

Review

Robotics in cancer care: a systematic evidence map of clinical applications, patient-centered evidence, and psychosocial gaps

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Abstract:

Objectives: Robotic technologies increasingly shape how cancer care is delivered and experienced, but the literature remains focused on platforms and conventional clinical outcomes. This systematic evidence map examined publication growth and thematic structure from 2016 to 2025 and assessed the visibility of patient-reported, psychosocial, social, ethical, and implementation concerns.

Methods: Web of Science and Scopus articles and reviews were harmonized, deduplicated, and screened using a rule-assisted workflow. The primary corpus comprised 12,587 eligible records; 12,274 records with abstracts underwent non-negative matrix factorization. An expanded-search diagnostic sample included 620 records, of which 87 were marked for inclusion by both assessors and added to a 12,674-record audit inventory. Unmatched records were not screened exhaustively, and all estimates derive from the primary corpus.

Results: Annual output rose from 746 records in 2016 to 1,944 in 2025, and robot-assisted oncologic surgery accounted for 81.6% of records. The ten topics clustered around cancer sites, procedures, evidence synthesis, and conventional outcomes; none focused primarily on psychological or social care. Patient-centered indicators were visible in 2,462 records (19.6%). The expanded audit did not alter the primary-corpus estimates.

Conclusion: Despite rapid publication growth, patient-centered concerns did not become more visible in the metadata over time. The map captures the presence of psychosocial constructs in indexed metadata, not their measurement with validated instruments or their effects. Future studies should pair clinical outcomes with psychological adjustment, decision quality, social participation, caregiver effects, accessibility, and ethical safeguards.

Keywords: cancer; robotics; patient-centered care; psycho-oncology; patient-reported outcomes; supportive robotics; evidence mapping; health equity

1. Introduction

Cancer care is experienced not only as a sequence of diagnostic and therapeutic procedures but also as sustained uncertainty, altered bodily function, dependence on others, disrupted social roles, and repeated decisions under emotional strain. A technology can therefore be clinically successful while leaving important dimensions of the care experience unexamined. Robotics is especially relevant to this tension because it enters settings in which patients may surrender direct control to a complex system, rely on mediated clinician contact, or use a robot to preserve mobility and social connection. Its value cannot be inferred from precision, smaller incisions, or technical feasibility alone; it also depends on whether patients understand and accept

the intervention, trust the care arrangement, recover functions that matter to them, and retain autonomy within technologically reorganized care.

Robotic oncology nevertheless encompasses markedly different relationships between technology and the patient. Surgical robots reorganize the operative encounter and shape recovery expectations; robotic radiotherapy and image-guided intervention alter treatment burden and perceptions of accuracy; micro- and nanorobots raise questions about bodily integrity, uncertainty, and consent before routine clinical use is plausible; and social, telepresence, or rehabilitation robots interact directly with daily life. In prostate cancer, for example, satisfaction after robot-assisted surgery may diverge from urinary or sexual outcomes because expectations, information, and treatment choice influence how recovery is interpreted [1,2]. In head and neck cancer, swallowing, pain, distress, and quality of life may be as consequential to patients as local control [3,4]. These examples locate robotics within psycho-oncology: the platform affects not only what clinicians can do, but also how patients anticipate, experience, and make sense of care.

The literature has largely developed within specialty boundaries. Urologic, colorectal, thoracic, gynecologic, and head and neck research asks procedure-specific questions, while radiotherapy, robotic bronchoscopy, micro/nanoscale delivery, rehabilitation, and remote care have formed partly separate communities. This specialization clarifies technical problems but obscures whether the field is accumulating evidence about patient experience at the same pace as evidence about platforms. Existing syntheses commonly focus on one cancer, one device, publication trends, or conventional perioperative outcomes. They rarely connect thematic structure and evidence design with psychological wellbeing, treatment acceptance, decision-making, social participation, caregiver effects, accessibility, and ethical concerns. Publication growth can therefore be mistaken for patient-centered maturity.

We addressed this gap through a funnel-shaped evidence-mapping design. Records from Web of Science and Scopus were standardized, deduplicated, and screened; non-negative matrix factorization (NMF) identified the field's dominant themes; application, cancer site, and evidence design were cross-classified; and an additional patient-centered overlay examined whether nine psychosocial, behavioral, experiential, and ethical domains were explicitly visible in bibliographic metadata. Publication volume was not treated as technological superiority, topic weight as clinical effectiveness, or keyword visibility as proof of a measured benefit. Three research questions guided the review:

(1) **Research Question 1** (RQ1—development and care distribution): How did publication volume, robotic application domains, cancer sites, and evidence designs change from 2016 to 2025, and where in the cancer-care pathway was research concentrated?

(2) **Research Question 2** (RQ2—thematic structure): What major themes emerged, how did they change over time, and to what extent did the dominant thematic structure foreground or marginalize supportive and psychosocial concerns?

(3) **Research Question 3** (RQ3—patient-centered evidence and gaps): How were patient-reported, psychological, behavioral, social, accessibility, autonomy, caregiver, and ethical dimensions distributed across robotic pathways, and what evidence and implementation gaps followed from that distribution?

The questions form a progressive sequence. RQ1 locates the field across time, applications, diseases, and designs. RQ2 tests which concerns become visible when the corpus is organized by dominant language. RQ3 then overlays patient-centered indicators on the technology–evidence map to identify where patient experience is

explicit, where it is eclipsed by technical endpoints, and which psychosocial or ethical uncertainties require targeted evaluation.

2. Literature review

2.1. Robot-assisted oncologic surgery: from operative performance to patient experience

Robot-assisted surgery was the first branch of cancer robotics to develop a substantial evidence base. Three-dimensional visualization, tremor filtering, articulated instruments, and stable retraction may facilitate dissection and reconstruction in confined anatomical spaces. These capabilities, however, are intermediary mechanisms rather than patient benefits. Their meaning depends on tumor stage, operator experience, the comparator, perioperative care, recovery expectations, and which outcomes patients value [5,6]. A technically completed procedure may still be accompanied by anxiety, decisional regret, persistent dysfunction, or disappointment when preoperative expectations are poorly calibrated.

Urologic oncology provides the clearest illustration. Radical prostatectomy research now includes continence, sexual function, quality of life, treatment satisfaction, expectations, and decision regret alongside margin status and biochemical recurrence [1,2,7–9]. These outcomes are related but not interchangeable. A patient may be satisfied with communication and recovery despite residual dysfunction, or regret a treatment despite technically favorable results. Robot-assisted cystectomy and partial nephrectomy similarly require recovery, symptom, body-image, and daily-function outcomes to be interpreted with oncologic control [10–12].

Colorectal, gastroesophageal, and thoracic applications extend this argument. Conventional studies emphasize conversion, lymphadenectomy, complications, and length of stay [13–18]. Qualitative evidence nevertheless shows that fatigue, pain, bowel function, confidence in recovery, and the practical burden of discharge may shape how patients compare robotic, laparoscopic, and open pathways [19]. The relevant unit of interpretation is thus the platform-task-patient relationship: which operative step is altered, for whom, under what organizational conditions, and with what consequences for everyday functioning.

Head and neck and gynecologic oncology make the experiential stakes particularly visible. Transoral robotic surgery may reduce external incisions, yet swallowing, speech, pain, distress, adjuvant treatment, and quality of life remain interdependent [3,4,20,21]. In gynecologic cancer, minimally invasive recovery may coexist with concerns about oncologic safety, sexuality, body image, and return to family roles; prospective quality-of-life evidence after robotic hysterectomy illustrates why short-term surgical recovery should not stand in for the whole patient experience [22].

2.2. Robotic radiotherapy, diagnosis, and image-guided intervention: treatment burden and trust

Robotic radiotherapy and radiosurgery center on spatial tracking, non-coplanar beam delivery, and intrafraction positional correction. Unlike a surgical robot, these systems act through coordinated control of the treatment head, patient positioning, and imaging chain. Their principal clinical questions concern target coverage, organ motion, dose distribution, treatment time, and toxicity. A synthesis of skull-base tumors, for example, showed that interpretation remained constrained by heterogeneity in tumor type and dose schedule [23]. Because the same platform can treat several cancers, this literature often forms cross-site topics, although differences

in radiosensitivity and motion limit direct comparison.

Robotic diagnosis and image-guided intervention address access and stability. Robotic bronchoscopy uses steerable catheters and navigation to reach peripheral pulmonary lesions; studies report lesion access, diagnostic yield, complications, and imaging confirmation [24,25–28]. Robotic prostate biopsy, percutaneous puncture, ultrasonography, and intraoperative navigation use mechanical positioning to reduce trajectory error [29–31]. This line of research commonly progresses from engineering feasibility to multicenter diagnostic evaluation, placing its clinical evidence between mature surgical platforms and early micro/nanoscale systems.

Diagnosis, localization, and treatment are increasingly connected, but the patient's position in this chain is often weakly specified. Robotic bronchoscopy may reduce uncertainty about lesion access while introducing questions about how diagnostic yield, procedural discomfort, complications, repeat procedures, and false reassurance are communicated. Robotic radiotherapy may improve geometric control, yet treatment time, immobilization, toxicity, fear, and confidence in automation remain relevant to acceptability. Classification by device name alone therefore misses both task-level mechanisms and patient–clinician interactions. Evaluation should record what the robot does, where it enters the care pathway, what decision it changes, and how patients experience that change.

2.3. Micro/nanorobotics, rehabilitation, and supportive care

Micro/nanorobotics extends the concept of robotics from instrument manipulation to active in vivo transport and local response. Systems may be actuated by magnetic fields, light, ultrasound, enzymatic reactions, bacteria, or cells, while surface modification, collective behavior, and environmental responsiveness are used to increase tumor accumulation [32–36]. Key questions concern motion control, biocompatibility, payload stability, immune response, in vivo imaging, and clearance. Differences in experimental conditions, however, make platform performance difficult to compare using a common metric.

The appeal of micro/nanosystems lies in their response to limitations of passive delivery. Abnormal vasculature, interstitial pressure, hypoxia, and heterogeneity create barriers between circulation and a solid tumor. Active motion and external guidance may improve local access, but control range, energy input, scalable manufacturing, safe retrieval, and regulatory classification still limit translation [37–43]. The coexistence of many reviews and animal experiments with few clinical studies indicates an early evidence-design profile; it does not by itself quantify quality or readiness.

Rehabilitation and supportive robotics follow a different translational pathway because their intended effects are relational and behavioral rather than tumor-directed. Exoskeletons may support mobility, independence, and engagement in cancer rehabilitation [44]. Telepresence robots can help children maintain classroom participation and peer connection during prolonged treatment [45,46]. Social robots have been used to reduce procedural pain and distress, provide health education, or offer companionship in pediatric oncology [47–50]. These interventions should be evaluated through engagement, emotional response, autonomy, social participation, adherence, and family burden rather than kinematics alone.

2.4. Patient-centered, psychosocial, and ethical evidence gaps

Cancer robotics contains mature specialty clusters, but its patient-centered evidence is fragmented. Surgical studies often treat continence, pain, or length of stay

as isolated endpoints without connecting them to expectations, distress, satisfaction, or shared decisions. Micro/nanoscale studies emphasize engineering mechanisms before patient-facing questions can be tested. Supportive robotics directly targets participation and wellbeing but relies on small, context-specific evaluations. These differences preclude a single maturity scale and make psychosocial visibility an empirical question rather than an assumed property of ‘patient-centered’ technology.

Topic modeling and evidence mapping provide complementary views. Topic models identify stable structures from term co-occurrence and can track frequently studied questions and their temporal change. Evidence maps use predefined dimensions to locate technological routes, cancer sites, and study designs, thereby retaining infrequent but important applications. The former reduces dependence on an a priori classification, whereas the latter prevents the large surgical literature from dominating interpretation. Together they show both what the field discusses and what evidence underpins those discussions.

We therefore combined systematic searching, rule-assisted screening, topic modeling, evidence-design classification, and a patient-centered metadata overlay. The overlay was needed because infrequent but conceptually important constructs—such as social connection, caregiver burden, privacy, assent, and equity—would not necessarily form global topics in a surgically dominated corpus. This approach does not estimate pooled effects or substitute for full-text psychosocial quality appraisal. It identifies where patient-centered concerns are explicit enough to enter the indexed discourse and where focused systematic reviews or primary studies are needed.

3. Materials and methods

The review used a five-stage funnel: data collection and preprocessing, rule-assisted screening and structured extraction, topic modeling, technology–evidence mapping, and a patient-centered psychosocial overlay. The bibliographic record was the unit of analysis, and reporting followed PRISMA 2020 transparency principles. This was a metadata-based evidence map rather than a full-text effectiveness review: publication counts index research attention, design labels identify study-design distribution, and lexical labels indicate metadata visibility. None of these measures was interpreted as effect size, risk of bias, clinical readiness, or proof of patient benefit.

3.1. Data collection and preprocessing

Records were retrieved from the Web of Science Core Collection and Scopus on August 23, 2026. The primary Web of Science query was TS=(“robot-assisted” OR “robot assisted” OR robotic OR robot*) AND TS=(cancer); Scopus used TITLE-ABS-KEY(“robot-assisted” OR “robot assisted” OR robotic OR robot*) AND TITLE-ABS-KEY(cancer). The publication window was January 1, 2016, to December 31, 2025, and document types were restricted to Article and Review. The exports contained 17,035 Web of Science and 23,141 Scopus records (40,176 before filtering). The primary objectives of this study are bibliometric analysis and the mapping of the research evidence landscape. Specifically, by analyzing database records, this study examines the scale of development, areas of application, thematic structure, and research trends of robotics in cancer research. It does not constitute a systematic review of the efficacy or safety of specific clinical interventions, nor does it involve the pooling of effect sizes as found in traditional systematic reviews or meta-analyses. Therefore, this study was not registered with PROSPERO as a clinical systematic review. Exact executable primary database searches are reported in

Supplementary Table S1, while data ingestion, cross-database harmonization, and the expanded-search audit are described in Supplementary Method S1.

Preprocessing was performed in Python 3.12.14 using version-controlled scripts. Field names, Unicode, whitespace, year, and document type were standardized. DOI strings were lowercased and stripped of URL prefixes and terminal punctuation. Titles and first-author names were normalized for case, punctuation, spacing, and diacritics. Original record identifiers, source files, and database provenance were retained. **Table 1** summarizes eligibility; Supplementary Tables S1–S2 report the primary searches and field mapping. The separate supplementary file “Reproducibility_archive_PO-6468.zip” contains the available scripts, coding dictionaries, aggregate outputs, permitted identifiers, and software information; licensed raw database exports are not redistributed.

Table 1. Primary search scope and analytical eligibility.

Element	Operational definition
Databases	Web of Science Core Collection; Scopus
Publication window	1 January 2016–31 December 2025
Document types	Article; Review
Core concepts	Robot-assisted/robotic/robot* AND cancer
Analytical scope	Surgery, radiotherapy, diagnosis, intervention, micro-/nanorobotics, rehabilitation, and support
Primary exclusions	Incidental robot mention; no substantive oncology context; clearly benign/non-oncologic indication

A separate expanded-search E export was obtained on September 18, 2026: 26,167 Web of Science records and 32,606 Scopus records (58,773 exports). Restricting publication years to 2016–2025 and document types to Article or Review left 46,565 records; within-E deduplication retained 29,874 unique records. Of these, 8,161 did not match the primary deduplicated set. A diagnostic sample contained 500 simple-random and 120 targeted records. The two assessor worksheets agreed on inclusion for 87 records (76 Articles and 11 Reviews), which were added to the 12,587-record primary set to form a 12,674-record audit-based inventory. Because only 620 of the 8,161 unmatched records were assessed, this inventory is neither a completely screened expanded corpus nor a representative estimate of all unmatched records; the remaining unmatched records were not treated as confirmed exclusions.

3.2. Rule-assisted screening and structured extraction

3.2.1. Cross-database deduplication

Deduplication proceeded in three ordered stages: exact normalized DOI; exact normalized title plus first author and publication year; and title-token Jaccard similarity of at least 0.90 within first-author–year blocks. Adding publication year to the second pass corrected an overly permissive linkage in the initial analysis. Specifically, a previously identified 13-record group of recurring monthly items was not collapsed into one canonical record. It was separated into distinct publication-level records after comparison of title, first author, year, DOI, journal, and abstract; only records satisfying the corrected duplicate criteria were merged.

After date and document-type filtering, 32,775 records entered deduplication. Exact DOI matching removed 10,775 records, exact title-author-year matching removed 267, and conservative fuzzy matching removed 6. The corrected workflow therefore removed 11,048 duplicate records and retained 21,727 unique records. Supplementary Table S3 provides stage-specific counts and the 13-record audit.

3.2.2. Title and abstract screening

A prespecified, traceable rule-based workflow screened primary-search titles, abstracts, and keywords for substantive robotic and oncology focus. Its rules distinguished direct title evidence, corroborated keyword and abstract evidence, incidental mentions, missing cancer focus, and benign-only contexts. For the expanded-search audit, the assessor A and B worksheets were compared record by record. The strict joint-inclusion rule retained only records marked Include in both sheets; 87 records met that criterion and entered the audit-based inventory. Other sampled records were not treated as consensus exclusions.

The expanded-search diagnostic sample included 500 simple-random records and 120 targeted records. Of the 620 sampled records, 87 met the joint-inclusion criterion. The remaining 533 were not all jointly judged ineligible and were not counted as consensus exclusions. Because the sample did not provide a complete consensus reference classification, it was not used to estimate screening sensitivity, specificity, precision, negative predictive value, accuracy, or inter-rater reliability. The primary-search rule-assisted screen remained a metadata classification.

In the primary search, 21,727 unique records were screened, of which 12,587 were included and 9,140 excluded by the rule-assisted metadata screen. Incidental or absent robotic focus accounted for 8,708 exclusions (95.3%); 403 records (4.4%) lacked a substantive cancer application; and 29 (0.3%) concerned a clearly benign or non-oncologic indication despite cancer-related indexing. These are primary-search algorithmic counts, not a prevalence estimate for the underlying clinical literature or a human-adjudicated expanded-search flow.

Table 2 and **Figure 1** trace the primary search from 40,176 exports to 12,587 metadata-eligible records; 12,274 primary records with abstracts entered topic modeling. The separate expanded-search audit contributed 87 concordant inclusions, producing an audit-based inventory of 12,674 records. **Figures 2–6** and the model-derived results retain the explicitly labeled primary-corpus denominator.

Table 2. Primary-search record flow and analytical corpus.

Stage	Records (n)	Removed (n)
Records identified	40,176	—
Within 2016–2025	39,973	203
Article or Review	32,775	7,198
After corrected deduplication	21,727	11,048
Metadata-eligible corpus	12,587	9,140
Topic-model corpus with abstracts	12,274	313

Record flow and analytical corpus

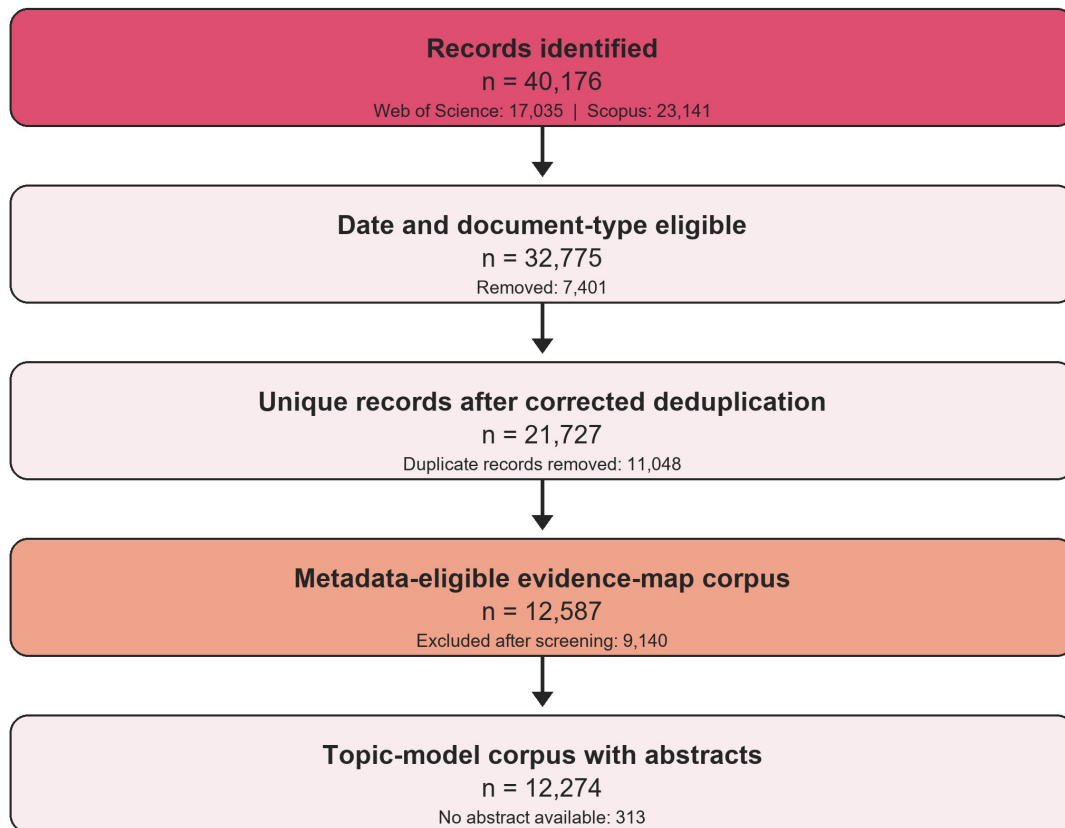


Figure 1. Primary-search identification, filtering, deduplication, metadata screening, and topic-model inclusion.

Annual output of metadata-eligible records, 2016–2025

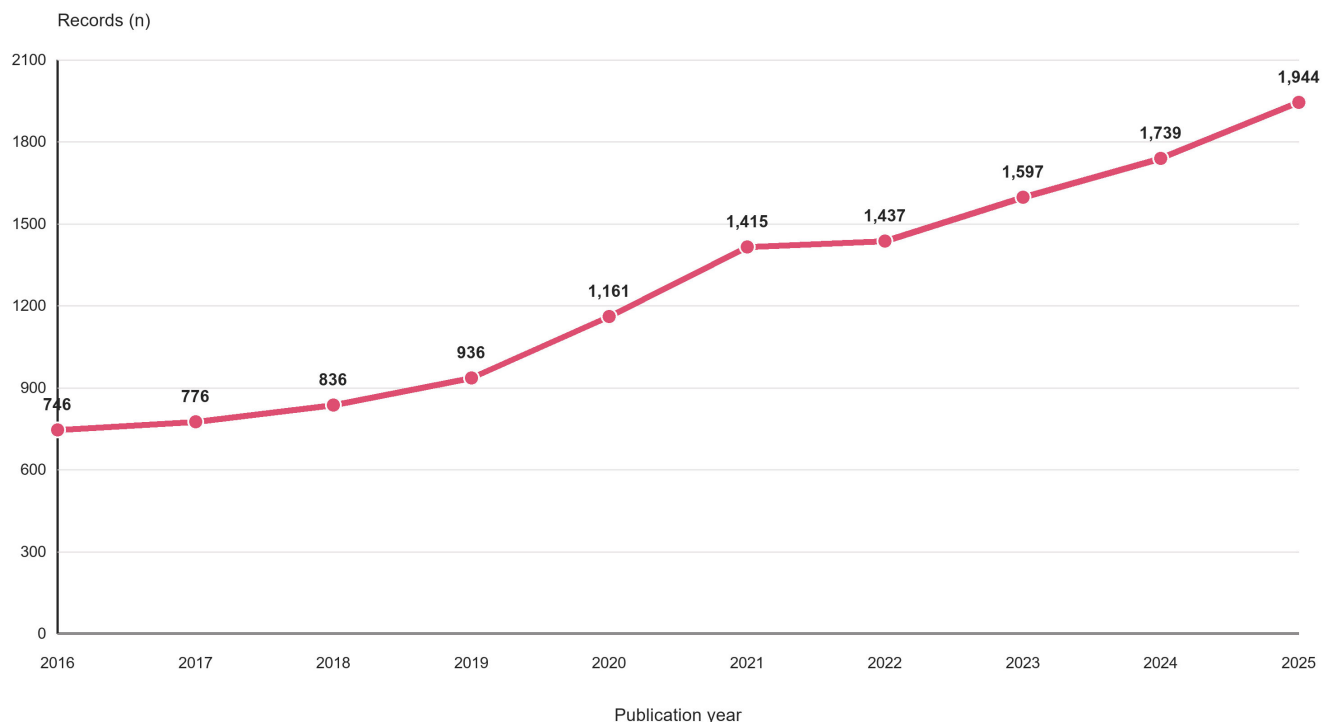


Figure 2. Annual output of the primary metadata-eligible corpus from 2016 to 2025.

Distribution of robot-enabled oncology application domains

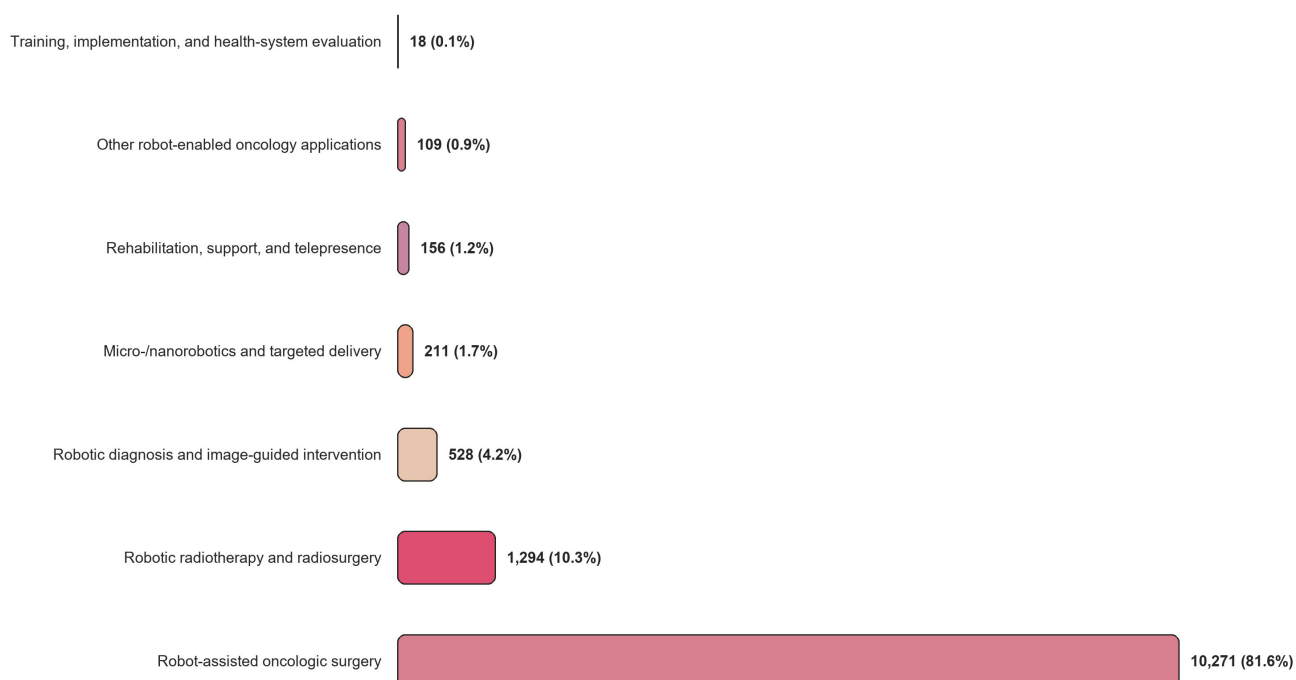


Figure 3. Distribution of robot-enabled oncology application domains.

Dominant-topic distribution in the ten-topic NMF solution

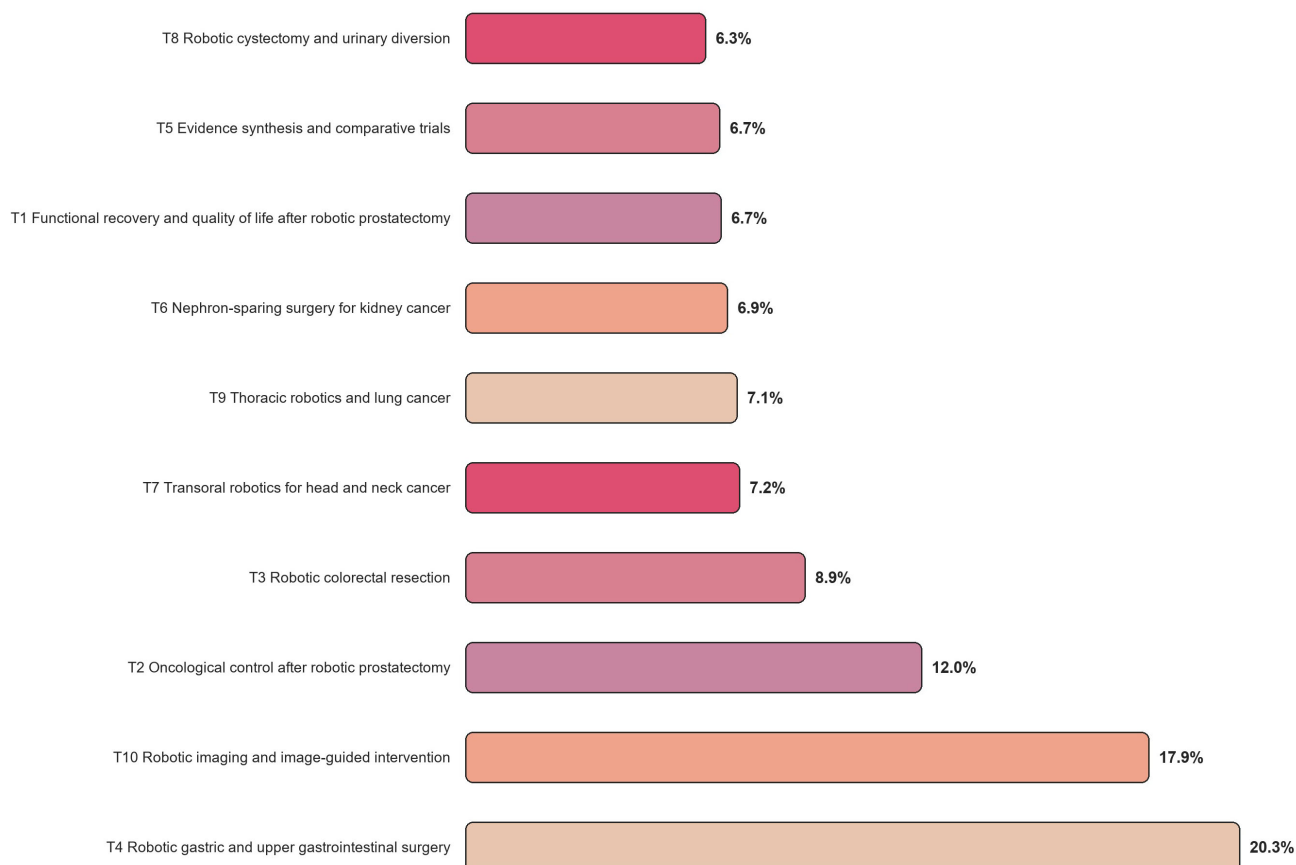


Figure 4. Mean prevalence of the ten topics identified by non-negative matrix factorization.

Evidence-design distribution across robotic application domains

	Observational	Prospective / interventional	Review / synthesis	Case / technical	Preclinical / engineering	Implementation / services	Other / unclear
Robot-assisted oncologic surgery	2,876	1,793	2,255	620	410	461	1,856
Robotic radiotherapy and radiosurgery	357	229	204	95	78	31	300
Robotic diagnosis and image-guided intervention	73	63	91	36	124	24	117
Micro-/nanorobotics and targeted delivery	3	3	53	0	78	6	68
Rehabilitation, support, and telepresence	36	41	28	8	8	8	27
Other robot-enabled oncology applications	11	9	17	1	23	1	47
Training, implementation, and health-system evaluation	2	1	2	0	3	10	0

Figure 5. Condensed evidence-design distribution across major robot-enabled oncology application groups.

Patient-centered metadata signals across robotic applications

a Domain-specific visibility (%)

	Quality of life and patient-reported outcomes	Psychological wellbeing	Functional and symptom outcomes	Acceptance, trust, and satisfaction	Autonomy and decision-making	Social participation and connection	Caregiver and family implications	Accessibility and equity	Ethics, privacy, and human-robot interaction
Robot-assisted oncologic surgery	6.6	1.2	12.8	1.5	0.3	0.0	0.0	0.4	0.1
Robotic radiotherapy and radiosurgery	11.7	2.6	18.4	1.1	1.1	0.0	0.0	0.5	0.2
Robotic diagnosis and image-guided intervention	2.1	3.0	8.7	2.1	0.4	0.0	0.0	0.0	0.4
Micro-/nanorobotics and targeted delivery	0.0	0.5	6.6	0.5	0.0	0.0	0.0	0.5	0.9
Rehabilitation, support, and telepresence	24.4	14.1	45.5	5.8	1.3	3.2	2.6	0.0	2.6

b Records with any patient-centered indicator

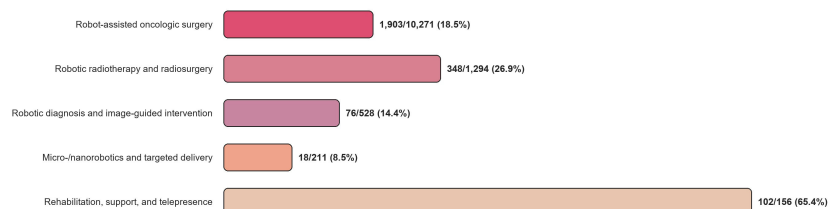


Figure 6. Patient-centered evidence signals across the primary cancer-robotics corpus.

Note. Panel a shows the percentage of records in each application domain containing each metadata-visible indicator. Panel b shows the proportion and count of records with at least one indicator. Categories are non-exclusive, and blank or zero-valued cells denote no explicit metadata signal under the coding rules rather than proof that the construct was absent from the full text.

3.3. Non-negative matrix factorization topic model

The topic model used 12,274 records with abstracts. Analytical text combined the title (repeated once), abstract, and author keywords. After Unicode normalization, lowercasing, stop-word and punctuation removal, and document-frequency filtering, models were evaluated with vocabularies of 600, 800, and 1,000 terms. TF-IDF weights were L2-normalized. The 800-term vocabulary was retained as a stable compromise between topic separation and computational sparsity; the psychosocial overlay was analyzed separately so that rare, substantively important terms were not required to form corpus-wide topics.

Topics were extracted by non-negative matrix factorization. Candidate values $k=6, 8, 10$, and 12 were assessed on the same 4,500-record sample across five initializations at each of three vocabulary sizes. Selection considered normalized reconstruction error, normalized pointwise mutual information coherence, topic diversity, cross-seed stability, and interpretability. At 800 terms, $k=10$ yielded error 0.905962, coherence 0.343925, diversity 0.893333, and stability 0.884345; $k=12$ reduced error to 0.899405 but had lower diversity (0.857778) and stability (0.841669). The ten-topic model was therefore retained and refitted to the full corpus for 100 multiplicative-update iterations with seed 20260823.

Each record was assigned to the topic with the highest document-level weight. The final normalized reconstruction error fell from 0.935444 at iteration 10 to 0.908301 at iteration 100; matched-topic stability between the 30- and 100-iteration solutions was 0.967784, supporting convergence. Annual shares were calculated within modeled publication year. Annual topic counts and shares are reported in Supplementary Table S5, candidate topic-number diagnostics and final NMF fit in Supplementary Table S6, and complete topic terms and weights in Supplementary Table S10.

3.4. Evidence mapping and patient-centered overlay

3.4.1. Multidimensional coding

Three mutually exclusive structured dimensions retained infrequent technologies that the global topic model could obscure: application domain, cancer site, and study design. Application domains were defined by the robot's task and position in the care pathway, not by a single device name. Design labels were descriptive categories only. The residual other/unclear design category was retained explicitly; no human-reference accuracy estimate is claimed for these metadata-derived design labels.

3.4.2. Patient-centered and psychosocial overlay

A prespecified multi-label overlay was applied to all 12,587 primary-search eligible records. Nine domains were selected to distinguish functional/symptom, patient-reported quality-of-life, psychological, behavioral/acceptance, autonomy/decision, social, caregiver/family, accessibility/equity, and ethical/privacy/human-robot interaction constructs. The psychological lexicon explicitly included distress, anxiety, depression, fear, body image, uncertainty, adjustment, stigma, loneliness, and decisional regret. Domain-specific positive phrases, exclusions, and context rules are listed in Supplementary Table S9. Labels were non-exclusive because one record can legitimately address several dimensions.

The overlay measured explicit metadata visibility, not primary-outcome status, validated measurement, effect direction, or benefit. The composite 'any patient-centered indicator' was a coverage flag rather than a psychometric scale or homogeneous outcome. Domain-specific counts are descriptive lexical signals from the primary corpus. No human-reference false-positive or false-negative estimates are

asserted for the nine domains, and the very small social and caregiver categories are interpreted as context-dependent signals rather than validated prevalence.

3.4.3. Cross-dimensional mapping

Application domain was cross-classified with study design to form an application-by-design distribution, not an evidence-maturity or quality scale. The patient-centered labels were overlaid on applications and years. Counts represent indexed research attention; they do not establish risk of bias, comparative effectiveness, clinical readiness, or psychosocial benefit.

Primary application and design codes were mutually exclusive, whereas patient-centered labels were non-exclusive. Multiple-cancer and unspecified/pan-cancer categories were retained for arithmetic closure. The complete seven-domain by seven-design matrix is presented in main-text **Table 6**; detailed precedence rules and prespecified audit-sampling materials are provided in the Supplementary Materials. These materials document an intended validation design and do not constitute completed human-reference validation.

4. Results and discussion

4.1. Development and distribution across cancer care

4.1.1. Temporal distribution

Figure 2 shows sustained expansion in the primary metadata-eligible corpus of 12,587 records: 10,560 Articles (83.9%) and 2,027 Reviews (16.1%). Annual output increased from 746 in 2016 to 1,944 in 2025, a cumulative increase of 160.6% and a compound annual growth rate of approximately 11.2%. The figure is descriptive and does not imply parallel growth or quality across robotic pathways.

The 87 concordantly included records from the expanded-search sample comprised 76 Articles and 11 Reviews, with 85 abstracts available. They span 2016–2025. Because they were identified through a sampled audit of E-only records, their annual pattern is not interpreted as the output trend of the full expanded search.

4.1.2. Distribution by application domain

Table 3 reports application counts and **Figure 3** shows their concentration. Robot-assisted oncologic surgery accounted for 10,271 records (81.6%), followed by robotic radiotherapy/radiosurgery (1,294; 10.3%) and diagnosis/image-guided intervention (528; 4.2%). Micro/nanorobotics (211; 1.7%) and rehabilitation, support, and telepresence (156; 1.2%) remained in the quantitative long tail.

Table 3. Distribution of robot-enabled oncology application domains.

Application domain	Records (n)	Share (%)
Robot-assisted oncologic surgery	10,271	81.6
Robotic radiotherapy and radiosurgery	1,294	10.3
Robotic diagnosis and image-guided intervention	528	4.2
Micro-/nanorobotics and targeted delivery	211	1.7
Rehabilitation, support, and telepresence	156	1.2
Other robot-enabled oncology applications	109	0.9
Training, implementation, and health-system evaluation	18	0.1

4.1.3. Distribution by cancer site

Studies covering multiple cancers or anatomical sites accounted for 3,197 records (25.4%). Among single-site categories, prostate cancer was most common (1,912; 15.2%), followed by colorectal (1,588; 12.6%), kidney/urinary tract (1,441; 11.4%), lung/thoracic (961; 7.6%), gynecologic (775; 6.2%), head and neck (726; 5.8%), hepatobiliary/pancreatic (631; 5.0%), and upper gastrointestinal cancer (602; 4.8%). The remaining categories each represented 4.0% or less, showing that indexed robotic research was concentrated in selected procedural specialties.

4.1.4. Distribution by evidence design

Observational comparative or cohort studies were the largest design category (3,358; 26.7%), followed by reviews/evidence syntheses (2,650; 21.1%), other/unclear primary studies (2,415; 19.2%), and randomized or prospective interventional studies (2,139; 17.0%). Case/technical reports (760; 6.0%), preclinical/engineering studies (724; 5.8%), and implementation/training/health-services studies (541; 4.3%) completed the distribution. These are design counts, not a study-quality hierarchy.

Table 4 summarizes all seven design categories. The 2,415 other/unclear records remain visible rather than omitted. Main-text **Table 6** gives the complete seven-domain by seven-design matrix, including the residual application and design categories. No human-reference coding accuracy is claimed for the residual design category.

Table 4. Distribution of evidence designs.

Evidence design	Records (n)	Share (%)
Observational comparative or cohort study	3,358	26.7
Review and evidence synthesis	2,650	21.1
Other/unclear primary study	2,415	19.2
Randomized or prospective interventional study	2,139	17.0
Case report, case series, or technical report	760	6.0
Preclinical, engineering, or feasibility study	724	5.8
Implementation, training, or health-services study	541	4.3

Taken together, **Figures 2 and 3** and **Tables 3 and 4** show that the literature expanded steadily from 2016 to 2025, but this growth was driven largely by robot-assisted oncologic surgery. Research was concentrated in prostate, colorectal, renal, and urinary tract cancers, with observational studies and evidence syntheses forming substantial shares. Increasing volume therefore reflects wider research attention rather than synchronized maturation across technological routes.

4.2. Thematic structure and psychosocial visibility

4.2.1. Topic overview

Table 5 presents the interpretive label, number of dominant-topic records, and mean prevalence of each topic in the ten-topic NMF solution.

Table 5. Concise summary of the ten-topic NMF solution.

Topic	Interpretive label	Dominant n	Dominant share (%)
T1	Functional recovery and quality of life after robotic prostatectomy	824	6.7

Continuation Table:

Topic	Interpretive label	Dominant n	Dominant share (%)
T2	Oncological control after robotic prostatectomy	1,468	12.0
T3	Robotic colorectal resection	1,094	8.9
T4	Robotic gastric and upper gastrointestinal surgery	2,491	20.3
T5	Evidence synthesis and comparative trials	820	6.7
T6	Nephron-sparing surgery for kidney cancer	845	6.9
T7	Transoral robotics for head and neck cancer	884	7.2
T8	Robotic cystectomy and urinary diversion	774	6.3
T9	Thoracic robotics and lung cancer	875	7.1
T10	Robotic imaging and image-guided intervention	2,199	17.9

The revised ten-topic solution remained organized by cancer site, procedure, and conventional outcome language. The largest dominant-topic groups were gastric/upper gastrointestinal and perioperative surgery (2,491; 20.3%) and robotic imaging/image-guided intervention (2,199; 17.9%), followed by oncological control after robotic prostatectomy (1,468; 12.0%). Functional recovery after prostatectomy formed a distinct topic (824; 6.7%), but no global topic centered on psychological adjustment, social connection, caregiver experience, autonomy, or equity. **Figure 4** displays dominant-topic shares; **Table 5** reports all counts and labels.

Highest-weight terms supported the labels: the functional prostatectomy topic emphasized continence, urinary recovery, erectile function, and quality of life; the oncologic prostatectomy topic emphasized biochemical recurrence and prostate-specific antigen; and site-specific topics were anchored by colorectal, renal, bladder, head-and-neck, and thoracic vocabulary. A cross-cutting evidence-synthesis topic was dominated by meta-analysis, systematic review, randomized trial, and database-search terms. The broader imaging/intervention topic contained generic system, imaging, guidance, tissue, and accuracy language. Complete term weights are reported in Supplementary Table S10 so that label interpretation can be independently inspected.

4.2.2. Correspondence between application domains and topics

Most high-frequency topics were contributed by robot-assisted surgery. Radiotherapy records were dispersed across head and neck, lung, and comparative-effectiveness topics, while diagnostic records appeared chiefly in the lung and thoracic topic. Micro/nanorobotics and supportive robotics were too small to form stable corpus-wide topics. More importantly for RQ2, no independent topic was organized primarily around psychological wellbeing, acceptance, social participation, caregiver experience, or equity. This does not show that these concerns were absent from all studies; it shows that their vocabulary did not organize the dominant knowledge structure of a surgically weighted field.

4.2.3. Temporal dynamics

The revised topic model included 730 records from 2016 and 1,892 from 2025. Annual topic shares varied, but interpretation is restricted to descriptive redistribution of indexed attention; full annual counts and shares are reported in Supplementary Table S5. Because topic solutions are conditional on vocabulary and initialization,

the multi-seed sensitivity results are presented alongside rather than treating one trajectory as uniquely true.

Absolute counts and relative shares answer different questions: a topic can gain records while losing corpus share. We therefore moved the complete annual topic matrix to Supplementary Table S5 and retained only the central pattern in the main text, reducing overlap among text, **Table 5**, and **Figure 4**.

Together, **Table 5** and **Figure 4** show that high-frequency themes were clinical and procedural; the absence of a dominant psychosocial topic reflects limited corpus-wide semantic prominence, not proof that psychosocial outcomes were absent from full texts.

4.3. Patient-centered evidence, study-design distribution, and translational gaps

4.3.1. Overall evidence structure

Table 6 presents the complete application-by-design distribution; **Figure 5** visualizes the major application groups. Robot-assisted surgery contributed records across every design category, while micro/nanorobotics was concentrated in preclinical/engineering, review, and residual primary-study categories. Supportive robotics included observational, prospective, feasibility, implementation, and review designs despite its small size. These patterns describe how evidence is distributed; they do not establish risk of bias, comparative effectiveness, or clinical readiness.

Table 6. Complete evidence-design matrix across robot-enabled oncology application domains.

Application domain	Obs.	Pros.	Review	Case/tech.	Preclin.	Implement.	Other/unclear	Total
Robot-assisted oncologic surgery	2,876	1,793	2,255	620	410	461	1,856	10,271
Robotic radiotherapy and radiosurgery	357	229	204	95	78	31	300	1,294
Robotic diagnosis and image-guided intervention	73	63	91	36	124	24	117	528
Micro-/nanorobotics and targeted delivery	3	3	53	0	78	6	68	211
Rehabilitation, support, and telepresence	36	41	28	8	8	8	27	156
Other robot-enabled oncology applications	11	9	17	1	23	1	47	109
Training, implementation, and health-system evaluation	2	1	2	0	3	10	0	18
Total	3,358	2,139	2,650	760	724	541	2,415	12,587

Note. The matrix includes all seven application domains and seven evidence-design categories, including the other/unclear column and both residual application categories. Its row totals equal the application totals in **Table 3**, and its column totals equal the design totals in **Table 4**; the grand total is 12,587 primary-corpus records. **Figure 5** provides a condensed visualization of the major application groups. Supplementary Table S7 repeats the complete matrix for auditability.

Robot-assisted surgery included 2,876 observational studies, 1,793 prospective

studies, 2,255 reviews, and 1,856 other/unclear primary studies. Micro/nanorobotics included 78 preclinical/engineering studies, 53 reviews, and 68 residual studies; supportive robotics included 36 observational, 41 prospective, 28 reviews, and 27 residual studies. Retaining the residual column prevents the more interpretable categories from overstating classification coverage.

4.3.2 Patient-Centered and Psychosocial Evidence

Across the primary analytic corpus, 2,462 of 12,587 records (19.6%) contained at least one metadata-visible patient-centered indicator. Functional and symptom outcomes were most frequent (1,690; 13.4%), followed by quality of life/patient-reported outcomes (883; 7.0%), psychological wellbeing (201; 1.6%), and acceptance/trust/satisfaction (196; 1.6%). Accessibility/equity appeared in 50 records (0.4%), autonomy/decision-making in 48 (0.4%), ethics/privacy/human–robot interaction in 28 (0.2%), social participation in 6 (<0.1%), and caregiver/family implications in 4 (<0.1%). **Table 7** separates these heterogeneous domains; the composite row is only a coverage indicator.

Table 7. Metadata-visible patient-centered and psychosocial indicators in the primary corpus.

Patient-centered or psychosocial domain	Records, n	Corpus share, %
Quality of life and patient-reported outcomes	883	7.0
Psychological wellbeing	201	1.6
Functional and symptom outcomes	1,690	13.4
Acceptance, trust, and satisfaction	196	1.6
Autonomy and decision-making	48	0.4
Social participation and connection	6	<0.1
Caregiver and family implications	4	<0.1
Accessibility and equity	50	0.4
Ethics, privacy, and human-robot interaction	28	0.2
Any patient-centered indicator	2,462	19.6

Note. Categories are non-exclusive and were coded from titles, abstracts, author keywords, and index keywords. Counts indicate explicit metadata visibility, not confirmation that an outcome was a primary endpoint or that a favorable effect was observed.

Patient-centered density and absolute volume differed by application. Rehabilitation, support, and telepresence had the highest within-domain proportion (102/156; 65.4%), followed by radiotherapy/radiosurgery (348/1,294; 26.9%), surgery (1,903/10,271; 18.5%), diagnosis/image guidance (76/528; 14.4%), and micro/nanorobotics (18/211; 8.5%). Surgery nevertheless contributed 77.3% of all indicator-positive records because of its much larger denominator. **Figure 6** displays domain-specific percentages and the any-indicator coverage flag separately.

The annual any-indicator proportion fluctuated between 19.2% and 21.0%, from 19.7% in 2016 to 19.8% in 2025. Logistic regression found no linear temporal change (odds ratio per year 0.998, 95% CI 0.982–1.014; $p=0.778$). This null trend concerns lexical visibility and may also reflect changes in abstract conventions and indexing rather than stable measurement practice.

4.3.3. Evidence pathways and structural gaps

The combined map revealed four structural gaps. Surgical research dominated both volume and absolute patient-centered signals, but those signals were concentrated in function and quality of life. Disease-site coverage was uneven. Micro/nanorobotics remained largely preclinical. Supportive robotics was the most patient-centered proportionally, yet its small and context-specific literature limited conclusions about sustained engagement, caregiver work, access, and effectiveness. These are gaps in the indexed evidence structure, not demonstrations that the corresponding outcomes were absent from individual full texts.

Read together, **Tables 6–7** and **Figures 5–6** distinguish study-design distribution from patient-centered visibility. A broad range of study designs does not guarantee attention to psychosocial experience, and a high proportion of patient-centered terms does not establish effectiveness or quality. This distinction is central to interpreting the large surgical corpus and the small supportive-robotics literature on comparable conceptual footing.

5. Discussion

5.1. Growth, distribution, and patient-care relevance (RQ1)

From 2016 to 2025, cancer-robotics publication volume grew substantially while the annual coverage of patient-centered metadata signals remained statistically unchanged. Studying the complete robotics corpus is appropriate for psycho-oncology because it supplies the denominator needed to determine whether psychological and social concerns keep pace with technological growth. The result is not a claim that four-fifths of papers should be psychosocial; it shows which patient-facing constructs become visible when the entire innovation landscape is mapped.

The concentration identified by RQ1 has two implications. Mature platforms more readily generate cohorts, procedural comparisons, and long-term outcomes, creating a cumulative evidentiary advantage. Conversely, infrequent supportive applications may reflect limited investment rather than limited relevance. Priority setting should consider cancer burden and procedural need, but also whether an application addresses isolation, functional dependence, treatment distress, or barriers to participation. These needs are not secondary merely because their literature is small.

Database provenance adds a further qualification to RQ1. Only 50.7% of the deduplicated records were represented in both databases, while 34.9% were unique to Scopus and 14.3% to Web of Science. Dual-database retrieval therefore materially broadened coverage. At the same time, the observed distribution remains conditional on the indexing practices and document-type conventions of these sources. The concentration of the corpus should be interpreted as the structure of indexed research attention, not as a complete census of every robotic oncology project or clinical program.

5.2. Dominant themes and the invisibility of psychosocial concerns (RQ2)

The robust topic solution remained organized by site, procedure, technical task, and conventional outcomes. No dominant topic centered on distress, trust, autonomy, social connection, caregiver experience, or equity. Corpus imbalance is one explanation: surgical abstracts are numerous and use stable specialty terminology, whereas psychosocial outcomes may be secondary, reported only in full text, or expressed with heterogeneous language. The finding should therefore be read as

limited semantic prominence in indexed metadata rather than absence of psycho-oncological inquiry.

Prostatectomy research demonstrates why functional and psychosocial outcomes must remain conceptually distinct yet clinically connected. Continence and sexual function are functional outcomes; quality of life is patient reported; satisfaction and trust are experiential; anxiety, adjustment, and regret are psychological or decisional. Combining them into one effect would be invalid. The multi-label overlay instead uses the any-indicator flag only to summarize coverage, while all substantive interpretation remains domain specific.

The topic solution also clarifies why keyword frequency alone is insufficient. Several high-weight terms were outcome-specific, including biochemical recurrence, continence, lymph-node dissection, conversion, and propensity matching. The model therefore captured how investigators framed clinical problems, not simply which platform names appeared most often. However, corpus imbalance remained influential: a global model optimized on the complete literature favored the vocabulary of surgical specialties. The evidence map was essential for recovering smaller routes whose internal structure could not dominate the corpus-wide factorization.

5.3. Patient experience in clinical-scale robotics (RQ3)

Within the 2,462 indicator-positive records, function/symptoms and quality of life dominated; psychological wellbeing appeared in 201 records and acceptance/trust/satisfaction in 196. These distributions suggest that patient-centered surgical evaluation is most often framed through recovery, while adjustment, expectations, treatment choice, and clinician–patient interaction remain less visible. Randomized prostatectomy and cystectomy trials also caution that platform comparisons should not be generalized beyond the outcomes and follow-up actually assessed.

Upper gastrointestinal and thoracic surgery further show that robotic value often resides in a specific task within a confined anatomical space. Esophagectomy studies consider pulmonary complications, recurrent laryngeal nerve injury, and lymph-node dissection, but platform, anastomotic technique, and learning stage add heterogeneity [14,18,51]. Future studies should use the platform–task–operator–patient relation as the unit of interpretation, stating which step is altered, whether the effect depends on experience, and whether it improves outcomes that matter to patients.

The same logic applies to diagnosis and radiotherapy. Lesion access, navigation stability, and dose conformity are necessary technical endpoints, but patients encounter uncertainty, discomfort, waiting, repeat procedures, toxicity, and decisions that follow from the result. A comparison of transoral robotic surgery and radiotherapy showed that swallowing and quality of life can differentiate treatment experience even when oncologic questions remain central [3]. Future evaluations should connect device accuracy with communication, decisional conflict, patient-reported symptoms, repeat procedures, and subsequent treatment choices.

5.4. Supportive, rehabilitation, and emerging robotics

Micro/nanorobotics and supportive robotics face distinct translational constraints. As summarized in **Figure 7**, the left pathway maps control, manufacturing, safety, and regulatory gaps in micro/nanorobotics, whereas the right pathway maps implementation, accessibility, autonomy, caregiver, and sustained-engagement challenges in supportive robotics. The pathways remain separate because their objects of validation and plausible harms differ.

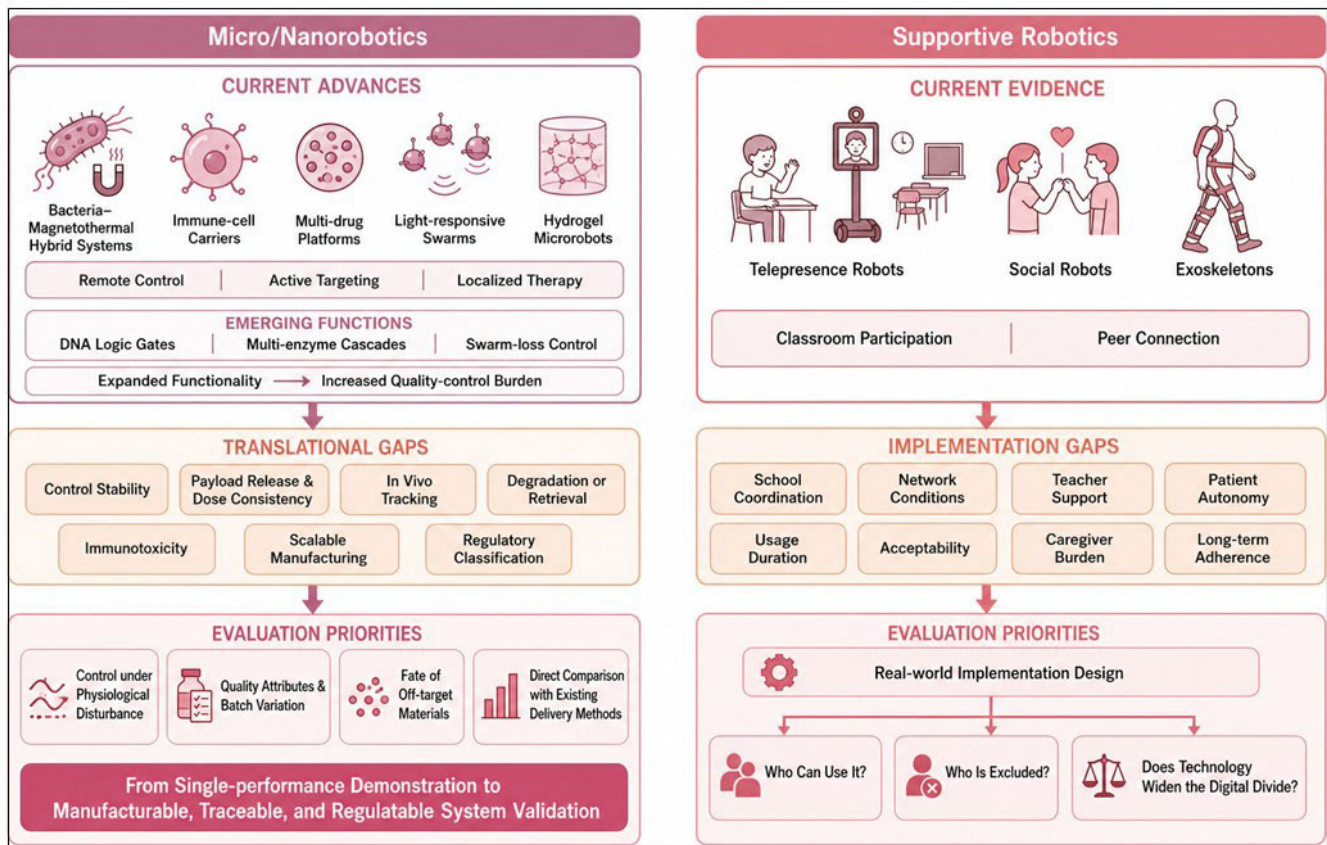


Figure 7. Translational gaps and evaluation priorities of emerging robotics in cancer research.

Note. The left pathway summarizes the technological advances, translational gaps, and evaluation priorities of micro/nanorobotics. The right pathway presents the observed roles, implementation gaps, and evaluation priorities of supportive robotics. Arrows indicate the organizational flow of the framework, not causal relationships or sequential stages of clinical maturity.

Micro/nanorobotics research has produced diverse actuation and payload designs. Bacteria–magnetothermal hybrid systems, immune-cell carriers, multi-drug platforms, light-responsive swarms, and hydrogel microrobots have demonstrated remote control, active targeting, or localized therapy [32–35,37]. Most studies, however, compare motion or tumor inhibition in cellular, ex vivo, or animal models. Clinical translation requires progress across a connected set of thresholds: control stability in complex biological fluids, payload release and dose consistency, in vivo tracking, degradation or retrieval, immunotoxicity, scalable manufacturing, and regulatory classification. Recent DNA logic gates, multi-enzyme cascades, and swarm-loss control have expanded functionality [38,39,41], while also increasing the quality-control burden.

Progress in micro/nanorobotics should not be judged by the number of animal experiments. More informative milestones are control under physiological disturbance, explicit quality attributes and batch variation, the fate of off-target materials, and direct comparison with existing delivery methods. The concentration of preclinical studies does not diminish the field’s potential; it calls for a shift from single-performance demonstrations to manufacturable, traceable, and regulatable system validation.

Supportive robotics faces relational and implementation challenges. The lexical rules identified six social-participation and four caregiver/family signals in

the primary corpus. These include telepresence for classroom and peer connection during pediatric cancer treatment and social-robot education about nutrition, catheter care, sleep hygiene, and privacy within a pediatric care network. Two other social hits arose from broader social-function or reintegration language and may be false positives. These small metadata counts are descriptive signals, not validated estimates of psychosocial intervention effects.

5.5. Human-centered evaluation, ethics, and equity

This review combines unsupervised topic discovery with conceptually structured mapping. The nine domains align with different psycho-oncological functions: functional/symptom status; patient-reported quality of life; emotional adjustment; acceptance and trust; autonomy and decisions; social participation; caregiver/family effects; accessibility/equity; and ethics/privacy. Human-centered evaluation should select from these domains according to the robot–task–patient relationship rather than applying one universal endpoint set.

Robotic risk should be stratified by application scale and patient relationship. Clinical platforms raise questions about learning curves, failure management, cost, expectation inflation, and unequal institutional access. Documented socioeconomic, rural, racial, and insurance-based inequities in access to robotic surgery show that innovation may reproduce existing differences in care rather than automatically reduce them [52]. Ethical analysis of robotic prostatectomy similarly cautions that innovation should be judged through fair allocation and evidence, not technological enthusiasm alone [53]. Micro/nano systems add uncertainty about material fate and long-term biosafety, while supportive robotics adds privacy, child assent, surveillance, and the possibility that mediated contact replaces rather than augments human support [54]. Combined with the above viewpoints, this is consistent with the opinion that In the future, AI technologies, multimodal intelligent interaction, personalized health management, and cross-disciplinary collaborative innovation may become the key driving forces for the continuous development of this field, [55].

A stage-matched but human-centered research agenda follows from RQ3. Surgical studies should prespecify patient-reported outcome and experience measures, psychological adjustment, decision quality, and recovery expectations alongside oncologic and perioperative endpoints. Diagnostic and radiotherapy studies should connect accuracy with distress, communication, repeat procedures, and downstream decisions.

Micro/nanorobotics requires reproducible manufacturing, biodistribution, retrieval, and toxicity criteria, together with early attention to consent under uncertainty and future affordability.

Supportive robotics requires pragmatic implementation studies that report who is eligible, who declines, who lacks infrastructure, whether caregivers assume additional work, and whether benefits persist after novelty fades. Robotics research now extends from acute injury repair to longer-term functional reconstruction, although the link between technical performance and clinically meaningful benefit remains incompletely tested [56]. Similar views have also been verified in research.

6. Conclusions and limitations

6.1. Conclusions

The primary-corpus analysis in this metadata-based evidence map reframed cancer robotics as a patient-care field. RQ1 showed rapid but surgically concentrated

growth. RQ2 showed that dominant themes were clinical and procedural, with no independent psychosocial topic. RQ3 identified patient-centered signals in 2,462 records (19.6%), primarily function/symptoms and quality of life, while psychological, decisional, social, caregiver, equity, and ethical domains were far less visible. The annual coverage proportion did not change significantly. Future research should evaluate robotic systems through pathway-appropriate clinical, experiential, relational, and justice-oriented outcomes.

6.2. Limitations

The primary search used the broad robot* root but a narrow cancer term. The expanded-search E audit identified 8,161 records not matched to the primary deduplicated set, demonstrating that the original strategy did not capture every potentially relevant record. Only 620 E-only records were sampled, and 87 concordant inclusions were added to the audit-based inventory. The other E-only records were not exhaustively adjudicated. Consequently, the 12,674-record audit-based inventory is neither a complete nor a representative expanded-search corpus; quantitative trends, topic modeling, and overlay proportions are restricted to the explicitly labeled 12,587-record primary corpus. The 313 primary records without abstracts did not enter the topic model. Abstract limits, indexing practices, specialty terminology, and outcomes reported only in full texts can reduce lexical visibility.

No human-reference sensitivity, specificity, accuracy, or inter-rater reliability estimate is reported for screening, duplicate decisions, study-design coding, or the patient-centered lexical overlay. The domain and design labels are descriptive metadata signals, not validated measures of study quality or clinical effectiveness. NMF results depend on vocabulary, topic number, initialization, and corpus composition, although the reported multi-seed and vocabulary checks support the selected solution for the primary corpus. This map did not pool treatment effects, assess risk of bias, distinguish validated from unvalidated patient-reported measures, or establish whether robots supplement or displace human care. Focused full-text reviews remain necessary.

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Data availability statement: Analytic scripts, coding dictionaries, aggregate outputs, software information, and permitted identifiers are provided in the separate supplementary file “Reproducibility_archive_PO-6468.zip.” Primary-corpus aggregate data and analytical specifications are also reported in the article and Supplementary Materials. Record-level Web of Science and Scopus exports are not redistributed because of database licensing restrictions. No public repository DOI is

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Supplementary Materials

Robotics in Cancer Care: A Systematic Evidence Map of Clinical Applications, Patient-Centered Evidence, and Psychosocial Gaps

This file reports the reproducibility details and extended tables for the 12,587-record primary analytic corpus. A separate expanded-search diagnostic sample contributed 87 concordant inclusions, yielding a 12,674-record audit-based inventory. Because only 620 of the 8,161 unmatched records were assessed, this inventory is neither a completely screened expanded corpus nor a representative estimate of all unmatched records. Primary topic, design, and psychosocial tables were not recomputed on the audit-based inventory.

Supplementary Methods

Supplementary Method S1. Data ingestion and cross-database harmonization

Twenty BibTeX export files were parsed: 18 sequential Web of Science files and two Scopus exports. Each record retained its citation key, source file, and source database. Text fields were Unicode-normalized, whitespace was collapsed, and terminal punctuation was removed from DOI strings. DOI values were converted to lowercase and stripped of URL or DOI prefixes. Titles and first-author surnames were normalized by lowercasing, removing diacritics and punctuation, and collapsing spaces. The original fields remained available for audit, while normalized values were used only for filtering and linkage.

Expanded-search E audit: The September 18, 2026 exports contained 26,167 Web of Science and 32,606 Scopus records. Year and Article/Review restrictions left 46,565 records; within-E deduplication retained 29,874. Of these, 8,161 were not matched to the primary deduplicated corpus. A 620-record sample comprised 500 simple-random and 120 targeted records. The 87 records marked Include by both assessors were added to the primary set to form the audit-based inventory. The unsampled E-only records and non-concordant sample decisions were not counted as confirmed exclusions. The inventory is not representative of all unmatched records, and no sample-based screening performance estimate is reported.

Supplementary Method S2. Deduplication and metadata screening audit

Deduplication used exact normalized DOI, exact normalized title plus first author and publication year, and Jaccard similarity ≥ 0.90 within first-author-year blocks. This corrected the initial title-author linkage that could merge recurring titles across years. The previously flagged 13-record group was not collapsed into one canonical record; it was separated into distinct publication-level records after comparison of year, DOI, journal, title, first author, and abstract. Only records satisfying the corrected duplicate criteria were merged. Stage-specific counts and prespecified audit-sampling materials are reported below.

Metadata screening required a robot-centered title or a robot-related author keyword accompanied by at least one robot-related abstract occurrence. Cancer relevance required an explicit malignant or oncologic term in the title, abstract, or author keywords. A cancer-specific procedure in the title combined with cancer indexing also satisfied eligibility. A benign-only title overrode weak indexed cancer leakage unless cancer was directly stated in the title, abstract, or author keywords. Robot-focus and cancer-focus scores were retained for audit but were not interpreted as evidence-quality scores.

Supplementary Method S3. Topic-model implementation

The modeled text concatenated the title twice, abstract, and author keywords. After lowercasing and removal of punctuation, stop words, tokens shorter than three characters, and ordinal numbers, candidate terms were required to occur in at least 15 documents and no more than 65% of the corpus. The 800 terms with the highest global frequency-weighted inverse-document-frequency ranking formed the vocabulary. Log-scaled term frequency and smoothed inverse document frequency were applied, followed by document-level L2 normalization.

Candidate NMF solutions used the same 4,500-record sample across $k=6, 8, 10$, and 12 ; vocabularies of 600, 800, and 1,000 terms; five initializations per condition; and 100 maximum iterations. Diagnostics included normalized reconstruction error, NPMI coherence, topic diversity, and matched-topic stability. The selected $k=10$, 800-term model

was refitted to all 12,274 records for 100 iterations with seed 20260823.

Supplementary Method S4. Evidence-map coding precedence

Application-domain coding followed a fixed precedence to prevent multiple assignment: micro/nanorobotics; radiotherapy or radiosurgery; rehabilitation, social robotics, exoskeletons, or telepresence; diagnostic and image-guided intervention; surgery; secondary diagnostic indicators; training and implementation; and other robot-enabled oncology applications. Cancer-site labels were assigned from site-specific terms. Records matching more than one site entered the multiple-cancer category, and records without a site signal entered the unspecified or pan-cancer category.

Evidence design was assigned in the following order: review or evidence synthesis; randomized or prospective interventional study; observational comparative or cohort study; case or technical report; preclinical, engineering, or feasibility study; implementation, training, or health-services study; and other or unclear primary study. Each record received one application domain, one cancer-site category, and one evidence-design category. These labels support corpus-level evidence mapping and do not replace full-text study appraisal.

Supplementary Tables

Supplementary Table S1. Complete database search strategies and retrieval settings

Database	Search field	Search expression	Limits applied	Records
Web of Science Core Collection	Topic (TS)	TS=(“robot-assisted” OR “robot assisted” OR robotic OR robot*) AND TS=(cancer)	Retrieved 23 August 2026; 2016-2025; Article or Review retained after export	17,035
Scopus	TITLE-ABS-KEY	TITLE-ABS-KEY(“robot-assisted” OR “robot assisted” OR robotic OR robot*) AND TITLE-ABS-KEY(cancer)	Retrieved 23 August 2026; 2016-2025; Article or Review retained after export	23,141

Note. The raw combined retrieval contained 40,176 records. Year and document-type restrictions were applied during reproducible preprocessing, yielding 32,775 records eligible for deduplication.

Supplementary Table S2. Cross-database field mapping and normalization rules

Analytical field	Web of Science BibTeX	Scopus BibTeX	Harmonized treatment
Record identifier	BibTeX citation key	BibTeX citation key	Retained as entry_id; all merged identifiers retained
Source provenance	Sequential export filename	export_* filename or source=Scopus	Mapped to source_database and source_file
Document type	type or entry type	type or entry type	Mapped to Article or Review; other types excluded
Publication year	year	year	First four-digit year parsed; retained only if 2016-2025
Title	title	title	Original retained; normalized lowercase ASCII form used for linkage
Authors	author	author	Original retained; normalized first-author surname used for linkage
Source title	journal	journal	Retained as journal without inferential recoding
DOI	doi	doi	Lowercase; URL/DOI prefixes and terminal punctuation removed
Abstract	abstract	abstract	Whitespace normalized; presence recorded before screening and modeling
Keywords	author_keywords, keywords, keywords-plus when available	author_keywords and keywords when available	Retained separately and combined only for screening or modeling as prespecified
Affiliation	affiliation or affiliations	affiliation or affiliations	Retained for provenance; not used to determine eligibility

Supplementary Table S3. Aggregate deduplication and duplicate-group audit

Audit component	Metric	Records/groups (n)	Share (%)
Corpus	Records eligible before deduplication	32,775	100.0
DOI pass	Duplicate records removed	10,775	32.9
Exact title–author–year pass	Duplicate records removed	267	0.8
Fuzzy title pass	Duplicate records removed	6	<0.1
Corpus	Unique records retained	21,727	66.3
Corpus	Total duplicate records removed	11,048	33.7
13-record audit	Recurring records split after manual metadata inspection	13	Not merged

Note. Shares are calculated using the 32,775 records entering deduplication as the denominator; <0.1 indicates less than 0.1%. The previously flagged 13-record group was not retained as one canonical record. It was separated into distinct publication-level records, and only database copies meeting the corrected duplicate criteria were merged. This clarification does not alter the stage-specific counts or the final corpus size.

Supplementary Table S4. Metadata-screening outcomes and exclusion audit

Outcome	Operational reason	Records (n)	Share (%)	Retained audit fields
Screened	All unique records	21,727	100.0	decision; reason; scores; provenance
Included	Robot-centered cancer application	12,587	57.9	application; site; design
Excluded	All exclusion reasons	9,140	42.1	exclusion reason
Exclusion	Incidental/absent robotic focus	8,708	95.3 of exclusions	rule reason
Exclusion	No substantive cancer application	403	4.4 of exclusions	rule reason
Exclusion	Benign/non-oncologic indication	29	0.3 of exclusions	rule reason

Note. Percentages for individual exclusion reasons use 9,140 excluded records as the denominator. The inclusion share uses all 21,727 screened records. Screening was metadata-based and did not constitute independent dual-reviewer full-text assessment.

Supplementary Table S5. Annual dominant-topic distribution, 2016-2025

Year	Modeled n	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
2016	730	43	96	72	161	29	53	57	48	39	132
2017	766	51	112	70	127	46	40	82	42	46	150
2018	810	58	107	67	158	40	75	82	46	47	130
2019	911	66	120	73	183	70	67	65	57	66	144
2020	1,133	68	149	119	227	56	77	103	78	69	187
2021	1,380	99	161	125	281	85	87	102	120	95	225
2022	1,412	96	194	126	300	78	90	104	92	108	224
2023	1,563	104	168	126	321	124	120	100	85	136	279
2024	1,677	107	182	166	329	132	114	99	105	125	318
2025	1,892	132	179	150	404	160	122	90	101	144	410

Note. Panel A reports dominant-topic record counts. The modeled annual total differs from the metadata-eligible total when abstracts were unavailable.

Panel B. Annual dominant-topic share (%)

Year	Total	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
2016	100.0	5.9	13.2	9.9	22.1	4.0	7.3	7.8	6.6	5.3	18.1
2017	100.0	6.7	14.6	9.1	16.6	6.0	5.2	10.7	5.5	6.0	19.6
2018	100.0	7.2	13.2	8.3	19.5	4.9	9.3	10.1	5.7	5.8	16.0
2019	100.0	7.2	13.2	8.0	20.1	7.7	7.4	7.1	6.3	7.2	15.8
2020	100.0	6.0	13.2	10.5	20.0	4.9	6.8	9.1	6.9	6.1	16.5
2021	100.0	7.2	11.7	9.1	20.4	6.2	6.3	7.4	8.7	6.9	16.3
2022	100.0	6.8	13.7	8.9	21.2	5.5	6.4	7.4	6.5	7.6	15.9
2023	100.0	6.7	10.7	8.1	20.5	7.9	7.7	6.4	5.4	8.7	17.9
2024	100.0	6.4	10.9	9.9	19.6	7.9	6.8	5.9	6.3	7.5	19.0
2025	100.0	7.0	9.5	7.9	21.4	8.5	6.4	4.8	5.3	7.6	21.7

Note. Topic labels are defined in main-text Table 5. Shares were calculated within each modeled publication year and sum to 100%, subject to rounding.

Supplementary Table S6. Candidate topic-number diagnostics and final NMF fit

vocabulary_size	k	runs	error_mean	error_sd	npmi_mean	npmi_sd	diversity_mean	stability_mean	stability_min
600	6	5	0.9166313886642456	0.0006418461022883	0.3444917611729877	0.0141179397192328	0.9088888888888887	0.9042217433452606	0.8210253715515137
600	8	5	0.9046604871749878	0.000406084219626	0.3331471178035191	0.0090954982355925	0.8683333333333334	0.9249313473701476	0.8953531980514526
600	10	5	0.8948156356811523	0.000220430678669	0.3288370799908075	0.0040016844620772	0.8693333333333333	0.9487717151641846	0.8993110656738281
600	12	5	0.885857903957367	0.0005138306785754	0.3331169750809597	0.0074299377584395	0.8522222222222222	0.8758668452501297	0.837007999420166
800	6	5	0.925467598438263	0.0011817962865216	0.3433910008278666	0.0315349654132186	0.9177777777777777	0.8620670884847641	0.7921066284179688
800	8	5	0.9157204031944276	0.0009750845869252	0.3463893447634441	0.0204142594399765	0.9	0.9028485268354416	0.8362501263618469
800	10	5	0.9059624671936036	0.0002575669639156	0.3439253503939238	0.0085041774775063	0.8933333333333333	0.8843453526496887	0.8378177881240845
800	12	5	0.8994048357009887	0.0008187734134203	0.3461710113396813	0.0121273991070545	0.8577777777777778	0.8416694849729538	0.8023147583007812
1000	6	5	0.931125235557556	0.0002985379286489	0.3710635454965505	0.0303891878046316	0.9222222222222222	0.8757040053606033	0.8312316536903381
1000	8	5	0.9222585916519164	0.0004001395552312	0.3536746019449966	0.0077440603835174	0.9	0.9040541797876358	0.866035521030426
1000	10	5	0.9141435742378234	0.0005223582167421	0.341809357683512	0.0120052924434283	0.8800000000000001	0.9204892963171004	0.8674956560134888
1000	12	5	0.90680433511734	0.0003967054141227	0.3408571213248654	0.0121924829943058	0.8866666666666667	0.8572538793087006	0.8293415904045105

Note. Candidate errors were calculated on the same fixed 4,500-record sample. Error decreased as k increased, so the minimum was not treated as a sufficient selection criterion. The ten-topic solution balanced clinical interpretability, topic separation, cancer-site coherence, and granularity.

Supplementary Table S7. Complete application-domain by evidence-design matrix

Application domain	Obs.	Pros.	Review	Case/tech.	Preclin.	Implement.	Other/unclear	Total
Robot-assisted oncologic surgery	2,876	1,793	2,255	620	410	461	1,856	10,271
Robotic radiotherapy and radiosurgery	357	229	204	95	78	31	300	1,294
Robotic diagnosis and image-guided intervention	73	63	91	36	124	24	117	528
Micro-/nanorobotics and targeted delivery	3	3	53	0	78	6	68	211
Rehabilitation, support, and telepresence	36	41	28	8	8	8	27	156
Other robot-enabled oncology applications	11	9	17	1	23	1	47	109
Training, implementation, and health-system evaluation	2	1	2	0	3	10	0	18
Total	3,358	2,139	2,650	760	724	541	2,415	12,587

Note. Obs., observational comparative or cohort study; Pros., randomized or prospective interventional study; Case/tech., case report, case series, or technical report; Preclin., preclinical, engineering, or feasibility study; Implement., implementation, training, or health-services study. The grand total is 12,587 records. This supplementary table reproduces the complete seven-domain by seven-design matrix presented in main-text Table 6 for auditability.

Supplementary Table S8. Manual-validation sampling plan

Component	Sampling	Records/pairs	Planned output if completed
Screening	Simple random	500	Sensitivity, specificity, precision, NPV, accuracy, agreement
Screening error analysis	Targeted ambiguous	120	Boundary-error description
Deduplication: merged	Complex groups plus random size-2 groups	200 groups	Correct/incorrect merge
Deduplication: unmerged	Borderline plus lower-similarity pairs	200 pairs	Missed-duplicate rate
Patient-centered overlay	Positive and negative strata in all nine domains	786 judgments	Domain-specific classification performance
Evidence design	250 residual plus 30 per determinate category	430 records	Rule validity and residual-design profile

Note. This table documents a prespecified sampling plan only. It does not report completed human-reference validation or observed performance estimates.

Supplementary Table S9. Patient-centered domain definitions and core lexical coverage

Domain	Conceptual role	Included lexical families	Context/exclusion principle
Quality of life and patient-reported outcomes	Patient-reported quality of life and experience	<p>\bquality of life\b; \bhealth[-]related quality of life\b; \bhrqol\b; \bpatient[-]reported outcomes?\b; \bpatient[-]reported outcome measures?\b; \bproms?\b; \bpatient[-]reported experience measures?\b; \bpreds?\b; \beortc qlq(?:[-]?[a-z0-9]+)?\b; \bfunctional assessment of cancer therapy\b; \bepic[-]?26\b; \beq[-]?5d\b; \bsf[-]?(?:12 36)\b</p> <p>\bpsychological distress\b; \bemotional distress\b; \bdistress\b; \banxiety\b; \banxious\b; \bdepress(?:ion ive ed)?\b; \bfear of(?:cancer)?recurrence\b; \bfear\b; \bbody image\b; \buncertainty\b; \bpsychological adjustment\b; \bpsychosocial adjustment\b; \badjustment to(?:cancer illness treatment)\b; \bstigma\b; \bloneliness\b; \bpsychological outcomes?\b; \bpsychological functioning\b; \bemotional responses?\b; \bpsychological well[-]?being\b; \bemotional well[-]?being\b; \bmmental health\b; \bcoping\b; \bpost[-]traumatic stress\b; \bptsd\b; \bself[-]esteem\b</p>	<p>No additional domain-specific restriction in the executable overlay. Patterns were searched in available title, abstract, author-keyword, and index-keyword text.</p>
Psychological wellbeing	Emotional and psychological state	<p>\bpatient[-]reported pain\b; \bprocedural pain\b; \bsymptom burden\b; \burinary continence\b; \bincontinence\b; \berectile function\b; \bsexual function\b; \bswallow(?:ing)?\b; \bdysphagia\b; \bspeech function\b; \bbowel function\b; \bphysical function\b; \bfunctional recovery\b; \bcancer rehabilitation\b; \bsleep quality\b; \bsleep hygiene\b; \bfatigue\b; \bactivities of daily living\b; \bmobility\b; \bfunctional status\b</p>	<p>No additional domain-specific restriction in the executable overlay. Patterns were searched in available title, abstract, author-keyword, and index-keyword text.</p>
Functional and symptom outcomes	Symptoms and day-to-day function	<p>\bpatient satisfaction\b; \btreatment satisfaction\b; \buser satisfaction\b; \btechnology acceptance\b; \buser acceptance\b; \bpatient acceptance\b; \bacceptability\b; \btrust in(?:the)?robot(?:ic)?\b; \btrust in robotic\b; \battitudes? toward(?:s)? robotic\b; \bpatient preferences?\b; \bwillingness to(?:use adopt)\b; \bpatient experience\b; \buser experience\b; \bperceived usefulness\b</p>	<p>No additional domain-specific restriction in the executable overlay. Patterns were searched in available title, abstract, author-keyword, and index-keyword text.</p>
Acceptance, trust, and satisfaction	Technology and treatment experience	<p>\bpatient autonomy\b; \bshared decision[-]making\b; \bpatient decision[-]making\b; \btreatment decision[-]making\b; \bdecision regret\b; \bdecisional regret\b; \bdecisional conflict\b; \binformed choice\b; \bpatient choice\b; \bpatient assent\b; \bchild assent\b; \bperceived control\b; \bself[-]determination\b</p>	<p>No additional domain-specific restriction in the executable overlay. Patterns were searched in available title, abstract, author-keyword, and index-keyword text.</p>
Autonomy and decision-making	Choice, assent, and decisional agency		

Continuation Table:

Domain	Conceptual role	Included lexical families	Context/exclusion principle
Social participation and connection	Participation and interpersonal connection	\bclassroom participation\b; \bschool participation\b; \bschool attendance\b; \bpeer connection\b; \bpeer support\b; \bsocial participation\b; \bsocial connectedness\b; \bsocial connection\b; \bsocial isolation\b; \bloneliness\b; \bsocial interaction\b; \bsocial inclusion\b	Lexical match retained only when the record was coded as rehabilitation/support/telepresence or its title contained a cancer, oncology, tumour/tumor, malignancy, or leukaemia term.
Caregiver and family implications	Family and caregiver experience	\bcaregiver burden\b; \bcaregiver experience\b; \bcaregiver support\b; \bfamily burden\b; \bfamily support\b; \bfamily experience\b; \bparental experience\b; \bparent experience\b; \bfamily caregivers?\b; \bparents? and children\b; \bcaregiver acceptability\b	The same supportive-domain or cancer-title restriction applied. An additional contextual route required a family/caregiver term together with a social/supportive robot term in a supportive-domain record.
Accessibility and equity	Access and distributional equity	\bhealth equity\b; \bhealthcare equity\b; \binequit(?:y ies)\b; \bhealth(?:care)?disparit(?:y ies)\b; \bsocioeconomic(?:inequities disparities)\b; \brural(?:disparities inequities)\b; \bunderserved patients?\b; \bdigital divide\b; \baccess to care\b; \bgeographic access\b; \binsurance[-]based inequities\b; \bracialdisparit(?:y ies)\b; \bethnic disparit(?:y ies)\b; \bfinancial toxicity\b; \baffordability\b	No additional domain-specific restriction in the executable overlay. Patterns were searched in available title, abstract, author-keyword, and index-keyword text.
Ethics, privacy, and human-robot interaction	Ethics, privacy, and interaction	\bethical(?:concerns? issues? implications? challenge s?)\b; \bbioethics?\b; \bprivacy\b; \bconfidentiality\b; \bdata protection\b; \bhuman[-]robot interaction\b; \bchild[-]robot interaction\b; \baccountability\b; \bpatient assent\b; \bchild assent\b; \bvalue[-]sensitive design\b	No additional domain-specific restriction in the executable overlay. Patterns were searched in available title, abstract, author-keyword, and index-keyword text.

Supplementary Table S10. Complete topic terms and weights

topic_id	rank	term	normalized_weight
1	1	continence	0.0355272218585014
1	2	urinary	0.0301744993776083
1	3	sparing	0.022314541041851
1	4	recovery	0.0215375646948814
1	5	incontinence	0.0199151393026113
1	6	function	0.0196096617728471
1	7	prostatectomy	0.0189990568906068
1	8	rarp	0.0183528624475002
1	9	erectile	0.0162899438291788
1	10	functional	0.0153779136016964
1	11	nerve	0.0144664570689201
1	12	sexual	0.0136895244941115
1	13	radical	0.0132770575582981
1	14	life	0.0132722733542323
1	15	quality	0.0114147383719682
1	16	early	0.0110911149531602
1	17	pad	0.0110601773485541
1	18	retzius	0.010168932378292
1	19	scores	0.0100452182814478
1	20	postoperative	0.0100307865068316
1	21	urethral	0.0094279255717992
1	22	catheter	0.0090565923601388
1	23	dysfunction	0.0084409425035119
1	24	post	0.0077190049923956
1	25	prostate	0.0076611340045928
1	26	score	0.0075941560789942
1	27	potency	0.0074744853191077
1	28	preservation	0.0073539284057915
1	29	technique	0.007241585291922
1	30	removal	0.0070916637778282
2	1	prostatectomy	0.0384845547378063
2	2	prostate	0.03162756934762
2	3	radical	0.0285133551806211

Continuation Table:

topic_id	rank	term	normalized_weight
2	4	rarp	0.0245791934430599
2	5	biochemical	0.01191181037575
2	6	positive	0.0110875507816672
2	7	psa	0.0105645321309566
2	8	recurrence	0.0098913116380572
2	9	pca	0.0098124872893095
2	10	bcr	0.009646444581449
2	11	gleason	0.0078340368345379
2	12	antigen	0.0076829162426292
2	13	specific	0.0075874985195696
2	14	pelvic	0.0072472942993044
2	15	localized	0.0072236768901348
2	16	ralp	0.0071999244391918
2	17	factors	0.0071678957901895
2	18	men	0.0068796682171523
2	19	margins	0.0066473614424467
2	20	who	0.0065019279718399
2	21	had	0.0064570168033242
2	22	regression	0.0062301307916641
2	23	biopsy	0.0059270747005939
2	24	margin	0.0058408980257809
2	25	preoperative	0.0057979212142527
2	26	psm	0.005788710899651
2	27	pathological	0.0057854368351399
2	28	node	0.0056227203458547
2	29	respectively	0.0054813232272863
2	30	underwent	0.0053837988525629
3	1	rectal	0.0607057809829711
3	2	resection	0.0294238328933715
3	3	excision	0.0280044935643672
3	4	mesorectal	0.0272014401853084
3	5	tme	0.0210502035915851
3	6	colorectal	0.0186769608408212

Continuation Table:

topic_id	rank	term	normalized_weight
3	7	laparoscopic	0.017639035359025
3	8	transanal	0.0150311263278126
3	9	anterior	0.0139446938410401
3	10	term	0.0102416211739182
3	11	short	0.009136950597167
3	12	pelvic	0.0091165089979767
3	13	colon	0.0087794782593846
3	14	tatme	0.0086917374283075
3	15	anal	0.0081839840859174
3	16	resections	0.0076980073936283
3	17	complete	0.0076221777126193
3	18	oncological	0.0074086729437112
3	19	approach	0.0070757870562374
3	20	margin	0.006885047070682
3	21	conversion	0.0066828671842813
3	22	lateral	0.0066198701970279
3	23	local	0.0064272116869688
3	24	performed	0.0061756568029522
3	25	anastomotic	0.0060430038720369
3	26	neoadjuvant	0.0059579340741038
3	27	mid	0.0056908936239778
3	28	underwent	0.0055764303542673
3	29	advanced	0.0055164867080748
3	30	dissection	0.005488789640367
4	1	gastrectomy	0.0138412117958068
4	2	gastric	0.0122812753543257
4	3	postoperative	0.0108906365931034
4	4	laparoscopic	0.0106279514729976
4	5	time	0.01017985958606
4	6	complications	0.0099659590050578
4	7	hospital	0.0091696931049227
4	8	term	0.0086378687992692
4	9	operative	0.0086008077487349

Continuation Table:

topic_id	rank	term	normalized_weight
4	10	stay	0.0084218690171837
4	11	blood	0.0082998033612966
4	12	propensity	0.0082406299188733
4	13	underwent	0.0081373900175094
4	14	lymph	0.0080688893795013
4	15	loss	0.0079469177871942
4	16	short	0.0079173119738698
4	17	min	0.0073586534708738
4	18	score	0.0068897898308932
4	19	who	0.0068261823616921
4	20	minimally	0.006628468632698
4	21	open	0.006620502565056
4	22	invasive	0.0063376971520483
4	23	matched	0.0062089902348816
4	24	there	0.0060464772395789
4	25	nodes	0.0060424953699111
4	26	operation	0.005885886028409
4	27	matching	0.0058586443774402
4	28	two	0.0057597989216446
4	29	had	0.0057483194395899
4	30	than	0.0055632856674492
5	1	meta	0.0346853286027908
5	2	systematic	0.0312064830213785
5	3	laparoscopic	0.0169808790087699
5	4	randomized	0.015280625782907
5	5	trials	0.0152259534224867
5	6	open	0.0147953145205974
5	7	pubmed	0.0132853556424379
5	8	evidence	0.0130363684147596
5	9	cochrane	0.012913710437715
5	10	search	0.0125777442008256
5	11	controlled	0.0124951107427477
5	12	embase	0.0119747901335358

Continuation Table:

topic_id	rank	term	normalized_weight
5	13	literature	0.011694936081767
5	14	databases	0.011107481084764
5	15	comparing	0.0102621912956237
5	16	quality	0.0092264432460069
5	17	articles	0.0089695919305086
5	18	cost	0.0081987371668219
5	19	minimally	0.0081723369657993
5	20	approaches	0.0080091208219528
5	21	science	0.0079692965373396
5	22	invasive	0.0078851394355297
5	23	difference	0.0075355800800025
5	24	wmd	0.0074579007923603
5	25	conducted	0.0071050613187253
5	26	published	0.0070963315665721
5	27	effectiveness	0.0070369322784245
5	28	stay	0.006735076662153
5	29	analyses	0.0066884174011647
5	30	costs	0.0065989797003567
6	1	nephrectomy	0.0486763529479503
6	2	renal	0.0446466915309429
6	3	partial	0.044009406119585
6	4	rapn	0.0263177156448364
6	5	kidney	0.0211706813424825
6	6	ischemia	0.0123236598446965
6	7	cell	0.011416588909924
6	8	masses	0.0102454265579581
6	9	egfr	0.0091355675831437
6	10	rpn	0.0090224407613277
6	11	trifecta	0.0089131100103259
6	12	function	0.0085925385355949
6	13	rcc	0.0084689324721694
6	14	score	0.0084217991679906
6	15	estimated	0.0081471037119627

Continuation Table:

topic_id	rank	term	normalized_weight
6	16	functional	0.0071944468654692
6	17	time	0.0070823263376951
6	18	min	0.0069418894127011
6	19	opn	0.0069159418344497
6	20	perioperative	0.0068045281805098
6	21	size	0.0057674292474985
6	22	complications	0.0056494013406336
6	23	retroperitoneal	0.0056161396205425
6	24	preoperative	0.0054788957349956
6	25	mass	0.0054159620776772
6	26	follow	0.00522190798074
6	27	clamp	0.0051998062990605
6	28	blood	0.0050094276666641
6	29	preservation	0.0046977452002465
6	30	loss	0.0046897884458303
7	1	transoral	0.0462590456008911
7	2	tors	0.044832956045866
7	3	oropharyngeal	0.0319477505981922
7	4	neck	0.0278177335858345
7	5	head	0.0222935993224382
7	6	squamous	0.0211681220680475
7	7	hvp	0.0173154510557651
7	8	cell	0.0169087201356887
7	9	opsc	0.0154053634032607
7	10	primary	0.0132212210446596
7	11	survival	0.012890450656414
7	12	adjuvant	0.0126298516988754
7	13	therapy	0.0099814785644412
7	14	radiotherapy	0.009406816214323
7	15	oral	0.0092111742123961
7	16	disease	0.009018687531352
7	17	treated	0.0085928002372384
7	18	free	0.0078689586371183

Continuation Table:

topic_id	rank	term	normalized_weight
7	19	radiation	0.0078299297019839
7	20	stage	0.007513768505305
7	21	positive	0.0071785417385399
7	22	functional	0.0071001700125634
7	23	unknown	0.0070888926275074
7	24	dissection	0.0069834399037063
7	25	base	0.0069630360230803
7	26	recurrence	0.0064250850118696
7	27	management	0.0055903433822095
7	28	overall	0.0055021331645548
7	29	following	0.0054781720973551
7	30	margins	0.0054723066277801
8	1	cystectomy	0.0557237155735492
8	2	rarc	0.038709633052349
8	3	bladder	0.0341106653213501
8	4	radical	0.0273661948740482
8	5	diversion	0.0257649384438991
8	6	intracorporeal	0.0233813803642988
8	7	urinary	0.0191185884177684
8	8	orc	0.0185842141509056
8	9	ileal	0.0132986055687069
8	10	neobladder	0.0132823511958122
8	11	complications	0.0105923078954219
8	12	muscle	0.0102235386148095
8	13	open	0.0099953720346093
8	14	icud	0.00985939335078
8	15	perioperative	0.0097063155844807
8	16	conduit	0.0095760226249694
8	17	urothelial	0.0063094622455537
8	18	complication	0.0061259130015969
8	19	survival	0.0059166606515645
8	20	clavien	0.0055141947232186
8	21	grade	0.0051860306411981

Continuation Table:

topic_id	rank	term	normalized_weight
8	22	recurrence	0.0051388489082455
8	23	transfusion	0.0051222541369497
8	24	underwent	0.0051153115928173
8	25	blood	0.0050719049759209
8	26	overall	0.0049896812997758
8	27	pelvic	0.0048950742930173
8	28	performed	0.0047756345011293
8	29	chemotherapy	0.0046913777478039
8	30	who	0.0044586807489395
9	1	lung	0.0471631921827793
9	2	lobectomy	0.0340646989643573
9	3	vats	0.031305756419897
9	4	thoracic	0.0305450782179832
9	5	rats	0.030064158141613
9	6	thoracoscopic	0.0282132718712091
9	7	video	0.025940615683794
9	8	pulmonary	0.0175669528543949
9	9	small	0.0169718340039253
9	10	nsclc	0.0162680279463529
9	11	cell	0.0146053452044725
9	12	non	0.0145776541903615
9	13	segmentectomy	0.0138876577839255
9	14	thoracotomy	0.0134913921356201
9	15	resection	0.0133551117032766
9	16	stage	0.0095497425645589
9	17	invasive	0.007629903499037
9	18	early	0.0076296352781355
9	19	minimally	0.0073584746569395
9	20	lymph	0.0068494849838316
9	21	resections	0.0066510261967778
9	22	mediastinal	0.0065395780839025
9	23	approach	0.0064814947545528
9	24	postoperative	0.0058606835082173

Continuation Table:

topic_id	rank	term	normalized_weight
9	25	node	0.005488253198564
9	26	mortality	0.0051340805366635
9	27	perioperative	0.0050201914273202
9	28	anatomic	0.0050132954493165
9	29	open	0.0048964940942823
9	30	survival	0.0047017922624945
10	1	system	0.012561734765768
10	2	has	0.0088987490162253
10	3	imaging	0.0075035826303064
10	4	have	0.0074043241329491
10	5	invasive	0.0068331523798406
10	6	which	0.0066915010102093
10	7	guided	0.0066399308852851
10	8	technology	0.0066205072216689
10	9	been	0.0065713282674551
10	10	such	0.0064657186158001
10	11	minimally	0.0063532353378832
10	12	systems	0.006334547419101
10	13	tissue	0.0063055171631276
10	14	field	0.0060114921070635
10	15	accuracy	0.0059778508730232
10	16	potential	0.0057413587346673
10	17	magnetic	0.0057388888671994
10	18	development	0.0056359698064625
10	19	future	0.0054100062698125
10	20	drug	0.0053027756512165
10	21	delivery	0.0052770539186894
10	22	medical	0.0052085323259234
10	23	robots	0.0051977261900901
10	24	control	0.0050450749695301
10	25	biopsy	0.0050007845275104
10	26	their	0.0050001894123852
10	27	image	0.0049368147738277

Continuation Table:

topic_id	rank	term	normalized_weight
10	28	needle	0.004900352563709
10	29	techniques	0.0048551457002758
10	30	precision	0.0047946791164577

Supplementary Table S11. Software environment and reproducibility information

Component	Version/status	Availability
Python	Version 3.12.14	Software environment reported in this supplementary material
pandas	Version used in the analytical environment	Software environment reported in this supplementary material
Custom NumPy NMF implementation	Parameters, random seeds, and convergence criteria documented	Analytical procedures described in the Methods and supplementary material
Coding dictionaries	Used for rule-based classification and evidence mapping	Available from the corresponding author on reasonable request
Aggregate outputs	CSV/JSON-compatible tabular outputs	Available from the corresponding author on reasonable request
Licensed raw exports	Not redistributed	Access remains subject to Web of Science and Scopus licensing conditions

Status of manual-validation materials

The 87 expanded-search records retained for audit were independently marked as eligible by both assessors. Supplementary Table S8 presents the prespecified sampling framework and should not be interpreted as a completed human-reference validation study. The associated screening, deduplication, study-design, and patient-centred domain samples are retained as audit materials; therefore, they were not used to estimate sensitivity, specificity, or other human-reference performance measures. Unless explicitly identified as expanded-search audit data, the tables in this supplement report descriptive or model-based results from the primary corpus.