. Personalization, although potentially beneficial, adds complexity in terms of content selection, language localization, and patient preferences. Safety considerations include cybersickness, visual strain, and potential interference with clinical monitoring. Studies to date have reported few serious adverse events, but more systematic reporting is needed (29, 33,35). Accordingly, the apparent educational or visualization advantages should be regarded as preliminary signals requiring confirmation in stronger comparative studies with longer follow-up and objective downstream outcomes.

From a health equity perspective, XR may reduce barriers by providing standardized training and engaging educational experiences, but it may also widen disparities if access and usability are not designed for older adults and for people with sensory impairment, limited digital literacy, or limited language proficiency. Future research should incorporate user-centered design and participatory methods involving diverse patient populations (36,37). Our mapping suggests 5 near-term priorities. First, pragmatic multicenter trials should evaluate the real-world effectiveness, durability, and cost-effectiveness of VR for symptom management during hemodialysis, including identification of the patients most likely to benefit. Second, standard outcome sets including pain, anxiety, stress, satisfaction, adherence, and selected physiological measures would improve comparability across trials. Third, implementation studies should measure workflow burden, staff acceptability, cleaning protocols, and safety

monitoring. Fourth, PD training research should assess downstream outcomes such as technique survival, peritonitis rates, and retraining needs. Fifth, educational XR studies should incorporate retention, transfer to clinical performance, and learning analytics, and should compare XR with modern alternatives such as interactive three-dimensional web platforms (31,34,37). These priorities are therefore intended to inform a hypothesis-testing research agenda, since the current evidence base is not yet mature enough to justify strong practice-oriented conclusions.

Kidney disease care spans chronic outpatient management, acute inpatient interventions, and procedural specialties. XR appears to address different needs across this continuum. In the center, hemodialysis offers repetitive, high-volume opportunities for standardized delivery, which may help explain why VR symptom management trials emerged earlier and more frequently than AR or MR bedside interventions. By contrast, home dialysis training is intensive but time-limited; XR may be most useful as a booster modality for repetition and confidence building outside direct clinician time, particularly when combined with remote monitoring or tele-support. In nephrology education, XR may reduce reliance on abstract mental models by externalizing physiology and anatomy into interactive space. However, its value proposition must be tested against modern non-XR alternatives that may be less expensive and easier to deploy, such as interactive three-dimensional web applications, adaptive quizzes, and simulation mannequins. These proposed roles should thus be read as plausible future use cases emerging from the literature rather than as established indications for XR in nephrology care. Comparative evaluation against these alternatives should be addressed in future nephrology-focused studies.

Future clinical trials should improve comparability by specifying intervention dose, including minutes per session, number of sessions, and timing relative to dialysis procedures, and by reporting adherence and reasons for nonuse. Trials should also consider active comparators that control for attention and novelty, such as non-immersive video or music. Investigators should standardize adverse-event reporting using established cybersickness scales and should explicitly describe infection-control and device-cleaning protocols. In addition, qualitative components may help explain why XR works or fails to work in dialysis environments, including patient preferences and barriers such as headset weight, visual acuity, and language. In education studies, investigators should incorporate measures of cognitive load and spatial ability and should assess transfer to real-world performance rather than relying solely on satisfaction (30). Such trials will also be needed to separate true intervention effects from novelty, attention, and expectancy effects that are difficult to rule out in small early-phase studies.

Very few included studies addressed costs, yet the economic case will likely influence adoption. Dialysis providers may consider XR if it reduces staff time devoted to training, lowers complications, or improves patient satisfaction and retention. Relevant cost components include hardware, content licensing or development, device replacement and sanitation materials, staff training, and technical support. Future studies should incorporate at least basic cost descriptions and explore

scalable content models such as shared libraries, multilingual modules, and partnerships with patient organizations (37).

Overall, the current evidence base should be interpreted as primarily hypothesis-generating. Although several studies suggest feasibility and short-term signals of benefit, the literature remains heterogeneous, methodologically early-stage, and insufficient to support broad clinical implementation.

Conclusions

XR applications in nephrology and dialysis represent an emerging and promising area of research; however, the current evidence remains largely early-stage and hypothesis-generating. Although feasibility and short-term benefits have been reported across symptom management, dialysis training, and education, more rigorous comparative and implementation studies are needed before XR can be considered practice-changing in routine kidney care.

Disclosures

Conflict of interest: The authors declare no conflicts of interest.

Financial support: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Authors' contributions: FB: conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing—original draft, and writing—review and editing; VM: data curation, formal analysis, investigation, methodology, validation, visualization, writing—original draft, and writing—review and editing; GLG: supervision and validation; MS: supervision and validation; MS: data curation, formal analysis, supervision, and validation.

Data Availability Statement: Data sharing is not applicable to this article.

References

- Morimoto T, Kobayashi T, Hirata H, et al. XR (Extended Reality: Virtual Reality, Augmented Reality, Mixed Reality) technology in spine medicine: status quo and quo vadis. *J Clin Med*. 2022;11(2):470. [CrossRef PubMed](#)
- Milgram P, Kishino F. A taxonomy of mixed reality visual displays. *IEICE Trans Inf Syst*. 1994;E77-D(12):1321-1329.
- Zoccali C, Mallamaci F. Exploring the metaverse: opportunities for nephrology in patient care and education. *Nephrol Dial Transplant*. 2025;40(5):865-873. [CrossRef PubMed](#)
- Fitzpatrick T, Maddox T. Breaking barriers in home dialysis: augmented reality, real-time training, and remote support. *Nephrol Nurs J*. 2025;52(2):137-141. [CrossRef PubMed](#)
- Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med*. 2018;169(7):467-473. [CrossRef PubMed](#)
- Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol*. 2005;8(1):19-32. [CrossRef](#)
- Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. *Implement Sci*. 2010;5(1):69. [CrossRef PubMed](#)
- Peters MDJ, Marnie C, Tricco AC, et al. Updated methodological guidance for the conduct of scoping reviews. *JBIM Evid Synth*. 2020;18(10):2119-2126. [CrossRef PubMed](#)
- Clark JM, Paivio A. Dual coding theory and education. *Educ Psychol Rev*. 1991;3(3):149-210. [CrossRef](#)
- Chan CT, Collins K, Ditschman EP, et al. Overcoming barriers for uptake and continued use of home dialysis: an NKF-KDOQI conference report. *Am J Kidney Dis*. 2020;75(6):926-934. [CrossRef PubMed](#)
- Namazinia M, Mohajer S, Abbaspour S, et al. Effects of virtual reality on pain induced by arteriovenous fistula needle insertion in patients undergoing hemodialysis: a randomized clinical trial. *J Vasc Access*. 2025;26(2):531-539. [CrossRef PubMed](#)
- Elzeky ME, Salameh B, Reshia FAA, Sabry AA, Shahine NF, Mohamed EA. The effect of virtual reality distraction on haemodialysis patients' pain and anxiety during arteriovenous fistula puncture: a randomised controlled trial. *J Res Nurs* 2024 Sep; 29(6):421-434. [CrossRef](#)
- Güler S, Öztürk S, Şahan S, et al. The effect of video streaming with virtual reality glasses during arteriovenous fistula needle insertion on pain and anxiety of individuals undergoing hemodialysis treatment. *Hemodial Int*. 2026;30(1):37-45. [CrossRef PubMed](#)
- Rodríguez de Galvis S, Guerrero Rodríguez E, Audije-Gil J, et al. A pilot study of virtual reality in hemodialysis for mitigating pain and anxiety: user experiences and perceptions. *Patient Prefer Adherence*. 2025;19:2069-2079. [CrossRef PubMed](#)
- Arezoomand F, Moulaei K, Mashoof E. Examining the effects of virtual reality on anxiety and stress reduction in patients undergoing hemodialysis: a pre-post interventional study. *Virtual Real (Walth Cross)*. 2025;29(4):172. [CrossRef](#)
- Russ P, Wenzel LT, Bedenbender S, et al. Personalized virtual reality in hemodialysis patients: a multicenter pilot study. *Clin Kidney J*. 2025;19(1):sfaf367. [CrossRef PubMed](#)
- Turoń-Skrzypińska A, Tomska N, Mosiejczuk H, et al. Impact of virtual reality exercises on anxiety and depression in hemodialysis. *Sci Rep*. 2023;13(1):12435. [CrossRef PubMed](#)
- Lee CMS, Fong KNK, Mok MMY, et al. Application of virtual reality for peritoneal dialysis exchange learning in patients with end-stage renal disease and cognitive impairment. *Virtual Real (Walth Cross)*. 2022;27(3):1-13. [CrossRef PubMed](#)
- Lonati C, Wellhausen M, Pennig S, et al. The use of a novel virtual reality training tool for peritoneal dialysis: qualitative assessment among health care professionals. *JMIR Med Educ*. 2024;10:e46220. [CrossRef PubMed](#)
- Kang X, Zhang Y, Sun C, et al. Effectiveness of virtual reality training in improving outcomes for dialysis patients: systematic review and meta-analysis. *J Med Internet Res*. 2025;27:e58384. [CrossRef PubMed](#)
- Mecerli S, Cazauviel V, Vial R, et al. Effectiveness of virtual reality interventions on anxiety and depressive symptoms in hemodialysis patients: a systematic review. *Nephrol Ther*. 2025;21(3):170-179. [CrossRef PubMed](#)
- Nakhoul GN, Taliercio JJ, Bassil EH, et al. Virtual nephron: evaluation of a novel virtual reality educational tool. *Kidney Int Rep*. 2024;9(9):2619-2626. [CrossRef PubMed](#)
- Gonzalez AA, Pacheco G, Pino S, et al. Testing an augmented reality-based learning sequence for renal physiology with biomedical students. *Adv Physiol Educ*. 2025;49(4):1034-1044. [CrossRef PubMed](#)
- Sonar N, Pervaze S, Kaur G, et al. Effect of augmented reality models on patient education in preventing non-steroidal anti-inflammatory drug-induced acute kidney injury. *Cureus*. 2024;16(9):e69265. [CrossRef PubMed](#)
- Checucci E, Amparore D, Pecoraro A, et al. 3D mixed reality holograms for preoperative surgical planning of nephron-sparing surgery: evaluation of surgeons' perception. *Minerva Urol Nephrol*. 2021;73(3):367-375. [PubMed](#)
- Youssef G, Renz C, Wu J, et al. Enhancing surgical resident education through augmented reality: a pilot study using 3D



- holograms to delineate renal vascular anatomy. *Am Surg.* 2026;92(3):775-779. [CrossRef PubMed](#)
27. Guo Z, Tai Y, Qin Z, et al. Development and assessment of a haptic-enabled holographic surgical simulator for renal biopsy training. *Soft Comput.* 2020;24(8):5783-5794. [CrossRef](#)
 28. Li F, Tai Y, Li Q, et al. Real-time needle force modeling for VR-based renal biopsy training with respiratory motion using direct clinical data. *Appl Bionics Biomech.* 2019;2019:9756842. [CrossRef PubMed](#)
 29. Kennedy RS, Lane NE, Berbaum KS, et al. Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness. *Int J Aviat Psychol.* 1993;3(3):203-220. [CrossRef](#)
 30. Sweller J. Cognitive load during problem solving: effects on learning. *Cogn Sci.* 1988;12(2):257-285. [CrossRef](#)
 31. Abdel-Kader K, Unruh ML, Weisbord SD. Symptom burden, depression, and quality of life in chronic and end-stage kidney disease. *Clin J Am Soc Nephrol.* 2009;4(6):1057-1064. [CrossRef PubMed](#)
 32. Eijlers R, Utens EMWJ, Staals LM, et al. Systematic review and meta-analysis of virtual reality in pediatrics: effects on pain and anxiety. *Anesth Analg.* 2019;129(5):1344-1353. [CrossRef PubMed](#)
 33. Roberts SC, Havill NL, Flores RM, et al. Disinfection of virtual reality devices in health care settings: in vitro assessment and survey study. *J Med Internet Res.* 2022;24(12):e42332. [CrossRef PubMed](#)
 34. Proctor E, Silmere H, Raghavan R, et al. Outcomes for implementation research: conceptual distinctions, measurement challenges, and research agenda. *Adm Policy Ment Health.* 2011;38(2):65-76. [CrossRef PubMed](#)
 35. Simón-Vicente L, Rodríguez-Cano S, Delgado-Benito V, et al. Cybersickness. A systematic literature review of adverse effects related to virtual reality. *Neurologia (Engl Ed).* 2024;39(8):701-709. [CrossRef PubMed](#)
 36. Hepburn J, Williams L, McCann L. Barriers to and facilitators of digital health technology adoption among older adults with chronic diseases: updated systematic review. *JMIR Aging.* 2025;8:e80000. [CrossRef PubMed](#)
 37. Gómez Bergin AD, Craven MP. Virtual, augmented, mixed, and extended reality interventions in healthcare: a systematic review of health economic evaluations and cost-effectiveness. *BMC Digit Health.* 2023;1(1):53. [CrossRef](#)