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REVIEW ARTICLE

The dual paradigm of personalized oncology: harmonizing targeted therapies with patient quality of life. A narrative review

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ABSTRACT

Objective. This narrative review synthesizes current evidence on personalized (precision) medicine in oncology, with the dual objective of describing the molecular foundations that enable individualized cancer treatment and examining how personalized care is experienced and valued by patients throughout the cancer care continuum. **Material and Methods.** A literature search was conducted in PubMed/MEDLINE and complementary databases to identify English-language review articles, clinical practice guidelines, and primary studies addressing precision oncology, biomarker-driven therapies, immunotherapy, artificial intelligence, survivorship, and health-related quality of life. Sources were selected purposively based on their relevance, methodological quality, and recency, and the evidence was synthesized using a thematic rather than a systematic approach. **Results.** Six interrelated themes emerged: (i) genomic and multi-omic profiling supported by biobanking and advanced computational tools; (ii) artificial intelligence and digital modeling; (iii) molecularly targeted and tumour-agnostic therapies; (iv) cancer immunotherapy and its evolving biomarkers; (v) survivorship and the long-term consequences of cancer treatment; and (vi) the integration of patient preferences, psychosocial support, and health-related quality of life into individualized care. Across these domains, technical precision and patient-centred personalization emerged as complementary rather than competing goals, while equitable access remained a persistent challenge. **Conclusion.** Realizing the full potential of personalized oncology requires aligning molecularly targeted interventions with patients' lived experiences, preferences, and priorities. Multidisciplinary care, validated biomarkers, transparent and clinically interpretable computational tools, equitable access to innovative therapies, and the routine integration of patient-reported outcomes are essential for translating precision medicine into meaningful clinical and patient-centred benefits.

Keywords: precision oncology, personalized medicine, cancer immunotherapy, artificial intelligence, quality of life.

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1. INTRODUCTION

Cancer care has shifted decisively away from a uniform, disease-stage-driven model toward an approach that tailors prevention, diagnosis, and treatment to the molecular characteristics of each tumour and to the circumstances of each patient. The personalization of cancer treatment implies a deliberate reconsideration of the one-size-fits-all paradigm that long governed cytotoxic therapy, in which regimens and doses were derived primarily from population averages rather than individual biology [19]. Advances in high-throughput sequencing, multi-omic profiling, and computational modelling have made it feasible to characterize the genetic and signalling landscape of individual cancers and, increasingly, to act on that information at the point of care [19,43].

Yet the word “personalized” carries two distinct meanings that are often conflated. The first is molecular: matching a therapy to a specific genomic alteration, protein signature, or immune phenotype. The second is humanistic: aligning care with the values, goals, symptom burden, and quality-of-life priorities of the person receiving it. Both meanings are well represented in the contemporary literature, and both are essential. Health-related quality of life (HRQoL), psychosocial wellbeing, and survivorship outcomes are now recognized as integral endpoints of cancer care rather than secondary considerations [40,45].

The molecular and humanistic dimensions of personalization are frequently discussed in separate scholarly communities, and this review aims to bridge them. We first outline the molecular foundations of precision oncology and the computational tools that support it, then examine targeted, tumour-agnostic, and immunotherapeutic strategies, and finally turn to survivorship and the patient experience, arguing that these strands are complementary facets of a single goal: care that is genuinely individualized.

2. SEARCH STRATEGY

As a narrative review, this article does not follow a systematic protocol or include a quantitative meta-analysis. Literature was identified through PubMed/MEDLINE supplemented by reference-list screening (“snowballing”). Search terms combined controlled and free-text vocabulary including “personalized medicine,” “precision oncology,” “biomarker,” “liquid biopsy,” “artificial intelligence,” “immunotherapy,” “survivorship,” and “quality of life” linked with Boolean operators. Priority was given to clinical practice guidelines, authoritative reviews, and informative primary studies, emphasizing recent publications while retaining foundational older works. Because source selection was purposive, the review is susceptible to selection bias, a limitation revisited in the Discussion.

3. MOLECULAR FOUNDATIONS OF PRECISION ONCOLOGY

From genomic testing to multi-omic profiling

The clinical entry point to precision oncology is molecular characterization of the tumour. Genomic testing now informs diagnosis, prognostication, and treatment selection across a widening range of malignancies and age groups, including children, adolescents, and young adults, where actionable findings can alter management and clarify hereditary risk [17]. Beyond DNA, the field has expanded toward multi-omic analysis. Personalized phosphoproteomics, for example, enables interrogation of the signalling networks that drive individual tumours and can reveal clinically actionable kinase dependencies in otherwise treatment-resistant diseases such as castration-resistant prostate cancer [47]. Recurrent molecular vulnerabilities such as mismatch-repair defects, which alter chemosensitivity and enable synthetic-lethal targeting further show how mechanistic insight becomes individualized therapy [6].

Infrastructure: biobanking and data integration

Robust molecular medicine depends on infrastructure that is often invisible in clinical narratives. Systematic biobanking the structured collection, annotation, and storage of patient samples linked to clinical data, provides the substrate for biomarker discovery and validation, particularly in cancers with poor outcomes and limited treatment options such as head and neck carcinoma [7]. Similarly, prospective biospecimen collection embedded within randomized controlled trials has become a deliberate strategy for discovering and validating predictive biomarkers under rigorous conditions [18]. These efforts underscore that precision oncology is as much a data and logistics enterprise as a laboratory one, and that the value of a biomarker ultimately depends on its adoption into routine treatment decisions [33].

Computational modelling, machine learning, and digital twins

Translating molecular data into treatment decisions increasingly relies on computational methods. Predictive simulation approaches can construct in-silico “avatars” of a patient’s tumour from mutation and copy-number data, allowing candidate drugs and combinations to be screened virtually before clinical use, an approach validated ex vivo in high-risk multiple myeloma [19]. More broadly, machine learning applied to pharmacogenomic and multi-omic datasets can detect genetic patterns associated with drug response, supporting therapies that are both more effective and less toxic, although challenges of interpretability, data quality, privacy, and equity remain unresolved [3,5]. Artificial intelligence is now being applied across the cancer continuum from early detection and diagnosis to the tailoring of treatment [12] and deep-learning models trained on histopathology images can estimate recurrence risk and predict chemotherapy benefit, bringing computation into prognostic decision-making [42]. For instance, multimodal AI models, serving as core engines for digital twins, already demonstrate notable performance over standard risk tools in prostate cancer, predicting long-term outcomes and guiding therapy selection [51]. One machine-learning-based model for prostate cancer, for example, achieved high biochemical recurrence prediction accuracy [51]. In a broader oncological context, predictive digital

twins have optimized radiotherapy and dosing strategies in simulated and early clinical settings, leading to improved tumor control or reduced toxicity [52]. This progression highlights the shift from reactive to predictive and preventive healthcare, enhancing patient outcomes through increasingly personalized medicine [21,52]. Critical for adoption, reviews in urologic precision oncology consistently stress that interpretability and transparency are paramount; opaque AI models hinder clinical trust, necessitating explainable AI methods and human–AI workflows to expose decision drivers and visualize treatment rationales [21]. Patient surveys further reinforce this, showing a strong preference for clinician-mediated AI systems, underscoring the need for explainable, trustworthy tools at the bedside [53, 54]. Despite their transformative potential, challenges such as data interoperability, prospective validation, computational costs, and robust ethical frameworks remain, requiring ongoing multidisciplinary collaboration and standardized protocols for their full clinical realization [14]. Such tools are also being explored to structure complex decisions at the bedside [25].

4. MOLECULARLY TARGETED AND TUMOUR-AGNOSTIC THERAPIES

Early successes in personalization were driven by agents directed against a single oncogenic driver, an approach that transformed several malignancies but proved insufficient where tumours harbour multiple concurrent aberrations [19]. Targeted therapy has since matured in several directions. The first is lineage-aware targeting of recurrent drivers; melanoma exemplifies how genotype-to-phenotype correlation, molecular tumour boards, and companion diagnostics have reshaped practice, while illustrating the persistent problem of acquired resistance [35]. The second is the tumour-agnostic paradigm, selecting therapy by a shared molecular alteration regardless of anatomical origin; BRAF, for instance, is a tumour-agnostic target whose actionability nonetheless retains lineage-specific dependencies and resistance mechanisms [22]. Selected molecular strategies that have since matured in precision oncology are summarized in Table 1.

Table 1. Selected molecular strategies in personalized oncology and their clinical rationale.

Strategy	Clinical rationale	References
Single-driver targeted therapy	Inhibition of one patient-specific oncogenic driver; effective but limited by multiple concurrent aberrations.	[19]
Lineage-aware targeting	Genotype-to-phenotype matching with companion diagnostics; resistance remains a key challenge (e.g., melanoma).	[35]
Tumour-agnostic targeting	Treatment chosen by shared molecular alteration across tissues, with lineage-specific dependencies (e.g., BRAF).	[22]
Receptor-pathway targeting	Pan-tumour application of HER2-directed therapy as alterations are recognized beyond breast cancer.	[2]
Synthetic-lethal targeting	Exploiting DNA-repair (mismatch-repair) defects to selectively kill deficient tumour cells.	[6]
Biomarker-guided immunotherapy	Neoantigen-directed vaccines, combination checkpoint blockade, and tumour-mutational-burden-based selection.	[16,26,36,49]
Cellular therapy	Antigen-specific CAR T cells engineered to the tumour's surface markers (e.g., claudin-18.2).	[27,38]
ctDNA-guided management	Dynamic monitoring to personalize escalation or de-escalation of adjuvant therapy.	[20,34]

Targeting of receptor pathways further shows the convergence of biomarker testing and therapeutic design. HER2-directed strategies, anchored in breast cancer, are increasingly applied pan-tumour as HER2 alterations are recognized beyond their original context [2]. Optimizing treatment for biologically defined, underserved subgroups such as early-stage triple-negative breast cancer shows that personalization includes intensifying or de-escalating therapy by individual risk [1]. Even where cytotoxic and adjuvant therapy dominate, as in non-small-cell lung cancer, molecular characteristics increasingly inform who benefits from additional treatment [41]. The same logic reaches disease categories once considered intractable, with liver cancer reviews reframing management around personalized care [9], and precision strategies adapted for rare tumours, where small patient numbers make molecularly guided approaches especially valuable [28]. The N-of-1 I-PREDICT study, matching individually dosed drug combinations to each patient's molecular profile, offers a blueprint for this paradigm [43].

5. CANCER IMMUNOTHERAPY AND ITS BIOMARKERS

Immunotherapy, and in particular immune checkpoint inhibition, has become a central pillar of personalized oncology. A defining feature of the immunotherapeutic era is the search for biomarkers that identify which patients are most likely to benefit. Neoantigens

tumour-specific peptides arising from somatic mutations represent an emerging class of targets that links the molecular individuality of a tumour directly to a personalized immune response [16], and they now anchor a growing field of neoantigen-driven cancer vaccines designed for individual patients [36]. At the mechanistic level, efforts to enhance the efficacy of checkpoint blockade include co-targeting intracellular checkpoints, reflecting a move toward rationally combined, individualized immunotherapeutic regimens [26].

Biomarker refinement is sharpening patient selection. Tumour mutational burden illustrates both promise and nuance: in melanoma, an extreme "hypermutation" threshold identifies patients achieving near-curative outcomes with checkpoint blockade [49], and burden can also be acquired after targeted therapy in microsatellite-stable colorectal cancer, opening new windows for immunotherapy [48]. Cellular therapies extend personalization further: claudin-18.2-specific CAR T cells have shown potential in advanced gastrointestinal cancer [38], and CAR T-cell strategies are being pursued for children [27]. Personalization is also moving earlier, with adjuvant and perioperative checkpoint inhibition reconsidered through de-escalation, expansion, and individualized intensity [24].

Immunotherapy also brings the patient experience into focus. Because checkpoint inhibitors carry a distinctive spectrum of immune-related adverse effects, patients express specific expectations about discussing HRQoL throughout their care pathway, and many report these conversations are insufficiently addressed [45]. Molecular sophistication does not, by itself, guarantee that care is experienced as personalized.

6. LIQUID BIOPSY, DYNAMIC MONITORING, AND EQUITABLE ACCESS

If genomic profiling personalizes the choice of therapy, circulating tumour DNA (ctDNA) increasingly personalizes its timing and intensity. The principal biomarker classes that underpin these decisions, together with their representative clinical applications, are summarized in Table 2.

Table 2. Principal classes of cancer biomarkers and their clinical applications in personalized oncology.

Biomarker class	Example	Clinical application	References
Predictive (treatment-selecting)	HER2 status; BRAF mutation	Matching patients to targeted or tumour-agnostic therapy	[2,22,33]
Immunotherapy-response	Tumour mutational burden; neoantigen load	Identifying patients most likely to benefit from checkpoint blockade	[16,48,49]
Minimal residual disease / monitoring	Circulating tumour DNA (ctDNA)	Tracking response and personalizing escalation or de-escalation	[20,34]
Hereditary / germline	Homologous recombination repair / BRCA mutations	Informing therapy choice and familial risk via sequencing	[8,17]
Functional / signalling	Phosphoproteomic kinase activity	Revealing actionable pathway dependencies in resistant disease	[47]

Longitudinal ctDNA analysis has demonstrated clinical utility in metastatic colorectal cancer, tracking disease behaviour during palliative chemotherapy [34], while ctDNA can guide the management of molecularly defined subgroups toward exceptional benefit from immunotherapy [48]. In muscle-invasive bladder cancer, the TOMBOLA trial used tumour-informed ctDNA after cystectomy to stratify recurrence risk and to direct early immunotherapy to ctDNA-positive patients while sparing ctDNA-negative patients unnecessary adjuvant treatment, an explicit example of personalized escalation and de-escalation [20].

These advances, however, are only as valuable as their reach. Real-world analyses show that the concordance between comprehensive genomic profiling and the biomarker-recommended therapies it identifies is imperfect, revealing a gap between testing and action in advanced metastatic castration-sensitive prostate cancer, with disparities also evident by patient race in access to next-generation sequencing [8]. National data from Australia similarly document uneven biomarker-test utilization across demographic and geographic lines despite increased public funding, underscoring that equitable access to genomic diagnostics is now a central challenge for personalized oncology [25].

Furthermore, in low- and middle-income countries (LMICs), the obstacles to equitable access are profoundly magnified, contributing to a disproportionate burden of cancer mortality in these regions [54,55]. These contexts frequently struggle with substantial infrastructure deficits, encompassing limited pathology, molecular laboratories, radiotherapy facilities, and diagnostic services, which

impede or prevent timely and accurate cancer diagnosis and staging [54,56]. The exorbitant costs associated with advanced genomic testing, innovative immunotherapies, and targeted drugs represent a significant barrier, even when pricing is ostensibly lower than in high-income nations [55]. Moreover, a critical scarcity of skilled healthcare professionals, including molecular scientists, pathologists, oncologists, and genetic counselors, restricts the effective implementation of precision medicine [54,56]. Systemic disadvantages, such as financial hardship, geographical isolation, underdeveloped referral pathways, and low health literacy, further prolong the interval from symptom presentation to diagnosis and subsequent treatment initiation [54].

Addressing this profound global inequity demands concerted, multifaceted interventions. This includes fostering the development and deployment of scalable, economically viable diagnostic platforms specifically designed for LMIC environments, such as low-cost gene-expression assays [56-58]. The integration of digital diagnostics with artificial intelligence also presents a promising avenue for enabling remote diagnostic reads and scaling specialized expertise [54]. Beyond technological advancements, crucial initiatives involve targeted funding from global health organizations, such as the WHO, and programs designed to improve access to essential cancer medications [55]. Robust international collaborations and capacity-building consortia are indispensable for establishing local genomics infrastructure, training programs, and comprehensive biobanks [57]. Collaborative models, including twinning programs, telemedicine, and the establishment of regional reference laboratories, can significantly enhance services and ensure the contextual relevance of research [55,56]. Finally, increasing the participation of LMICs in clinical trials, particularly for immunotherapies where their involvement is currently limited, is vital. This is essential for generating local evidence and ensuring that precision tools and immunotherapies are both culturally appropriate and clinically effective for local adoption [57,59]. Only through such comprehensive and collaborative strategies can the promise of personalized oncology genuinely benefit all patients, irrespective of their geographic location or socioeconomic status [55,57].

7. SURVIVORSHIP, QUALITY OF LIFE, AND THE PATIENT EXPERIENCE

Survivorship as a distinct phase of care

As survival improves, the long-term consequences of cancer and its treatment have become a defining concern. Survivorship guidelines, such as the joint breast cancer survivorship guideline, formalize surveillance, management of late effects, and care coordination [40]. Survivorship is increasingly recognized for people living with advanced and metastatic disease, not only after curative treatment [31]. The experience is not solely one of loss; treatment-related impairment can coexist with post-traumatic growth as patients reconstruct meaning amid lasting physical change [15]. Delivering this care equitably is itself a personalization problem, as survivorship models must be adapted for patients in regional, rural, and remote settings [37].

Quality of life, preferences, and shared decision-making

HRQoL has moved from the periphery to the centre of oncological evaluation. Patients increasingly expect HRQoL to be discussed at every step of the care pathway and identify their oncologists and general practitioners as the clinicians best placed to lead these conversations [45]. Patients also differ in what they want: among older adults with advanced cancer, those prioritizing quality of life over survival experience measurably different outcomes, underscoring why eliciting preferences is integral to personalized care [39]. Formal preference-elicitation methods, such as discrete-choice experiments, are now used to quantify how patients weigh the benefits and harms of adjuvant therapy in renal cell carcinoma [10] and how they value genetic testing and adjuvant treatment in HER2-negative early breast cancer [29], providing an evidence base for genuinely shared decision-making.

Psychosocial dimensions and supportive care

Psychosocial interventions form an important component of individualized supportive care, although the evidence is heterogeneous. Representative patient-reported and supportive-care interventions, the needs they address, and their reported effects are summarized in Table 3.

In gynaecological cancer, for example, counselling and cognitive-behavioural approaches appear more promising than purely information-based interventions for improving quality of life [23]. Psychological resources also modify outcomes; self-efficacy for coping has been shown to moderate the relationship between distress and quality of life in patients receiving palliative breast cancer care, highlighting targets for individualized psychological support [13]. Body image is a further individualized concern, being closely linked to emotional distress across both men and women with cancer [30]. Targeted programmes can address specific needs: an online support group reduced psychosexual distress among women treated for gynaecological cancer [14], illustrating how supportive care can be matched to clearly defined patient populations.

Table 3. Selected patient-reported and supportive-care approaches in personalized cancer care.

Approach	Need addressed	Reported effect	References
Preference elicitation (discrete-choice experiments)	Treatment trade-offs and shared decision-making	Quantifies how patients weigh benefits against harms	[10,29,39]
Counselling / cognitive-behavioural therapy	Distress, anxiety, and low quality of life	More effective than information-only approaches	[13,23]
Online / digital support groups	Psychosexual distress; body image	Reduced distress in defined patient populations	[14,30]
Telemedicine	Access, distress, and physical function	Improved distress, function, and self-efficacy (meta-analysis)	[44]
Mobile-app coaching / co-designed tools	Physical activity; long-term support	Tailoring to individual preferences improves engagement	[32,50]
Survivorship care models	Late effects and care coordination	Structured follow-up adapted to setting and disease stage	[31,37,40]

Digital and behavioural personalization

Personalization extends into the design of interventions themselves. Breast cancer survivors express clear preferences for how mobile, app-based activity coaching should be tailored to their circumstances [32]. Telemedicine improves distress, physical function, and self-efficacy in meta-analysis, offering a scalable channel for individualized support [44], and patients are increasingly co-designers of such tools, as in a psychosocial support website for people with long-term responses to immunotherapy or targeted therapy [50]. Even patient education is being personalized, with AI-generated content tailoring cancer information and helping bridge knowledge gaps for those with limited access to health education [46]. This closes the loop between molecular and humanistic personalization: in both, individual characteristics determine the optimal intervention as seen in locally advanced rectal cancer, where treatment increasingly balances outcomes against quality of life [4].

8. DISCUSSION

The literature synthesized here supports a unifying argument: the molecular and humanistic meanings of personalization are not in tension but are two expressions of one principle that care must be fitted to the individual (Table 4). The molecular strand has delivered multi-omic profiling, biobanking, computational and artificial-intelligence decision support, targeted and tumour-agnostic agents, biomarker-guided and cellular immunotherapy, and ctDNA-based monitoring [2,3,5–7,12,16,18–22,26,34–36,38,42,47,49]. The humanistic strand has established survivorship, HRQoL, psychosocial support, and patient preference as legitimate, measurable, and modifiable endpoints [10,13–15,23,31,32,39,40,44,45,50]. Care that advances one strand while neglecting the other is incompletely personalized.

Table 4. Two complementary dimensions of personalization in cancer care.

Dimension	Core question	Primary inputs	Representative tools	Illustrative references
Molecular / precision personalization	Which therapy matches this tumour's biology?	Genomic, proteomic, and multi-omic profiles; biomarkers; ctDNA	Sequencing, phosphoproteomics, biobanking, machine learning, digital twins	[5, 17, 19–21, 47]
Humanistic / patient-centred personalization	Which care matches this person's goals and life?	Preferences, symptoms, psychosocial context, quality of life	Patient-reported outcomes, preference elicitation, counselling, survivorship plans	[13, 15, 23, 32, 39, 45

Several gaps recur. First, biomarker validation and equitable deployment lag behind discovery, and computational tools raise unresolved questions of interpretability, data quality, and fairness [5,18,21]; even when actionable biomarkers are identified, the recommended therapies are not always delivered, and access to testing varies by demographic and geographic factors [8,25]. Second, despite consensus on the importance of HRQoL, many patients remain dissatisfied with how it is addressed in practice [45]. Third, evidence for psychosocial and behavioural interventions is uneven, and the most effective modalities are incompletely defined [13,23].

Finally, the patient-experience literature concentrates on a limited range of cancers and settings, leaving many populations under-studied [37].

This review has limitations inherent to its design. As a narrative rather than systematic review, source selection was purposive and therefore susceptible to selection bias; no quantitative synthesis or formal risk-of-bias appraisal was undertaken. The intent was integrative to connect literatures usually kept apart rather than exhaustive. Readers seeking pooled effect estimates should consult dedicated systematic reviews and meta-analyses.

9. CONCLUSION AND FUTURE DIRECTIONS

Personalized oncology has matured into a discipline in which molecular precision and patient-centred care are inseparable. Translating precision into benefit requires that genomic targeting be matched by genuine attention to each patient's goals, symptoms, and quality of life. Future work should prioritize rigorous validation of biomarkers and computational tools, transparent and interpretable deployment of artificial intelligence, equitable access to molecular testing and targeted therapy, routine integration of patient-reported outcomes, and multidisciplinary teams capable of delivering both technical and humanistic personalization. Only by advancing these dimensions together can personalized medicine fulfill its promise of care that is precise in its biology and meaningful in its human impact.

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