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Research Article Open Access

Early Clinical Applications, Pitfalls, and Imaging Integration of ctDNA-MRD in Early-Stage Solid Tumors

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Abstract This study explores the latest advancements in circulating tumor DNA (ctDNA) testing and discusses the clinical significance of ctDNA-based minimal residual disease (ctDNA-MRD). As a liquid biopsy marker, ctDNA-MRD can capture the signals of trace residual diseases at the molecular level and is gradually being used to assess the risk of recurrence and guide follow-up management. Numerous studies have shown that patients with positive ctDNA test results after treatment are more likely to experience recurrence and have poorer survival outcomes. In many cases, the changes in ctDNA prece de imaging findings, providing doctors with earlier reference for adjusting treatment plans and follow-up strategies. In practical applications, ctDNA-MRD also has certain limitations. Factors such as individual biological differences, low ctDNA release levels, clonal hematopoiesis interference, and differences in detection platforms can all affect the accuracy of the results, potentially leading to false negatives or false positives. If one relies too heavily on a single test result, it may result in insufficient or excessive treatment. ctDNA is suitable for dynamic monitoring, while imaging is still indispensable for locating lesions. The combined application of the two is considered a more reliable approach. With further clinical validation, ctDNA-MRD is expected to gradually evolve fro m a predictive indicator to a more practically meaningful decision support tool.

Keywords Circulating tumor DNA; Minimal residual disease; Early-stage solid tumors; Molecular relapse; Imaging integration

1 Introduction

In the treatment of early-stage solid tumors, determining whether the disease has been completely cured has always been a challenge. Even after surgery or systemic treatment, there may still be residual malignant cells at the molecular level in the body, which is what we commonly refer to as minimal residual disease (MRD). These lesions are difficult to detect clinically, but they may eventually lead to cancer recurrence or metastasis (Pantel and Alix-Panabières, 2024). Currently, the recurrence rate of early-stage solid tumors is still not low, which indicates that traditional imaging examinations and serum markers are not sensitive enough in monitoring molecular-level residual lesions.

Over the years, high-throughput sequencing and error correction technologies have become increasingly mature, and the sensitivity of circulating tumor DNA (ctDNA) detection has also significantly improved. Therefore, micro-residual disease assessment based on ctDNA (ctDNA-MRD) has become an important alternative indicator for evaluating molecular residual disease (Semenkovich et al., 2023; Quinn et al., 2025). Many prospective studies and systematic reviews have confirmed that if ctDNA remains positive after radical treatment, the risk of recurrence and death for patients will significantly increase, and this positive signal often appears earlier than imaging abnormalities or clinical symptoms. In various solid tumors, ctDNA signals can predict the risk of recurrence 4 to 12 months in advance, and its prognostic value is very stable (Zhu et al., 2023; Zheng et al., 2024).

However, there are still many challenges to be addressed in the practical clinical application of ctDNA-MRD. For instance, there are differences in results among different detection platforms, and the criteria for positive determination are not uniform. Moreover, there is currently no mature framework that can effectively integrate it with imaging, clinical pathological indicators (Boukouris et al., 2025). Imaging is crucial for lesion localization, but its sensitivity in detecting minor lesions is limited; while ctDNA can better reflect the overall tumor burden and clonal evolution. The complementarity of their time and information aspects can improve the accuracy of

recurrence risk assessment, especially when imaging results are unclear, and it can also provide reference for decision-making on adjuvant therapy (Pantel and Alix-Panabières, 2024).

This study will explore the current clinical application status of ctDNA-MRD in early solid tumors, analyze the common misunderstandings and actual challenges that may arise during its interpretation process, and also discuss the feasible paths for its combination with multimodal imaging. By integrating existing research evidence and related controversies, it is hoped to promote the transformation of ctDNA-MRD from a research tool to a standardized clinical application method, providing support for the precise treatment of early solid tumors.

2 Technical Foundation and ctDNA-MRD Detection Strategy

2.1 Biological source and dynamic characteristics of ctDNA

Circulating tumor DNA (ctDNA) accounts for a relatively small proportion in circulating free DNA (cfDNA). It mainly comes from the apoptosis, necrosis, or active release of tumor cells, carrying the unique characteristics of the tumor, such as somatic mutations, copy number alterations, and abnormal methylation. The fragments of ctDNA in plasma are mostly concentrated around 160-180 base pairs. This characteristic of the fragments is also utilized in fragmentomics and multi-omics MRD detection (Zhu et al., 2023). In the early stages of tumors or after patients undergo radical treatment, the proportion of ctDNA is usually less than 0.1%. It is indeed quite challenging to find such a very low-frequency signal in the background of a large amount of normal DNA (Semenkovich et al., 2023). Moreover, the half-life of ctDNA is only a few hours, which actually has an advantage as it can quickly reflect the treatment effect and the changes in post-treatment tumor burden.

Before tumor recurrence, the level of ctDNA tends to increase exponentially, and its doubling time is closely related to the detection sensitivity (Isbell et al., 2024). In various solid tumors, ctDNA-negative residual disease can usually indicate the risk of recurrence 4 to 12 months earlier than imaging examinations (Zhu et al., 2023). However, it should be noted that the release amount of ctDNA is affected by tumor type, growth location, blood supply, and treatment conditions. If the release amount is low or there is inflammation after surgery, it may lead to false-negative results in the detection (Chen and Zhou, 2023). Therefore, when interpreting the test results, one should not only consider a single test but also combine continuous monitoring and clinical reality for judgment (Semenkovich et al., 2023).

2.2 Main detection methods of ctDNA-MRD

The commonly used clinical strategies for ctDNA-MRD detection currently can be broadly classified into two categories: one is information-based detection based on tissues, and the other is non-tissue-based detection. Let's start with the information-based detection. In simple terms, it involves sequencing the primary tumor (usually accompanied by germline samples) to identify the patient-specific mutation sites, and then conducting ultra-deep tracking detection on plasma samples. By combining UMI tagging and error correction techniques, the false positive rate can be reduced even when the tumor burden is low (Kasi et al., 2022). This method has demonstrated clinical value in risk stratification and adjuvant treatment decision-making for diseases such as colorectal cancer (Chidharla et al., 2023), but it also has limitations-it relies on high-quality tissue samples, has high detection costs, and may miss newly emerging clonal variations (Semenkovich et al., 2023).

There is another type of non-organ-based detection. This method does not rely on specific organs and directly analyzes the free DNA in the plasma. Based on the preset mutation panel, copy number abnormalities, or methylation characteristics, it determines whether MRD exists. In recent years, by integrating fusion mutations and methylation signals, the ability of this method to detect ultra-low abundance ctDNA has been enhanced (Zhu et al., 2023; Quinn et al., 2025), and the operation is also simpler and more suitable for situations without tissue samples. However, it is prone to interference from background noise, especially the impact of clonal hematopoiesis. Therefore, it usually needs to be combined with white blood cell sequencing or filtered using strict algorithms (Semenkovich et al., 2023).

2.3 The impact of pre-analysis processing on detection accuracy

In the MRD detection scenario, the content of ctDNA is already extremely low. Therefore, the pre-analysis

processing steps in the early stage have a particularly significant impact on the accuracy of the final detection results. For instance, the type of collection tube, centrifugation conditions, the time of plasma separation, the sample storage method, and the sample volume all can change the background level of cfDNA. If the operation is improper, it may lead to white blood cell lysis, increase genomic DNA contamination, reduce the proportion of ctDNA, and thereby increase the risk of false negatives (Chen and Zhou, 2023). Therefore, using dedicated cfDNA collection tubes and strictly controlling the processing time window are the key to ensuring the consistency of the detection results (Quinn et al., 2025).

In addition, the performance of the detection is not only related to the sequencing depth, but also influenced by error suppression techniques (such as UMI, double-strand sequencing, algorithm noise reduction), the number of target sites, and the multi-signal integration method. To accurately identify ultra-low-frequency genetic changes, systematic errors must be controlled within the order of 10^{-5}. Currently, different detection platforms have differences in positive thresholds and interpretation rules, which also limits the comparability of the detection results of each platform. At the same time, biological factors such as clonal hematopoiesis may lead to false positive results, which requires a comprehensive judgment combined with paired controls, longitudinal follow-up, as well as imaging and clinical information (Semenkovich et al., 2023).

3 Clinical Application of Blood-Free DNA (ctDNA)-Minimal Residual Disease (MRD) in Early Solid Tumors

3.1 Detection of postoperative minimal residual disease and risk stratification of recurrence

Even if radical resection surgery is performed on patients with early-stage solid tumors, the risk of recurrence cannot be completely eliminated. In my research, I found that some early-stage patients did not detect any abnormalities during postoperative imaging examinations, but their conditions still progressed during the follow-up period. This situation occurs mostly because there are still molecular-level lesions remaining in the body. Relevant studies have confirmed that during the "microscopic residual disease window period" of approximately 2 to 10 weeks after surgery, if ctDNA is positive during the test, it has a strong correlation with subsequent recurrence, and it usually occurs much earlier than the changes shown on imaging (Elliott et al., 2025).

Specifically for different types of tumors, for instance localized lung cancer, using deep sequencing based on tissue information can detect recurrence signs earlier than imaging examinations; while for resectable colorectal cancer, the status of ctDNA after surgery, in predicting the risk of recurrence, is even better than the traditional pathological staging, which also makes ctDNA-MRD an important molecular stratification tool (Chidharla et al., 2023). Unlike the static TNM staging system, ctDNA can reflect the dynamic changes of residual tumor clones. Large-scale prospective studies like GALAXY have confirmed that early positive ctDNA after surgery can independently predict disease-free survival and overall survival (Nakamura et al., 2024). However, it should be noted that the interpretation of these results requires considering signal intensity, duration, and clinical reality, and a negative ctDNA result does not mean there is absolutely no recurrence risk.

3.2 Application of ctDNA-MRD in treatment guidance and efficacy monitoring

Traditional adjuvant treatments are usually stratified based on population risk, which can easily lead to over-treatment or under-treatment issues. However, ctDNA-MRD can precisely provide a basis for individualized treatment decisions: if ctDNA remains positive, it indicates that there are still active tumor lesions in the body, and it may be necessary to strengthen the treatment or extend the treatment period; if it remains negative, unnecessary treatment interventions can be reduced, avoiding patients from bearing excessive treatment burdens (Semenkovich et al., 2023; Abidoye et al., 2025).

In patients with non-small cell lung cancer and colorectal cancer, patients with positive MRD showed more significant benefits from adjuvant therapy, while patients with negative MRD benefited less from chemotherapy. Currently, there are relevant randomized studies exploring strategies to adjust treatment intensity based on ctDNA test results (Vellanki et al., 2023). A longitudinal analysis of the GALAXY cohort also further demonstrated that continuous ctDNA clearance was associated with improved disease-free survival (DFS) and overall survival (OS), and a recurrence risk increase was indicated when ctDNA turned positive again (Nakamura et al., 2024).

Additionally, the dynamic changes of ctDNA have been regarded as potential alternative endpoints and trial screening tools for research (Semenkovich et al., 2023; Vellanki et al., 2023; Kobayashi et al., 2025). However, there are differences among different tumor types and different detection platforms. Without evidence from randomized controlled studies, relying solely on ctDNA results to adjust treatment still carries certain risks (Figure 1).

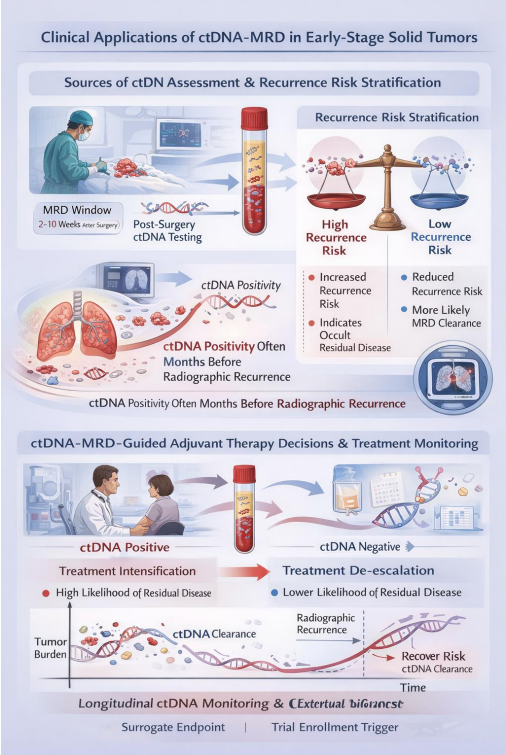

Figure 1 Role of ctDNA-MRD in Postoperative Recurrence Risk Assessment and Treatment Monitoring

3.3 Clinical significance of ctDNA dynamics for early recurrence prediction

One of the most compelling clinical advantages of ctDNA-MRD lies in its ability to predict recurrence ahead of conventional methods. Longitudinal studies across multiple cancers consistently demonstrate that conversion from ctDNA-negative to ctDNA-positive status, or persistent positivity during follow-up, predicts clinical recurrence with high sensitivity and specificity and typically precedes radiographic detection by several months, creating a "molecular recurrence window". In colorectal cancer, dynamic ctDNA monitoring detects recurrence earlier than carcinoembryonic antigen (CEA) testing and routine imaging, with lead times commonly ranging from 2 to 11.5 months; systematic reviews further show that patients who convert to or remain ctDNA-positive after surgery or adjuvant therapy have significantly worse recurrence-free or disease-free survival than those who remain ctDNA-negative (Chidharla et al., 2023; Negro et al., 2025). Similar findings have been reported in localized NSCLC, where persistent ctDNA positivity during surveillance precedes imaging-confirmed relapse by months and can be incorporated into time-to-event models for individualized risk estimation.

Beyond binary positivity, ctDNA trajectories convey additional clinically relevant information. Rates of increase, changes in mutational profiles, and the emergence of new variants can reflect clonal evolution and biological progression, and serial monitoring is better suited than single measurements to distinguish transient fluctuations from true relapse trends. These dynamic features provide a practical framework for integrating ctDNA with imaging over time—for example, using ctDNA conversion to trigger intensified imaging or biopsy, or reducing the posterior probability of "true recurrence" when imaging is equivocal but ctDNA remains persistently negative. Importantly, however, earlier detection of molecular recurrence does not automatically translate into survival benefit. Definitive evidence is still lacking to show that ctDNA-triggered early intervention universally improves outcomes, with unresolved questions regarding molecular recurrence thresholds, optimal timing of intervention, and the risk of overtreatment (Comino-Méndez et al., 2025). Consequently, the optimal role of ctDNA-MRD in

recurrence surveillance is likely as part of an integrated, verifiable decision-support framework that combines staging, treatment history, imaging, and other biomarkers (Kasi et al., 2022; Kobayashi et al., 2025).

4 Clinical Misunderstandings and Challenges in the Practical Application of ctDNA-MRD

4.1 Biological differences and false-negative results caused by low ctDNA release

In clinical practice, many people mistakenly believe that a negative postoperative ctDNA result indicates the absence of residual lesions in the body. However, this is not the case. ctDNA-MRD testing relies on capturing the DNA released by residual tumor clones to predict the risk of recurrence. However, this core biological assumption is not applicable in all situations. Especially in early-stage tumors or after radical treatment, the ctDNA levels in the body are already very low. Tumors that are small in size, grow slowly, have a mild degree of necrosis, or are located in areas with limited release capabilities (such as the central nervous system or abdominal cavity) are difficult to release sufficient DNA into the bloodstream. Even if there are residual lesions, the signals may not be detectable (Pellini and Chaudhuri, 2022; Zhong et al., 2023).

Although the specificity of ctDNA-MRD is usually quite high, its sensitivity is only 40% to 70%, and this problem becomes more obvious when conducting a single test (Pellini and Chaudhuri, 2022; Sato, 2025). In my research, I found that continuous multiple samplings can improve the accuracy of the detection. Additionally, the heterogeneity of tumors and clonal evolution make the interpretation of results more complex-those residual subclonal lesions that were not tracked or new dominant clones that emerged may not be captured by the preset detection panel (Semencovich et al., 2023). Moreover, postoperative inflammation, tissue repair, and adjuvant therapy can temporarily change the background environment of cfDNA, so the negative results in the early postoperative period are not reliable and cannot be regarded as evidence of complete cfDNA clearance (Faulkner et al., 2022; Zhong et al., 2023). Therefore, for low-release tumors, a negative ctDNA result can only be understood as "not detected", not equivalent to "absent", and must be combined with pathological risk factors and imaging follow-up for comprehensive judgment (Zhu et al., 2023; Wang et al., 2025).

4.2 Technical noise, chip interference and platform differences

Apart from the biological factors mentioned earlier, technical issues also introduce considerable uncertainty to the ctDNA-MRD detection. The core of MRD detection is to capture extremely subtle frequency changes, which makes the detection results highly susceptible to various factors, such as errors in polymerase chain reaction products, sequencing errors, oxidative damage, and various interferences during the in vitro processing. Even with the use of UMI tagging, dual-end sequencing, and computational noise reduction techniques, background errors cannot be completely eliminated. Once the true variant signal approaches the detection threshold, the risks of false negatives and false positives will significantly increase (Semenkovich et al., 2023).

Among them, the ambiguous potential clonal hematopoiesis (CHIP) is a crucial interfering factor. Genes such as *DNMT3A, TET2, ASXL1*, and *TP53*, which are age-related mutations, often appear in plasma cfDNA and can overlap with the tumor mutation profile. Without paired leukocyte sequencing or without a strict screening process, these mutations may be misidentified as ctDNA from tumor sources, thereby leading to false positive results (Kasi et al., 2022; Sato, 2025). In addition, the differences between different detection platforms are also significant, such as target design, library preparation, cfDNA input volume, sequencing depth, error models, and positive thresholds. These differences limit the comparability of the detection results. Low VAF variations may also lead to different results from different platforms, causing difficulties in individual result interpretation and cross-study integration (Figure 2). Therefore, standardized operating procedures and cross-platform validation are still necessary to improve the reliability of the detection (Pellini and Chaudhuri, 2022; Zhong et al., 2023; Hoang et al., 2025).

4.3 Risks of over-reliance on ctDNA-MRD in clinical decision-making

As the prognostic value of ctDNA-MRD has been increasingly recognized by more and more people, in clinical decision-making, sometimes its role is overemphasized. However, from the perspective of practical application, due to its limited sensitivity, a negative ctDNA result does not mean that the patient has completely recovered. I have found that some patients who later relapsed had negative ctDNA test results at key follow-up time points. If

the treatment intensity is prematurely reduced based solely on this negative result, it may affect the long-term treatment outcome (Faulkner et al., 2022; Hoang et al., 2025).

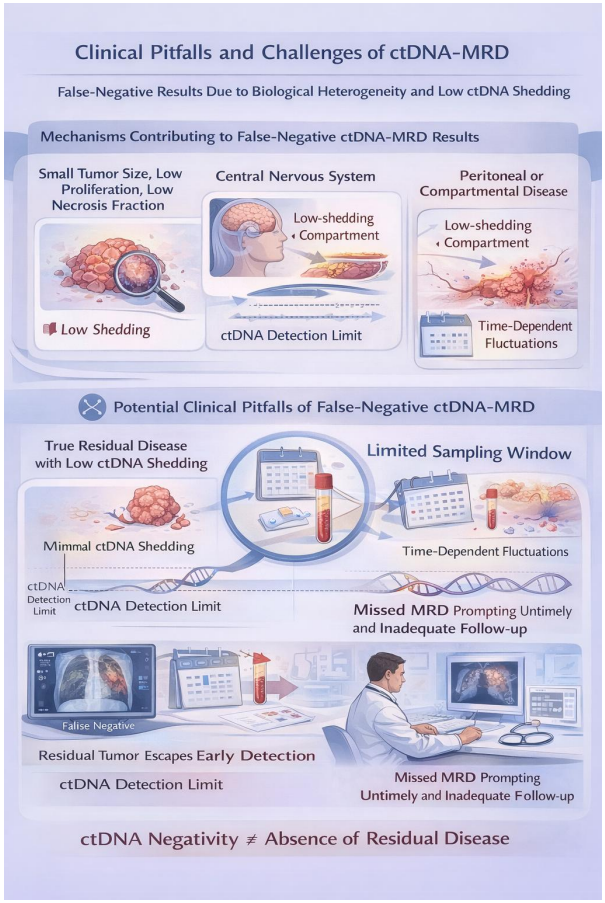

Figure 2 Biological and Technical Determinants of ctDNA-MRD Accuracy

Conversely, relying solely on positive ctDNA results and blindly intensifying high-cost and high-risk treatments will also expose patients to unnecessary risks, especially when there is no reliable evidence from randomized controlled studies to support it (Zhu et al., 2023). Over-interpreting ctDNA results can also lead to excessive imaging examinations, invasive surgeries, or prolonged systemic treatment times, which not only increase the economic burden on patients but also bring additional clinical risks (Semenkovich et al., 2023). Therefore, ctDNA-MRD can only serve as an auxiliary tool for clinical decision-making and cannot be used as the sole basis for decision-making. It must be combined with the patient's pathological characteristics, imaging results, treatment history, and other biomarkers, and also requires confirmation through prospective trials to determine whether MRD-guided intervention measures can truly improve the survival benefits of patients (Chen et al., 2025).

5 The Integrated Application of ctDNA-MRD and Imaging Technology

5.1 Complementarity in time and information

ctDNA-MRD and imaging do not look at the tumor from the same angle. ctDNA focuses on molecular signals circulating in the whole body and often raises an alarm before structural changes become visible. Imaging, on the other hand, shows where the lesion is, how large it is, and how it should be staged—information that remains essential for treatment planning (Pantel and Alix-Panabières, 2024). In non-small cell lung cancer and colorectal cancer, ctDNA conversion from negative to positive frequently precedes radiographic relapse by several months, a period described as the “molecular recurrence window” (Zheng et al., 2024; Azzi et al., 2025). Imaging abnormalities usually appear only after the tumor reaches a detectable size or metabolic threshold.

From a practical perspective, ctDNA reflects residual tumor burden, clonal shifts, and emerging resistance, while imaging answers a more direct clinical question: where is the disease and can it be treated locally? (Semenkovich

et al., 2023). Neither approach is sufficient alone. ctDNA lacks spatial resolution, and imaging may miss small or diffuse lesions. For this reason, several studies advocate placing ctDNA results alongside imaging and conventional markers within the same follow-up pathway, using molecular changes to prompt more focused radiological evaluation and guide intervention (Bent et al., 2022; Chidharla et al., 2023; Pantel and Alix-Panabières, 2024).

5.2 Managing discordant results

In real-world follow-up, discrepancies between ctDNA and imaging are not unusual. Rather than treating one test as definitive, it is more reasonable to interpret both within a structured clinical context. When both ctDNA and imaging are positive, the likelihood of residual or recurrent disease is high, and timely restaging with multidisciplinary discussion is warranted (Wang et al., 2025).

Positive imaging but negative ctDNA may be related to low release or detection sensitivity, or it could be caused by inflammation or post-operative changes. Repeated imaging, tissue biopsy, or dynamic ctDNA monitoring can help clarify (Semenkovich et al., 2023). On the contrary, a single positive ctDNA result often indicates molecular recurrence below the resolution of imaging (Zheng et al., 2024), and the recurrence risk has significantly increased before imaging diagnosis (Zhu et al., 2023; Azzi et al., 2025; Negro et al., 2025). Enhanced imaging or shortening the follow-up interval may detect hidden lesions (Dasari et al., 2023; Maddalena et al., 2024). At present, a more reliable approach is to repeat confirmation and dynamic follow-up rather than immediately upgrading treatment (Pantel and Alix-Panabières, 2024).

5.3 Integration of functional imaging and artificial intelligence

Functional imaging techniques such as PET-CT, DWI-MRI and dynamic enhancement technology can capture metabolic or perfusion abnormalities before structural changes occur, thereby shortening the time gap between molecular and imaging recurrence (Semenkovich et al., 2023; Pantel and Alix-Panabières, 2024). In cases where ctDNA is positive but conventional imaging is negative, functional imaging is helpful for localization; if ctDNA and functional indicators decrease simultaneously, it can also support the judgment of therapeutic efficacy (Emiloju et al., 2024).

Radiomics and artificial intelligence enhance the ability of individualized recurrence prediction by integrating imaging features, ctDNA dynamics, and clinical variables (Semenkovich et al., 2023; Hoang et al., 2025). Multimodal omics models that integrate ctDNA, protein markers, and imaging information show certain predictive gains (Sabit et al., 2025). However, inconsistent imaging collection standards, differences in ctDNA platforms, and the lack of prospective validation still limit its widespread application. To achieve the integrated application of multimodal MRD, a unified process, standardized time points, and clear clinical endpoints are required (Pantel and Alix-Panabières, 2024; Wang et al., 2025).

6 Concluding Remarks

Over the years, the emergence of ctDNA-MRD has led us to re-evaluate how "residual lesions" should be assessed. In the past, more reliance was placed on imaging, and only visible lesions were considered valid; now, there is an additional molecular perspective. Especially during the uncertain period following radical treatment for early solid tumors, ctDNA can capture extremely low levels of tumor molecular traces throughout the body, which are difficult to cover by imaging and traditional pathological indicators. A large number of prospective studies and systematic reviews have repeatedly proven that if ctDNA remains positive after treatment, the risk of recurrence and death will significantly increase. In cancers such as colorectal cancer and non-small cell lung cancer, the performance of ctDNA-MRD in risk classification often outperforms traditional staging and pathological high-risk factors, and thus has gradually become an important reference in postoperative stratification, adjuvant treatment decision-making, and follow-up optimization.

However, when it comes to actual clinical application, problems arise. The sensitivity of a single test remains limited in MRD or early disease scenarios. Although longitudinal monitoring can increase the detection rate, false negatives still exist. Low tumor release, limited lesions confined to specific anatomical regions, inappropriate

sampling time, and failing to meet the required detection sensitivity can all lead to the actual residual being "missed". Therefore, a more accurate understanding of ctDNA negativity should be "no signal detected at present", rather than complete clearance. On the other hand, CHIP, technical noise, and threshold differences between different platforms may also lead to false positives. If there is a lack of strict preprocessing procedures and variant filtering strategies, the interpretation of results can easily be disturbed, and even unnecessary examinations or treatment intensification may be triggered.

ctDNA-MRD does not work well as a standalone decision tool. In practice, its results need to be interpreted alongside imaging findings, pathological features, and the broader clinical context. ctDNA may signal molecular relapse earlier than structural changes appear, but it cannot indicate where the lesion is or how extensive it is—questions that imaging still answers more directly. Looking at both together usually provides a clearer and more dependable picture of residual disease. With further integration of multi-omics data, functional imaging, and artificial intelligence models, ctDNA-MRD may gradually move beyond simple risk estimation toward a more practical role in clinical decision-making. However, until stronger prospective evidence is available, a cautious approach remains advisable—combining multiple modalities, discussing cases within multidisciplinary teams, and, whenever possible, enrolling patients in clinical trials to ensure that potential benefits do not come at the expense of safety.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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Concentration and Heterogeneity of Medication Combination Patterns for Common Diseases in Retail Pharmacies: Evidence from Xiongcheng Jianmin Pharmacy in Zhuji City, 2023-2024

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Abstract This study systematically characterizes the concentration and heterogeneity of medication-use structures for common diseases in retail pharmacies from a "medication combination" perspective, aiming to reveal real-world decision-making logic in primary care medication use and to identify potential risks of inappropriate medication use. Using health insurance settlement sales and electronic dispensing data from Xiongcheng Jianmin Pharmacy in Zhuji City, Zhejiang Province, covering 2023–2024, transaction records were taken as the unit of analysis to construct disease-level indicators of medication combination concentration. Drawing on industrial organization theory, the Herfindahl–Hirschman Index (HHI) was introduced to quantitatively measure the degree of concentration or dispersion of medication combinations across different diseases based on sales revenue, and to compare structural differences among disease categories. A total of 19,661 valid purchase records were included during the study period, with cumulative sales of approximately RMB 4.376 million. The results indicate pronounced disease-specific differentiation in medication combination concentration in retail pharmacies: chronic conditions such as hypertension and hyperlipidemia exhibit highly concentrated medication use centered on a small number of core drugs, forming a stable structure characterized by a "single core drug plus a limited number of adjunctive medications"; in contrast, gastrointestinal diseases, sleep disorders, and functional conditioning conditions show lower concentration, with the coexistence of traditional Chinese medicines and chemical drugs, more dispersed structures, and marked heterogeneity, which are more susceptible to patients' individual preferences, pharmacists' recommendations, and price factors. Overall, medication combinations for common diseases in retail pharmacies display a structural pattern in which high-frequency core combinations dominate alongside numerous low-frequency long-tail combinations. Indicators of medication combination concentration and heterogeneity effectively capture real-world primary care medication behaviors and provide new quantitative tools and empirical evidence for identifying potential drug-related problems, optimizing pharmacist interventions, and advancing rational medication management.

Keywords Retail pharmacy; Medication combinations; Concentration; Heterogeneity; Rational drug use

1 Introduction

With the continued advancement of China's tiered diagnosis and treatment system and the ongoing improvement of the primary healthcare service network, the role of retail pharmacies in the supply of medicines for common and frequently occurring diseases has become increasingly prominent. Compared with medical institutions, retail pharmacies are characterized by wide geographic distribution, high accessibility, and convenient access to medicines, and have thus emerged as important healthcare service nodes for community residents to meet initial medication needs for acute minor illnesses and chronic conditions (Miller and Goodman, 2016). Previous studies have shown that, particularly in Asia and in low- and middle-income countries, patients are more inclined to obtain medications for common diseases through retail pharmacies. In China's urban and rural primary care settings, the functions of retail pharmacies have gradually expanded from simple drug sales to include a certain degree of pharmaceutical consultation and preliminary medication guidance, making them important venues for self-medication and primary health management among residents.

Against the backdrop of a continuously increasing burden of chronic diseases and the growing prevalence of multimorbidity, the complexity of medication regimens among primary care populations has risen markedly. Retail pharmacies have assumed an increasingly central role in the routine medication management of conditions

such as hypertension, diabetes, respiratory tract infections, and pain-related syndromes. However, evidence from primary care studies indicates that drug-related problems (DRPs) are highly prevalent in community populations, including inappropriate drug selection, irrational dosage or treatment duration, and poor medication adherence, with the proportion of affected patients exceeding 70% in some studies (Ni et al., 2022). In real-world retail pharmacy settings, medication use is often organized around "medication combinations," whereby consumers select multiple drugs during a single purchase to address a specific symptom or symptom cluster. The formation of such medication combinations is jointly influenced by disease spectrum, empirical medication pathways, pharmacists' recommendations, patients' knowledge and perceptions, and drug availability (Do et al., 2025). Existing research has demonstrated that polypharmacy is significantly associated with an increased risk of drug-related problems; nevertheless, when supported by adequate evidence, rational combination therapy can also play an important role in improving the control of complex symptoms (Xiao et al., 2023; Meng et al., 2023).

This study aims to explore the value of analyzing medication structures in retail pharmacies from a "medication combination" perspective in elucidating real-world medication decision-making processes. Compared with analyses focused on single drugs, a medication combination approach is better suited to capturing the characteristics of medication practices in primary care settings. The concentration of medication combinations reflects the dominance of a limited number of commonly used regimens in actual practice, whereas heterogeneity indicates the degree of dispersion among different combinations in terms of composition and potential risk profiles. Given that existing studies have largely focused on prescription structures in medical institutions or on aggregate pharmaceutical sales at the macro level, quantitative analyses of medication combination structures in real-world retail pharmacy contexts remain relatively scarce. Based on real sales and electronic dispensing data from Xiongcheng Jianmin Pharmacy in Zhuji City, Zhejiang Province, from 2023 to 2024, this study systematically examines the concentration and heterogeneity of medication combinations for common diseases in retail pharmacies, compares structural differences across disease categories, and identifies potential risks associated with inappropriate medication combinations, with the aim of providing empirical evidence to support the optimization of primary pharmaceutical management and the formulation of rational drug use policies.

2 Data and Research Methods

2.1 Data sources

The data used in this study were obtained from the health insurance settlement sales detail records of Xiongcheng Jianmin Pharmaceutical Co., Ltd. in Zhuji City, covering the period from January 2023 to December 2024. Transaction records served as the basic unit of analysis, encompassing all health insurance–reimbursed medication purchase activities that occurred at the pharmacy during the study period. The dataset exhibits a high degree of completeness and reliability. The main variables include the name of the medical institution, settlement date, disease code, drug name, drug category, sales volume, unit price, and payment structure. Among these, disease codes provide an approximate indication of the disease type associated with each purchase, while drug expenditure data offer a quantitative basis for analyzing medication-use structures and concentration (Fourkiotis and Tsadiras, 2024; Iqradiya and Wijayanti, 2025).

The study period was defined from January 1, 2023, to December 31, 2024, covering two consecutive complete calendar years. A total of 19,661 valid sales/dispensing records were included, with 10,080 records from 2023 and 9 581 from 2024. The transaction volumes across the two years were comparable, with no significant discontinuities or abnormal fluctuations observed. The cumulative sales revenue during the study period amounted to approximately RMB 4.376 million, with an average transaction value of about RMB 222.6, indicating that the pharmacy maintained a relatively stable scale of operation and service demand structure throughout the study period.

2.2 Analysis of medication combination concentration for common diseases

2.2.1 Diseases with high concentration

For certain common chronic diseases, medication combinations exhibit a highly concentrated pattern. For example, in conditions such as hypertension, hyperlipidemia, and some cardiovascular-related diseases, patients'

medication choices in retail pharmacies are highly centered on a small number of core therapeutic drugs. These diseases are typically supported by well-established clinical guidelines and mature pharmacological treatment regimens, and the core drugs involved tend to have low substitutability, resulting in stable medication-use structures at the retail pharmacy level. Although adjunctive medications are present, their types and frequency of use are relatively fixed and exert a limited influence on the overall combination structure. The presence of highly concentrated medication combinations reflects, on the one hand, a trend toward standardized medication use in primary care, and on the other hand, the relatively limited decision-making space available in retail pharmacies for these disease categories (Macvicar and Paterson, 2023).

2.2.2 Diseases with moderate concentration

Compared with chronic diseases, the concentration of medication combinations is relatively lower for certain gastrointestinal disorders, sleep disorders, and metabolic dysfunctions. These conditions are characterized by greater heterogeneity in symptom presentation and marked inter-individual differences among patients, leading to more diverse medication choices. In such diseases, one or two core drugs are usually present, but there is a wider range of options for concomitant medications. The concurrent use of traditional Chinese medicines and chemical drugs is relatively common. Pharmacists' recommendations, patients' prior medication experiences, and price considerations all play important roles in shaping the final medication combinations (Wang et al., 2023).

2.3 Conceptual framework for measuring medication combination concentration

In studies of medication use for common diseases in retail pharmacies, medication combination concentration is used to reflect whether drug sales under a specific disease context are primarily concentrated in a small number of core drugs, thereby revealing the structural characteristics of medication purchasing and decision-making by patients and pharmacists. A higher level of concentration generally indicates a narrower range of medication choices, a more pronounced dominance of core drugs, and stronger stability and path dependence in medication-use pathways. Conversely, a lower level of concentration suggests more dispersed drug use, greater diversity of medication combinations, and more pronounced differences in medication choices among patients.

Drawing on classical methods for measuring market structure and competitive patterns in industrial organization theory, this study treats medication combinations corresponding to different diseases in retail pharmacies as a form of "quasi-market structure." From the perspective of sales revenue—which jointly reflects frequency of use, price levels, and patient preferences—a medication combination concentration index is constructed. This index allows for an intuitive depiction of medication-use structures for different diseases at the retail pharmacy level and provides a quantitative basis for comparing differences in medication-use patterns across disease categories (Saha and Xu, 2025; Sapkota et al., 2025).

2.4 Construction of the herfindahl–hirschman index (HHI)

The Herfindahl-Hirschman Index (HHI) is employed in this study as the primary measure of medication combination concentration. The HHI captures overall concentration by summing the squares of the sales shares of individual drugs, thereby accounting for both the number of core drugs and their relative dominance, and demonstrating high sensitivity to changes in sales structure. In the field of industrial economics, this index is widely used to assess market concentration, competitive intensity, and monopoly power, owing to its intuitive calculation and clear interpretability.

In the context of this study, the introduction of the HHI facilitates the standardized quantification of medication sales structures in retail pharmacies, enabling a systematic evaluation of the degree of concentration or dispersion of medication combinations across different diseases. Compared with simple counts of drug varieties, the HHI more accurately reflects changes in the weight of core drugs within overall medication combinations, providing a more robust quantitative foundation for analyzing medication-use structures and their potential risks (Kvålseth, 2022).

2.4.1 Definition of the index

For a given disease d, the medication combination concentration index is defined as:

$$HH_d = \sum_{i=1}^{N_d} s_{id}^2$$

i denotes a specific drug;

Nd represents the number of drug types involved under disease *d*;

Sid denotes the share of sales revenue of drug *i* under disease *d*, which is calculated as follows:

$$S_{id} = \frac{Revenue_{id}}{\sum_{i=1}^{N_d} R\,evenue_{id}}$$

$Revenue_{id}$ denotes the sales revenue of drug *i* for disease *d*

3 Empirical Results on Medication Combination Concentration

3.1 Overall distribution of medication combination concentration across diseases

The concentration of medication combinations for common diseases in retail pharmacies is not uniformly distributed but instead exhibits pronounced differentiation across disease categories. Differences in pathological mechanisms, therapeutic objectives, and clinical medication guidelines lead to distinct medication-use structure patterns at the retail pharmacy level. Specifically, medications for chronic disease management have gradually formed relatively stable and standardized combination structures in retail settings, with core drugs occupying a dominant position in both sales and utilization, and medication pathways showing a high degree of consistency and predictability. In contrast, symptom-oriented and conditioning-related diseases are characterized by more diverse clinical presentations and greater inter-individual variability, with treatment goals focusing more on symptom relief and overall regulation. As a result, medication combinations for these conditions retain greater flexibility, with more dispersed drug choices and higher levels of diversity and variability in medication regimens (Sikora et al., 2023; Santana et al., 2025).

These findings reflect, on the one hand, the guiding role of clinical medication guidelines and standardized treatment pathways in shaping primary care medication practices, particularly in the field of chronic disease management. On the other hand, they also highlight the functional positioning of retail pharmacies in meeting residents' diverse and individualized health needs. Based on empirical evidence from real-world retail pharmacy sales data from 2023 – 2024, clear and stable differences in medication combination concentration and heterogeneity are observed across major disease categories, providing a solid foundation for further disease-specific analyses of medication-use structures (Table 1).

Table 1 Descriptive statistics of medication combination concentration (hhi) across diseases

Disease Category	Number of Drug Types	Sales Share of Top 3 Drugs	HHI
Hypertension	Few	High	High
Hyperlipidemia	Few	High	High
Sleep Disorders	Moderate	Moderate	Moderate
Gastrointestinal Diseases	Many	Moderately Low	Moderate
Functional Conditioning Conditions	Many	Low	Low

As shown in Table 1, there are significant differences in medication combination concentration across disease categories. Chronic conditions such as hypertension and hyperlipidemia exhibit markedly higher HHI values, indicating that medication use is highly concentrated on a small number of core drugs; in contrast, gastrointestinal diseases and functional conditioning conditions show relatively lower HHI values (Albayrak and Demirbaş, 2023).

3.2 Medication-use structure characteristics of high-concentration diseases

Diseases with high medication combination concentration typically exhibit clear and stable medication-use structures, with the core feature characterized by a "single core drug plus a limited number of adjunctive medications" pattern. In the sales and use of medicines for such diseases, the core drug is usually targeted at the

primary pathological mechanism or key symptoms, has a well-defined therapeutic indication, and occupies an absolutely dominant position in both sales revenue and frequency of use. By comparison, adjunctive medications are mainly used to alleviate accompanying symptoms, reduce adverse reactions, or improve overall treatment adherence, and therefore account for a relatively limited range of use and a smaller share of total sales.

Previous studies have shown that, in high-concentration diseases, core drugs generally exhibit low clinical substitutability. This is attributable, on the one hand, to their strong evidence base and well-established therapeutic efficacy, and on the other hand, to their high degree of consistency with clinical guidelines and empirical medication pathways. As a result, patients and pharmacists tend to adhere to existing regimens in actual medication decision-making, and medication pathways display a high level of stability and predictability (Bektay et al., 2025; Malekzadeh et al., 2025). Consequently, the medication-use structure for these diseases is overall characterized by a high degree of concentration in drug varieties, simple combination patterns, and low variability, which is particularly evident at the retail pharmacy level (Table 2).

Table 2 Examples of medication combination structures for high-concentration diseases

Rank	Drug Name	Share of Sales Revenue
1	Core antihypertensive/lipid-lowering drug	High
2	Adjunctive traditional Chinese medicine	Moderate
3	Other concomitant medications	Low

3.3 Heterogeneity characteristics of diseases with low to moderate concentration

Medication combinations for diseases with low to moderate concentration exhibit pronounced heterogeneity, as their medication-use patterns lack a clearly dominant single drug and show substantial variation in drug choices across patients. In real-world practice, traditional Chinese medicines and chemical drugs often coexist. Some patients tend to prefer traditional Chinese medicines that offer holistic regulation or relief of multiple symptoms, whereas others favor chemical drugs with clearly defined targets and faster onset of action. As a result, the overall medication-use structure for these diseases displays a high degree of diversity.

Moreover, medication decision-making for these diseases is more susceptible to non-clinical factors. On the one hand, patients' prior medication experiences, levels of health literacy, and subjective perceptions of drug safety partially shape their medication preferences. On the other hand, pharmacists' professional advice, recommendation habits, and promotional strategies in retail pharmacies also play an important role in the purchasing process. At the same time, drug prices and the trade-offs between cost and therapeutic effectiveness—particularly in contexts with a high proportion of out-of-pocket payment—further exacerbate differences in medication combinations (Ahmadipour and Sarafinejad, 2024; Gülpınar et al., 2024). Consequently, diseases with low to moderate concentration tend to exhibit medication-use characteristics at the retail pharmacy level that are marked by dispersed drug varieties, flexible combination patterns, and high structural volatility (Table 3).

Table 3 Distribution characteristics of medication combinations for diseases with low concentratio

Disease Category	Share of Core Drugs	Number of Concomitant Drugs	Share of Traditional Chinese Medicines
Gastrointestinal Diseases	Moderate	Many	Moderate
Sleep Disorders	Moderate	Moderate	Moderate High
Conditioning-Related Diseases	Low	Many	High

4 Discussion

Based on real-world data from retail pharmacies, this study systematically characterizes the concentration and heterogeneity of medication-use structures for common diseases from a meso-level analytical perspective centered on "medication combinations." The findings indicate that medication combinations for common diseases in retail pharmacies overall exhibit a structural pattern in which a small number of high-frequency core combinations dominate, alongside a large number of low-frequency long-tail combinations. This structure differs both from the

simple concentration patterns commonly observed in single-drug sales analyses and from the highly standardized treatment pathways found in prescriptions from medical institutions, reflecting the combined effects of self-medication practices, pharmacists' recommendations, and individual patient differences in the retail pharmacy context (Nnanga et al., 2025). In particular, diseases with relatively well-defined diagnostic and therapeutic pathways tend to show higher levels of medication combination concentration, highlighting the reliance of primary care medication practices on evidence-based guidelines and empirical treatment pathways. In contrast, in symptom-oriented conditions or diseases characterized by greater heterogeneity, medication-use structures are markedly more dispersed, exhibiting higher levels of combination diversity and individualization.

From the perspective of disease-type differences, the differentiation in medication combination concentration and heterogeneity has clear clinical and behavioral underpinnings. Conditions such as upper respiratory tract infections, pain, and inflammatory symptoms, for which symptom recognition is relatively straightforward and commonly used medications are stable, are more likely to form core medication pathways with high concentration and low heterogeneity. Conversely, mild gastrointestinal conditions, allergic reactions, and medication use related to chronic diseases complicated by multimorbidity show substantial variation in combination size, drug category composition, and patterns of concomitant use (Calzetta et al., 2024).

These findings suggest that heterogeneity in medication combinations should not be equated simplistically with irrational drug use; rather, to a considerable extent, it reflects disease complexity, differences in patient needs, and the expansion of decision-making space for medication use in primary care settings. At the same time, however, increased combination complexity also implies elevated risks of potential drug–drug interactions, duplicate medication use, and other drug-related problems, which warrant particular attention in elderly populations and in long-term medication use for chronic diseases (Ouraou et al., 2025).

At the practical and policy levels, this study demonstrates that indicators of medication combination concentration and heterogeneity can serve as important tools for promoting rational medication management in retail pharmacies. On the one hand, highly concentrated core medication combinations can provide an entry point for identifying "standardized medication pathways," thereby facilitating focused monitoring and standardized medication guidance in high-frequency transaction scenarios (Hajj et al., 2024). On the other hand, disease areas characterized by high heterogeneity and greater combination complexity require pharmacist-led individualized medication assessments and risk interventions.

Compared with management approaches focused on single drugs, analyzing medication-use structures from the perspective of medication combinations more closely aligns with real-world medication behaviors and is better suited to identifying potential structural risks (Lampe et al., 2023). Future research could further validate these findings across multiple regions and types of retail pharmacies, and integrate medication combination characteristics with clinical outcomes, adherence, and intervention effects, thereby providing more refined empirical evidence to support the development of primary pharmaceutical care systems and rational drug use policies.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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Research Insight Open Access

The Role of Nurses in Medication Reconciliation, Patient Education, and Adherence Management

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Abstract This study explored the core role of nursing staff in the drug safety management system. Nursing staff do not merely implement safety regulations; they also bear the core responsibilities of drug risk warning and prevention. In the drug verification process, nursing staff, through multiple duties such as prescription review, risk identification of medication use, and dynamic monitoring of high-risk drugs, build a crucial defense line to ensure the safety of patients' medication use. In the dimension of medication education, nursing staff, through the formulation of personalized guidance plans and the implementation of medication risk notification education, enhance patients' health literacy and self-care ability, and help them accelerate the recovery process. In the field of medication compliance management, nursing staff can significantly improve the long-term medication compliance level of patients with chronic diseases by establishing an efficient communication mechanism, implementing regular follow-up plans, and providing continuous nursing services. This study also analyzed the core challenges faced by nursing staff when conducting drug management work, and proposed that through strengthening professional training, improving the management system framework, and deepening interdisciplinary collaboration mechanisms, the role of nursing staff in the entire process of drug management can be guaranteed, which has important practical value and academic significance for improving the safety of drug treatment and optimizing clinical intervention effects.

Keywords Nurses; Medication reconciliation; Patient education; Medication adherence; Medication safety management

1 Introduction

In the daily clinical diagnosis and treatment work, the drug administration process usually involves multiple operational steps, such as prescribing, preparing the medication, bedside administration, and the transmission of medical orders, all of which are included. Any omission in any of these steps may lead to drug-related adverse events, thereby prolonging the hospital stay of patients, increasing the probability of readmission, and also increasing the overall medical expenses (Vasilevskis et al., 2025). In fact, various safety reports and international action initiatives have pointed out that in the "Drug Safety" special program implemented by the World Health Organization, the risk management and verification requirements emphasized are not merely for occasional operational mistakes by healthcare workers, but rather directly target the systematic loopholes in the medical service process. Therefore, improving the drug verification mechanism, strengthening the interdepartmental sharing and communication of drug-related information, and clearly explaining the medication methods and precautions to patients are all practical and effective measures to reduce the incidence of medication-related problems and even the risk of death caused by such problems.

In the construction and operation of the drug safety management system, nursing staff always occupy a core position. They not only have the most frequent and close contact with patients, but also are the last line of defense for ensuring safety in the drug usage process. Relevant studies have shown that the specific job responsibilities of nursing staff vary depending on the working scenarios-whether in the tense emergency scene, during patient transfer or department referral, or in the long-term management of chronic diseases and palliative care, their responsibilities have differences.

Although the tasks in different scenarios have their own focuses, the daily workload of nursing staff is generally heavy. They need to undertake multiple key tasks: verifying the patient's previous medication history, identifying potential medication safety hazards, checking and questioning questionable medical orders, collaborating with other relevant departments, explaining the specific dosage and timing of medication to patients and their families, closely monitoring the patient's physical reactions and various drug adverse reactions, and promptly answering patients' various medication-related questions. Through these meticulous tasks, the safety of drug use is effectively guaranteed, and individualized treatment plans can be better implemented in clinical practice (Li et al., 2025).

This study aims to examine the specific responsibilities of nursing staff in medication reconciliation, medication education, and support for medication adherence. Clarifying these roles more precisely is not only closely related to patient outcomes but also directly affects the efficiency of clinical team collaboration. By adopting a continuous tracking and evaluation model that spans inpatient care and outpatient follow-up, and by integrating verification processes with educational interventions, it is expected that medication errors can be reduced, patient adherence improved, and disease control outcomes strengthened. However, evidence at the institutional level remains inconsistent, and real-world implementation is often constrained by factors such as uneven training and inadequate support systems. A careful re-examination of the role of nursing staff can help guide capacity building, workforce allocation, and the optimization of multidisciplinary collaboration models, while also informing improvements in nursing education. More importantly, this approach will contribute to fully recognizing and leveraging the professional contributions of frontline nursing staff, thereby enhancing overall medication safety and promoting the quality of patient-centered nursing care.

2 The Conceptual Framework of Drug Validation and Its Significance in Clinical Practice

2.1 The meaning and key contents of drug validation

Drug verification, also known as prescription review or medication check, specifically refers to a systematic verification of drug names, dosages, administration routes, frequencies of administration, and patient basic information during the preparation stage before the patient starts taking medication. The core purpose of this process is to ensure that all information is consistent with the current valid medical orders, and to conduct a comprehensive assessment of the safety, appropriateness, and feasibility of the prescription. In the current era of widespread digital healthcare, drug verification work is generally carried out through electronic prescription systems or dedicated verification modules. This operation is not merely a simple mechanical verification, but rather a clinical decision-making process that requires professional analysis and judgment (Chan et al., 2025).

Specifically, drug validation mainly encompasses the following key aspects:

Verify the consistency between the medication and the doctor's orders: this includes the name of the drug, concentration, form, route of administration, single dose, frequency of administration, and treatment duration, ensuring that it is completely in line with the original doctor's orders.

Confirm patient information and condition: Verify the patient's identity, and simultaneously refer to their diagnosis, age, weight, renal function and other relevant indicators and test results;

Assessing treatment risks: Analyze potential risks such as dosage errors, medication mistakes, repeated dosing, contraindications, and drug interactions;

Documentation and Communication: Comprehensively document the verification results and promptly communicate and confirm with the prescribing doctor (Chan et al., 2025).

From the perspective of human factors engineering, if a structured double-checking mechanism can be established, clear standard operating procedures can be formulated, "verification pause points" can be set at key stages, and mutual verification among teams can be encouraged, it will help reduce the workload of medical staff, minimize external interference, and thereby lower the medication risks caused by human cognitive biases.

2.2 The critical role of medication reconciliation in preventing medication errors

A robust medication reconciliation mechanism serves as a crucial safeguard against the translation of systemic flaws into actual medication errors, effectively preventing errors from propagating through prescribing, preparation, and system programming stages to the patient. Numerous studies have demonstrated that structured reconciliation processes can significantly reduce medication error rates across various clinical settings. For example, in prehospital emergency care and pediatric anesthesia, the implementation of cross-checking or double-checking mechanisms enables the timely identification and correction of potential errors without delaying clinical care.In routine clinical practice, critical steps such as dose verification and patient identity confirmation are particularly susceptible to interruptions, thereby increasing the likelihood of errors. Simulation studies indicate that standardized procedures combined with targeted interventions can effectively reduce reconciliation failures and medication errors attributable to interruptions. In environments utilizing electronic prescribing and clinical decision support systems, insufficient review of system alerts-especially during system malfunctions， can further elevate medication-related risks, underscoring the essential safety role of manual medication reconciliation. Overall, medication reconciliation is widely regarded as an efficient and direct strategy for enhancing medication safety.

2.3 The necessity of establishing standardized medication reconciliation processes

Although medication reconciliation plays a vital role in ensuring medication safety, there remains a lack of unified standards in current clinical practice. Variability in workflows and operational approaches among healthcare personnel substantially weakens the protective effect of reconciliation processes. Evidence suggests that factors such as excessive workload, frequent environmental interruptions, the parallel use of paper-based and electronic systems, and habitual verification practices may compromise reconciliation quality and lead to the omission of critical steps. Quality improvement initiatives have shown that systematically integrating standardized medication reconciliation processes into ward management, medication regimen changes, and patient discharge procedures can reduce procedural variability, improve communication efficiency, and lower the incidence of medication errors. Such processes typically delineate responsibility, specify implementation timing and documentation requirements, and are supported by tools such as checklists, optimized electronic systems, and intelligent technologies (e.g., barcode scanning and mandatory verification steps), thereby providing a structured framework for medication safety.

3 The Role of Nurses in Medication Verification and Its Value in Risk Prevention

3.1 Key control practices throughout the medication verification process

In the processes of medication dispensing and administration, nurses are involved at every stage-from prescription initiation to medication preparation, administration, and post-administration monitoring-serving as a critical line of defense within medication safety verification systems. Nursing responsibilities extend beyond isolated time points and involve continuous, dynamic decision-making based on standard operating procedures and patients' clinical conditions. Prior to medication administration, nurses are required to complete several essential verification tasks, including confirmation of patients' allergy histories and key clinical indicators, assessment of potential drug incompatibilities, and verification of technical details such as dilution concentrations and dose calculations. These steps are frequently overlooked in practice yet are crucial for medication safety (Taş and Baykara, 2024; Nursery and Chrismilasari, 2024).

During the administration phase, nurses re-verify patient identity, assess the suitability of the care environment, and confirm the accuracy of dosage, route, administration method, and site. Continuous observation of patients' immediate responses enables early identification and timely management of potential adverse or emergency events (Uramatsu et al., 2024). Following medication administration, verification extends into a closed-loop management process focused on ongoing monitoring and standardized documentation. Nurses closely track patients' physiological and psychological responses and maintain detailed, traceable records of administration time, dosage, route, adverse reactions, and remaining medication volumes (Taş and Baykara, 2024).

Evidence indicates that nurses often employ implicit safety practices, such as optimizing medication preparation sequences and repeatedly cross-checking actual procedures against established protocols, to maintain process stability (Pérez et al., 2025). Furthermore, comprehensive verification strategies-including dual identity checks and cross-verification of critical medication parameters-are directly associated with significant reductions in medication errors. These findings underscore that medication verification is not merely a routine pre-administration task but a core safety function deeply embedded in nursing practice (Nursery and Chrismilasari, 2024).

3.2 Continuous identification of medication-related risks and nursing responses

Nursing staff remain at the patient's bedside for extended periods, enabling continuous assessment of clinical status and medication responses and allowing timely identification of newly emerging risks during the medication process. When patient conditions deteriorate or therapeutic effects are unsatisfactory, nurses may temporarily withhold, delay, or even discontinue medication administration and raise professional concerns regarding the appropriateness and safety of medical orders (Li, 2025). In clinical practice, nurses routinely conduct line-by-line verification of electronic medical records and physician orders. When inconsistencies or potential allergy risks are identified, double-check procedures are implemented and physicians are contacted for confirmation, thereby effectively bridging the gap between institutional requirements and real-world practice (Uramatsu et al., 2024).

Moreover, medication-related risks are not confined to the individual patient level. Environmental and organizational factors-such as workflow interruptions, ambiguous order wording, and procedural changes-also contribute to an increased risk of errors. Studies indicate that nurse-led improvement strategies, including the establishment of critical checkpoints and the use of cognitive aids, can significantly reduce verification and administration errors. Cross-sectional research further highlights structural factors such as insufficient training, inappropriate night-shift scheduling, and excessive workload as important contributors to medication errors. Accordingly, systematic countermeasures are required at the levels of process design, staff training, and working conditions. In daily practice, nurses proactively mitigate medication risks by repeatedly verifying dosages, clarifying ambiguous documentation, and appropriately utilizing pre-prepared medications, thereby transforming potential hazards into actionable solutions and reducing medication-related risks in a forward-looking manner.

3.3 Key control strategies for high-risk drugs and special populations

For high-risk drugs and susceptible populations (including pediatric patients, newborns, elderly patients, and critically ill patients, etc.), more stringent nursing supervision strategies and individualized verification plans need to be implemented. The incidence of medication errors in children and newborns has remained high, and such errors are particularly concentrated in dosage calculation, dilution ratio, infusion rate, nasal-gastric tube administration, etc. Educational intervention, double verification, application of intelligent infusion pumps, and prevention of interference during the operation process, etc., can significantly reduce the incidence of medication errors in this group, with the maximum reduction rate reaching 64%. In the intensive care unit, medication errors mainly occur in the use of antibiotics and the infusion of high-risk drugs. The insufficient knowledge of common drugs by nursing staff is an important cause of such errors, highlighting the importance of mastering solid pharmacology knowledge, carefully verifying drug concentrations and infusion rates, and strictly following operating procedures.

Some research findings indicate that the insufficient professional drug knowledge of nursing staff, coupled with the lack of adequate safety medication support conditions in clinical work scenarios, are the core factors that lead to clinical medication errors. Only by strengthening the professional knowledge level of nursing staff and creating a more suitable working environment for safe medication can the practical operational ability of nursing staff be effectively improved and help them develop a standardized and rigorous safety medication operation habit (Bibi et al., 2025). Throughout the entire process from drug dispensing to administering medication to patients, nursing staff should actively implement various safety control measures, such as strictly following the double-checking system, completing the final confirmation of medication administration at the bedside, conducting dose conversion work in accordance with norms, promoting standardized drug identification and storage management

models, strictly adhering to the medication operation procedures formulated by the department, and providing detailed medication guidance to patients (Figure 1) (Aly et al., 2023; Öztürk et al., 2024).

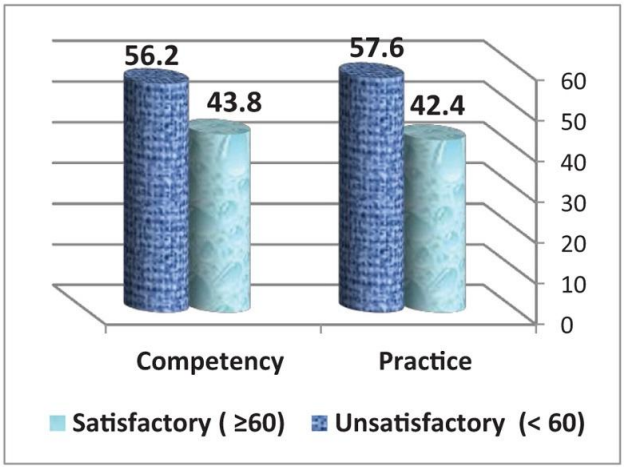

Figure 1 Percentage of nurses' practice and competency during administration of HAMs (Adopted from Aly et al., 2023)

For the elderly patient group after discharge, nursing staff can adopt a comprehensive intervention plan combining follow-up tracking, medication verification, and health education. Such intervention methods not only help reduce the probability of missed doses, repeated medication, etc., but also reduce the risk of drug interactions that may occur under complex combined medication regimens (Zhu et al., 2024). Focusing the work focus of medication verification on high-risk drugs and vulnerable populations can help medical service personnel more reasonably allocate limited medical resources and prioritize the prevention of higher-risk medication safety risks.

4 The Internal Logic and Clinical Significance of Drug Education

4.1 The logical mechanism of drug education in improving treatment outcomes

Health education on medication plays a crucial role in enhancing the clinical treatment outcomes. The core of such intervention methods is to assist patients in mastering the standardized medication methods and adjusting their daily behavioral habits to match their health needs. Clinical practice has confirmed that scientific and standardized medication guidance can significantly improve patients' compliance with medical instructions, thereby helping them more effectively manage the progression of their diseases. Clearly explaining to patients the pathogenesis of the disease, the core points of treatment, the frequency of medication use, possible adverse reactions, and the necessity of following medical advice for medication can enhance their health awareness, improve their self-health management ability, and ultimately improve the clinical treatment effects of chronic diseases such as diabetes, hypertension, and heart failure (Mustara et al., 2025; Singh et al., 2025).

Relevant data from randomized controlled trials and systematic reviews further verify that compared to traditional conventional management models, standardized medication guidance programs or targeted health education intervention measures demonstrate significant advantages in improving patients' medication compliance, optimizing blood sugar, blood pressure, and lipid control levels, and enhancing clinical treatment outcomes (Figure 2) (Mustara et al., 2025; Singh et al., 2025).

High-quality medication health education often requires customized planning based on the individual needs of patients, and is based on two-way communication between doctors and patients throughout the process. The core of this educational model is not one-way information dissemination, but a comprehensive service process that includes medication knowledge, questions about medication use, and behavioral intervention (Mustara et al., 2025). Multiple clinical practice studies have also pointed out that by distributing medication reminder cards, popularizing health education manuals, using intelligent reminder tools, and conducting multiple face-to-face communications or home visits to solve actual medication problems, it can help patients maintain good medication habits and self-health management abilities over the long term (Singh et al., 2025).

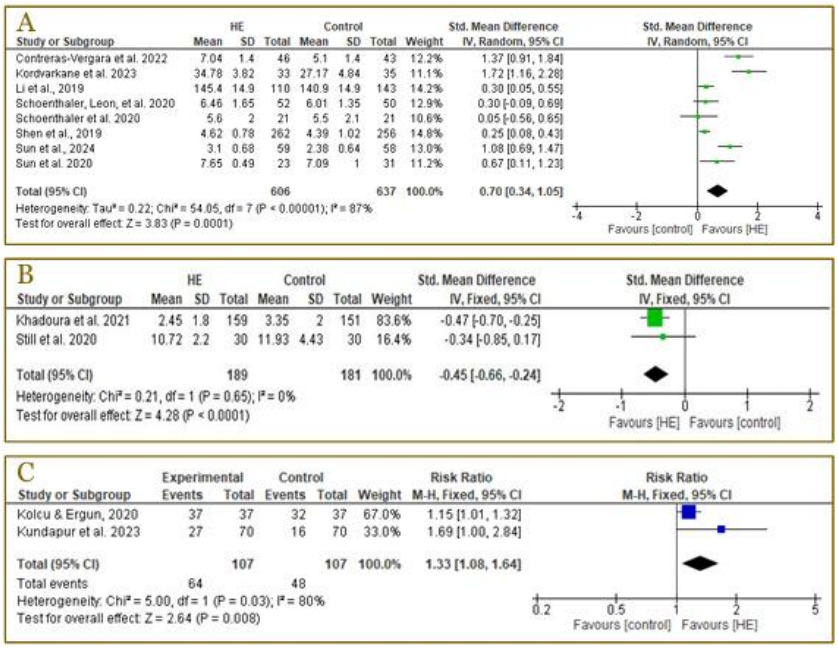

Figure 2 Meta-analysis assessing the impact of health education on medication adherence among individuals with hypertension (Adopted from Mustara et al., 2025)

Image caption: (A) The pooled effects size of health education on adherence to medication (continuous data); (B) The pooled effects size of health education on non-adherence to medication (continuous data); (C) The pooled effects size of health education on adherence to medication (dichotomous data) (Adopted from Mustara et al., 2025)

4.2 The key role of drug education in risk management

Patient medication health education plays a crucial role in ensuring the safety of clinical medication use. Without scientific and effective guidance, the goal of medication safety cannot be truly achieved. By guiding patients to identify, prevent, and properly handle various risks related to medication use (such as adverse drug reactions), their awareness of potential safety hazards can be enhanced, and they will actively report any issues that arise during medication use, thereby avoiding further damage to their health (Wasiullah et al., 2025). Systematic research targeting elderly patients has shown that a comprehensive intervention program covering medication education, prescription review, and efficacy monitoring can reduce the overall incidence of adverse drug reactions by approximately 19% and the incidence of severe adverse reactions by about 32%. This result fully confirms that scientifically planned medication health education occupies an irreplaceable core position in medication risk management.

In the design of specific educational content, medication risk communication needs to be comprehensive, detailed, and easy to understand. The content should include the expected therapeutic effects of the drugs, possible adverse reactions, types of high-risk drugs, as well as various risk factors such as age, underlying diseases, and combined medication (Wasiullah et al., 2025). Nursing staff should integrate medication risk communication into their daily medication guidance work, clearly explaining the indications for discontinuation of medication, situations requiring timely consultation with physicians, methods for avoiding repeated medication, proper medication sequence, and possible interactions between drugs and food, and over-the-counter drugs. In addition, conducting specialized training on medication safety for nursing staff has significant practical significance. Such training can expand their professional knowledge reserves, strengthen their sense of professional responsibility, and enhance their practical ability in safe medication operation. This measure not only reduces the occurrence of medication errors at the source but also enables nursing staff to provide more professional guidance to patients in preventing medication risks (Tajuddin et al., 2025).

4.3 Core goals and realization paths of patient participation in medication management

The core direction of medication education is to encourage patients to shift from a passive role of accepting

treatment to an active role in managing their own medications. By referring to theoretical models such as the "Patient Health Involvement Framework", it can be observed that the higher the patient's participation and initiative, the stronger their compliance with the treatment plan. The core reason for this correlation lies in the fact that patients' trust in the treatment will increase, and they will also establish their own sense of health responsibility. If an educational model can be established that encourages patients to ask questions actively, supports joint decision-making between doctors and patients, and respects patients' autonomous choices, this role transformation can be implemented more quickly, deepen the trust between doctors and patients during the treatment process, and lay a solid foundation for patients' long-term self-management (Wang, 2025).

To enable patients to truly participate in the management of their medication, the key lies in helping them acquire some basic medication management skills-such as learning to plan medication times, correctly using medication reminder tools, keeping medication records, and being able to clearly express their needs; at the same time, it is also necessary to assist them in overcoming medication-related obstacles from the environmental or psychological aspects. This is of great significance in clinical practice (Chien et al., 2025; Mustara et al., 2025; Singh et al., 2025). The patients fully understand the relevant information about medication, promptly clarify all kinds of questions arising during the medication process, and actively participate in the standardized medication communication process at key treatment nodes such as admission and discharge. In this way, they can more accurately grasp their own medication details, consciously avoid non-standard medication behaviors, and also cooperate more actively with the medical staff, jointly preventing medication errors and adverse drug reactions (Pendergast et al., 2025; Perry et al., 2025).

5 Core Functions of Nursing Staff in Medication Education

5.1 Popular interpretation of core medication information: administration methods, dosage, and routes

Nursing staff play an indispensable role as a communication bridge in the connection between clinical diagnosis and patient cognition. One of their core tasks is to convert professional medical instructions into understandable and practical medication guidelines for patients. Specifically, nursing staff need to clearly explain to patients the therapeutic purpose of the medication, the dosage, the frequency of administration, and the standardized medication methods. At the same time, they also need to inform patients about various attention points related to medication, and explain the relevance of these points to the patient's individual condition and the overall treatment plan (Nursery and Chrismilasari, 2024).

Many studies and clinical practices have shown that the safety of medication use is directly linked to the nursing staff's familiarity with the patient's condition. When providing medication guidance to patients, nurses must combine professional judgment and explain to the patients why this drug is suitable for their condition. They cannot simply mechanically apply general norms.

The relevant research findings show that many nursing staff in domestic hospitals often explain the usage methods of new drugs to patients and confirm whether they have understood the relevant content. However, when it comes to key information such as long-term medication precautions and subsequent dosage adjustments, there is often a lack of sufficient explanation.Nursing staff need to provide patients with detailed explanations about the effects, administration methods, treatment duration of various medications, as well as the core principles of safe medication use, such as how to avoid repeated use of the same drug, how to follow the prescribed medication sequence, and clearly specify relevant details, including how to avoid taking the wrong dosage and reminding patients not to use the medication at inappropriate times (Nursery and Chrismilasari, 2024).

5.2 Identification and guidance on adverse reactions

Monitoring of adverse drug reactions is an important component of the medication safety management system, and such content is often overlooked in routine medication guidance. Nursing staff are not only the main monitors of adverse drug reactions but also the key bridge of communication between the medical team, patients, and their families. They can detect abnormal reactions at the beginning of medication administration. If necessary, they can suspend the medication process and complete relevant records in accordance with standardized procedures. In actual clinical scenarios, many nurses have admitted that they are unsure about how to handle the expected

efficacy of the medication and adverse reactions, which also exposes the current shortcomings in medication education.

Some review studies on adverse reaction reporting and monitoring have indicated that both healthcare professionals and the patient population generally have a low level of awareness regarding drug adverse reactions, and the reporting rate of related adverse events is also at a relatively low level. This research conclusion suggests that systematic drug safety education efforts are highly necessary, and the educational content should cover the specific manifestations of common adverse reactions, the classification of high-risk drugs, and basic emergency handling principles.

5.3 Personalized medication guidance tailored to patients' individual characteristics

To ensure that health education on medication use achieves the desired results, it is necessary to tailor the guidance plan based on the patient's physical condition, cognitive ability, health literacy level, language habits, and personal preferences. From a clinical practice perspective, such personalized health guidance and intervention methods are the core components of personalized nursing services. They not only can significantly enhance patients' satisfaction with medical treatment but also can alleviate their negative psychological states during the diagnosis and treatment process (Jandaghian-Bidgoli et al., 2025). A collaborative study on elderly patients with multiple comorbidities found that if nurses actively conducted regular follow-ups, dynamically adjusted the care plan according to the patient's condition, and provided professional consultations, they could precisely identify the drug adverse reactions, potential medication risks, and complex issues in the treatment plan, making subsequent treatment arrangements more scientific and more in line with the patient's actual needs.

Nursing staff will flexibly adjust the communication methods according to the actual needs of different patients. For instance, they will prepare translation aids and written guidance manuals in advance, and explain in simple and understandable language, fully adapting to the language habits and cultural background of the patients. The specific measures of personalized guidance include: coordinating the medication time with the patient's daily routine rhythm, breaking down the complex combined medication plans into more clear and understandable parts, and organizing the patient and their family members to jointly review "Medication List" and other contents. The core goal of this type of guidance approach is to enhance the level of medication safety and at the same time motivate patients to actively participate in the treatment process (Jandaghian-Bidgoli et al., 2025). By integrating professional drug knowledge with the individual assessment results of patients, nursing staff can transform standardized treatment guidelines into precise suggestions that meet the actual needs of patients, helping patients develop safe, standardized and long-term adherent medication habits, and thereby establishing a personalized medication management system centered on patients.

6 The Role of Nursing Staff in Medication Adherence Management

6.1 Assessment of medication adherence and its influencing factors

Patients' ability to adhere to prescribed medication regimens is influenced by multiple factors, including disease characteristics, psychological status, social support, and clinical treatment conditions. Therefore, systematic assessment of medication adherence is a core responsibility of nursing staff. Nursing practice indicates that nurses should regularly verify patients' actual medication use, analyze reasons for missed doses or self-discontinuation, and identify common barriers such as concerns about adverse drug reactions, insufficient health literacy, complex treatment regimens, and lack of family support (Liang et al., 2025). In community and home-care settings, nurses can identify non-adherent behaviors by comparing prescriptions with actual medication-taking practices and conducting targeted inquiries. Commonly used assessment tools include the Morisky Scale and medication adherence checklists (Oliveira et al., 2024).

Studies have shown that financial burden, limited access to healthcare services, misconceptions regarding combination therapy, and excessive concerns about medication safety can all reduce medication adherence (Sipasulta and Andraini, 2025). In addition, patients' medication self-efficacy plays a key mediating role between perceived barriers and actual medication-taking behavior. Therefore, nurses should consider not only objective constraints but also patients' subjective confidence in managing their medications during the assessment process (Liang et al., 2025).

6.2 Enhancing medication adherence through communication, follow-up, and health education

Nursing staff play an indispensable role in supporting patients' long-term medication adherence. By establishing stable, trusting relationships and implementing structured follow-up combined with targeted health education, nurses can provide continuous support. Systematic reviews indicate that among patients with heart failure, hypertension, and multiple chronic conditions, nurse-led individualized medication counseling and motivational interviewing, combined with face-to-face consultations and telephone follow-up-can increase medication adherence rates by 15%~25% (Berardinelli et al., 2024). In hypertension management, nurses help patients develop regular medication habits by correcting misconceptions, addressing concerns, and alleviating excessive fear of adverse drug reactions (Ruswati, 2024).

Follow-up strategies include telephone calls, online communication, and home visits, enabling nurses to dynamically assess patients' needs and adjust intervention strategies accordingly. Research suggests that non-judgmental, encouraging communication significantly enhances patients' self-management capacity. However, reminder-based interventions alone are often insufficient; sustained improvement in medication-taking behavior requires follow-up to be embedded within a comprehensive, individualized support framework (Højgaard et al., 2025).

6.3 Long-term management of chronic diseases: the importance of continuous nursing support

For patients requiring long-term pharmacotherapy, integrating medication adherence management into comprehensive chronic disease care is a critical nursing responsibility. Evidence from systematic reviews and quality improvement projects demonstrates that nurse-led, patient-centered interventions significantly improve medication adherence among patients with hypertension, diabetes, tuberculosis, and cancer, and contribute to better clinical outcomes (Alruwaili et al., 2024; Oliveira et al., 2024; Ruswati, 2024; Sipasulta and Andraini, 2025).

In tuberculosis management, higher levels of nursing involvement-covering medication education, adherence reminders, family communication, and home follow-up-are associated with greater likelihood of completing the full treatment course (Sipasulta and Andraini, 2025). Combining nurse-led communication with self-management plans, repeated health education, personalized goal setting, and long-term follow-up further enhances medication adherence during post-discharge and community care phases (Li et al., 2025; Guo, 2025).

Moreover, patients' trust in nursing staff has been identified as a key determinant of adherence to treatment regimens, particularly among individuals with cardiovascular diseases, underscoring the importance of establishing long-term, empathetic nurse–patient relationships (Mamaghani et al., 2024). Through continuous assessment of practical barriers, motivation enhancement, and interdisciplinary collaboration, nurses can help transform medication adherence from a passive task into an active and sustained self-care behavior.

7 Problem Analysis and Development Recommendations

Within medication safety systems, nursing staff play a critical role; however, they continue to face multiple challenges in clinical practice. Nurses are required to undertake a wide range of complex tasks within limited time frames, and shortages in human resources make it difficult to fully implement standardized and detailed medication verification procedures. This, in turn, restricts the delivery of systematic medication-related health education, increases the risk of medication errors and verification omissions, and weakens patients' adherence to treatment. In addition, non-uniform standards across medical record systems and insufficient interdepartmental communication may lead to incomplete or inaccurate information transfer, further compromising the quality of nursing care.

At the same time, the continuous development of nurses' professional competencies has not kept pace with advances in clinical pharmacotherapy. Delays in updating knowledge of new medications and related practices pose challenges in identifying drug-drug interactions and providing accurate medication guidance. The cumulative effects of workforce constraints, institutional limitations, and competency gaps constitute the core problems currently affecting medication safety management. To improve overall effectiveness, pre-service training and

continuing education systems should be strengthened by integrating pharmaceutical knowledge, medication safety standards, and communication skills into routine training programs, while enhancing practical competence through simulation-based training and interprofessional discussions.

On this basis, a structured competency assessment and supervision mechanism should be established to enable ongoing evaluation of nurses' abilities in identifying medication deviations, utilizing clinical decision-support tools, and participating in therapeutic decision-making. This would help form a supportive closed-loop framework encompassing training, practice, assessment, and supervision. Meanwhile, healthcare institutions should reinforce institutional support by advancing integrated electronic medical record systems and clinical decision-support platforms, while strengthening collaboration among physicians, nurses, and pharmacists. Health management authorities should also encourage nurses' participation in policy formulation and quality improvement initiatives to ensure that medication safety measures are aligned with the practical needs of frontline clinical practice.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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Nursing Assessment Tools for Postpartum Pelvic Floor Dysfunction and Their Appropriate Use Scenarios

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Abstract This study explores the types and application characteristics of commonly used nursing assessment tools for postpartum pelvic floor dysfunction (PFD). A systematic comparison is provided of the Pelvic Floor Distress Inventory-20 (PFDI-20), Pelvic Floor Impact Questionnaire-7 (PFIQ-7), the ICIQ series, pregnancy- and postpartum-specific questionnaires, and brief screening tools such as the Pelvic Floor Health Index (PFHI), with particular attention to their assessment domains, reliability and validity, and clinical applicability. In addition, objective assessment methods-including digital palpation, surface electromyography, manometry, and ultrasound, are introduced to illustrate their complementary value in quantifying pelvic floor muscle function and evaluating rehabilitation outcomes, along with an analysis of the strengths and limitations of each method across different nursing contexts. Through a single case analysis spanning early postpartum hospitalization, systematic reassessment at 6 weeks postpartum, and subsequent pelvic floor rehabilitation with follow-up, this paper further demonstrates an integrated approach to applying nursing assessment tools across different postpartum stages. The findings highlight the practical significance of these tools in early screening, risk stratification, individualized intervention planning, and outcome evaluation. Overall, the combined use of subjective and objective assessment tools facilitates a shift in postpartum PFD nursing care from a passive, symptom-driven model to a proactive, evidence-based, and continuous management strategy. This review provides a structured reference to support nurses in the rational selection and application of assessment tools across care settings, thereby promoting standardized postpartum pelvic floor health management and improving long-term health outcomes for women.

Keywords Postpartum pelvic floor dysfunction; Nursing assessment; Pelvic floor assessment tools; Quality of life; Postpartum rehabilitation

1 Introduction

Postpartum pelvic floor dysfunction (PFD) refers to a group of syndromes that occur after pregnancy and childbirth as a result of injury or functional impairment of the pelvic floor muscles, fascia, connective tissue, and neural structures, leading to abnormalities in pelvic support, continence, and sensory function. Its clinical manifestations include urinary incontinence, fecal incontinence, pelvic organ prolapse, defecatory and sexual dysfunction, as well as chronic pelvic floor or perineal pain. Multiple symptoms often coexist and may persist or worsen over time (Firthous et al., 2025; Sitaraman et al., 2025). Evidence suggests that hormonal changes during pregnancy, sustained increases in intra-abdominal pressure, and mechanical stretching of pelvic floor tissues during childbirth-particularly vaginal delivery-are the primary pathophysiological mechanisms underlying PFD (Gao et al., 2024). With the growing number of postpartum women, PFD has become a common yet frequently overlooked health concern. Epidemiological studies indicate that approximately 40%-50% of women may experience at least one pelvic floor dysfunction symptom in the years following childbirth, with urinary incontinence being the most prevalent (Nestor et al., 2025).

Previous studies have identified vaginal delivery, prolonged labor, macrosomia, instrumental delivery, perineal trauma, multiparity, advanced maternal age, and elevated body mass index as major risk factors for postpartum PFD (Zhang et al., 2024; Hagawane et al., 2025). Despite its substantial disease burden, postpartum pelvic floor health remains insufficiently addressed in routine postnatal care, and related symptoms are often regarded as “normal postpartum changes,” leading to delays in assessment and intervention. Beyond physical impairment,

PFD is closely associated with reduced health-related quality of life (HRQoL), emotional distress, limitations in social functioning, and impaired intimate relationships (Wang et al., 2024; Nestor et al., 2025). Some women may also experience feelings of shame, anxiety, depression, and social avoidance (Cattani et al., 2024). Systematic reviews further confirm a consistent association between PFD and adverse postpartum mental health outcomes, highlighting the intertwined nature of its physical and psychological consequences (VanWiel et al., 2024). Without timely identification and intervention, certain pelvic floor dysfunctions may become chronic or progressive, persisting or even emerging years after childbirth (González-Timoneda et al., 2025; Sitaraman et al., 2025).

This study will examine the foundational role of nursing assessment within the prevention and management framework for postpartum pelvic floor dysfunction (PFD). Nurses and midwives play a critical role in symptom screening, risk identification, health education, and follow-up monitoring. Given that some women do not actively report symptoms due to embarrassment or limited awareness, systematic and standardized nursing assessment is particularly important. Validated instruments, such as the Pelvic Floor Distress Inventory-20 (PFDI-20), the Pelvic Floor Impact Questionnaire-7 (PFIQ-7), and tools recommended by the International Consultation on Incontinence, have been shown to effectively assess symptom severity and their impact on quality of life. Structured nursing interventions based on assessment findings can improve pelvic floor function and enhance health-related quality of life (HRQoL); however, a unified assessment tool applicable across different postpartum stages is currently lacking. Therefore, from a nursing perspective, systematically reviewing and optimizing assessment tools for postpartum PFD is essential for standardizing care processes and improving long-term health outcomes for women.

2 Major Types of Postpartum Pelvic Floor Dysfunction

2.1 Urinary incontinence and voiding dysfunction

Urinary incontinence (UI) and voiding dysfunction are among the most common types of postpartum pelvic floor dysfunction (PFD). UI mainly includes stress urinary incontinence (SUI), urgency urinary incontinence (UUI), and mixed urinary incontinence (MUI). Its occurrence is closely related to injury or functional impairment of pelvic floor support structures, the urethral sphincter, and neuromuscular pathways during pregnancy and childbirth. When intra-abdominal pressure increases and urethral closure pressure or support is insufficient, involuntary urine leakage may occur; urgency urinary incontinence more often reflects impaired coordination between the bladder and pelvic floor (Gao et al., 2024). Studies indicate that approximately one-quarter to one-half of women report varying degrees of urinary incontinence in the months to years following childbirth, with higher prevalence among those who undergo vaginal delivery, are of advanced maternal age, or have higher body mass index (Jamil et al., 2024). In the early postpartum period (approximately 6-10 weeks), the prevalence of urinary incontinence is about 18%-27% after vaginal delivery and 13%-20% after cesarean section, suggesting that mode of delivery, while important, is not the sole determinant. In addition to urinary incontinence, some women experience voiding difficulties such as hesitancy, incomplete emptying, or urinary retention, which are more common after cesarean section or complicated vaginal delivery and reflect impaired coordination between bladder outlet function and pelvic floor muscles.

From a nursing assessment perspective, urinary incontinence and voiding dysfunction not only affect daily activities, physical exercise, and childcare, but are also strongly associated with feelings of embarrassment, psychological distress, and reduced quality of life. Reliance solely on patient-initiated consultation may therefore lead to underassessment and delayed intervention (VanWiel et al., 2024; González-Timoneda et al., 2025). Accordingly, nursing assessment should systematically address symptom subtype (SUI/UUI/MUI), frequency and volume, degree of distress, and functional impact, supported by standardized instruments to quantify severity and referral thresholds. For example, the ICIQ-SF can be used for rapid assessment of urinary incontinence severity and its impact on daily life, while the PFDI-20 enables comprehensive evaluation of pelvic floor symptom burden, supporting risk stratification and outcome monitoring (Jamil et al., 2024). Evidence further indicates that pelvic floor muscle training implemented during pregnancy and the first postpartum year has a moderate protective effect against postpartum urinary incontinence, underscoring the value of early screening and intervention in nursing practice (Beamish et al., 2024).

2.2 Pelvic organ prolapse-related problems

Pelvic organ prolapse (POP) refers to the descent of the bladder, uterus, or rectum into or beyond the vaginal canal due to impairment of the supportive structures of the anterior vaginal wall, apex, or posterior vaginal wall. Connective tissue remodeling during pregnancy, sustained pelvic floor loading, and excessive stretching or avulsion of the levator ani muscle, as well as obstetric trauma during childbirth, are important antecedents. Vaginal delivery-particularly instrumental delivery or a prolonged second stage of labor, can significantly increase the risk of early postpartum anterior and posterior compartment prolapse. Studies have shown that approximately 9% of women may develop stage II prolapse involving the anterior and/or posterior vaginal wall at 6-8 weeks postpartum, with higher risk among those with vaginal delivery, multiparity, advanced age, higher BMI, and larger fetal birth weight (Gao et al., 2024). Although the proportion of early symptomatic prolapse may be relatively low, objective anatomical descent may indicate a gradually progressive prolapse process in the future.

Clinically, early-stage prolapse often presents with nonspecific symptoms, such as perineal heaviness, a sensation of vaginal bulging, or lower abdominal discomfort, and may be accompanied by urinary, bowel, and sexual dysfunction as the condition progresses. More importantly, symptomatic postpartum prolapse is significantly associated with impaired quality of life, psychological well-being, and sexual health. Compared with women without prolapse, those with prolapse are more likely to experience dyspareunia, reduced sexual satisfaction, impaired body image, and poorer psychological distress indicators (VanWiel et al., 2024). However, prolapse symptoms may be underestimated due to feelings of embarrassment or normalization beliefs. Therefore, nursing assessment should combine standardized questionnaires with targeted symptom inquiry, such as asking about vaginal bulging or heaviness and the need for manual assistance during defecation, while using tools such as the PFDI-20 and pelvic floor impact questionnaires to quantify symptom distress and functional impact. This approach provides a basis for conservative management (e.g., pelvic floor muscle training) and referral to urogynecology services (Gao et al., 2024; Beamish et al., 2024).

2.3 Sexual dysfunction and bowel function abnormalities

Sexual dysfunction and bowel function abnormalities are relatively concealed yet equally important components of postpartum PFD. Due to cultural factors, privacy concerns, and stigma, these issues are infrequently discussed, resulting in insufficient nursing assessment. Postpartum sexual dysfunction may manifest as dyspareunia, decreased libido, disorders of sexual arousal or orgasm, a sensation of vaginal laxity, and reduced sexual satisfaction. Its occurrence is influenced by multiple factors, including perineal trauma, hormonal changes, body image concerns, psychological distress, and alterations in pelvic floor neuromuscular function (Jansson et al., 2024; Sitaraman et al., 2025). Studies among primiparous women indicate that among those who resume sexual activity at 6-10 weeks postpartum, up to two-thirds report dyspareunia, and nearly half perceive sexual problems as significantly distressing. These findings suggest that “resumption of sexual activity≠restoration of sexual health,” highlighting the need for more nuanced nursing assessment and support. In addition, longitudinal evidence suggests that while some urinary symptoms may improve within the first postpartum year, sexual function may decline over time, underscoring its dynamic and complex nature (De Amorim et al., 2025). Systematic reviews further demonstrate consistent associations between PFD and adverse postpartum mental health outcomes, such as depression and anxiety, emphasizing the importance of integrating sexual health and psychological health into routine assessment frameworks (VanWiel et al., 2024).

Postpartum bowel dysfunction includes fecal incontinence, flatus incontinence, constipation, straining during defecation, incomplete evacuation, and anorectal discomfort. These conditions are primarily associated with injury to the anal sphincter complex, pelvic floor muscles, and pudendal nerve during childbirth, with higher risk among women who have undergone episiotomy or sustained obstetric anal sphincter injuries (Sitaraman et al., 2025). Research indicates that the incidence of anal incontinence during the first postpartum year ranges from approximately 2% to 15%, while an even larger proportion of women experience constipation, abnormal flatus, and anorectal discomfort. However, due to high levels of stigma, these problems are often concealed, resulting in long-term unmet nursing care needs (Sitaraman et al., 2025). Therefore, nursing assessment should, within a framework of privacy-respecting and culturally sensitive communication strategies, incorporate items related to

sexual and bowel function into routine follow-up, and combine relevant dimensions of pelvic floor function questionnaires to quantify symptom-related distress and support referral decisions (De Amorim et al., 2025).

3 Classification and Characteristics of Common Nursing Assessment Tools

3.1 Key features of subjective scales related to pelvic floor dysfunction

Subjective scales are among the most widely used tools in nursing assessment of postpartum PFD. Typically administered as standardized questionnaires, they systematically collect postpartum women's self-reported experiences of urinary incontinence, prolapse, bowel and sexual function problems, as well as the impact of these issues on quality of life. These tools feature clear structures, are relatively easy to administer, and are low cost. They are suitable for early screening, community follow-up, remote/online follow-up, and large-sample research. Importantly, by focusing on "bother" and "impact," they reflect a patient-centered nursing philosophy.

Within the broader landscape of instruments, subjective questionnaires can be further divided into two categories:

1) Perinatal (pregnancy/postpartum)-specific, multidimensional comprehensive questionnaires

These questionnaires typically adopt a subscale structure to assess bladder, bowel, pelvic organ prolapse, and sexual function domains separately, and often include symptom-related bother and risk factors; some also incorporate psychological items. Examples include the German Pelvic Floor Questionnaire for Pregnancy and the Postpartum Period and its derivative/cross-cultural versions (e.g., PFQ-PP and its multilingual versions), the APFDQ, and the Australian Pelvic Floor Questionnaire (APFQ). These instruments have undergone cross-cultural adaptation and psychometric validation across different languages and cultural contexts, demonstrating good content validity and internal consistency (Cronbach's α often≥0.70). They can discriminate between women with and without bothersome symptoms and support repeated administration during pregnancy and postpartum to track symptom trajectories (Titulaer et al., 2025; Zhu et al., 2025).

2) Generic/core instruments focusing on symptom burden and life impact

The PFDI-20 and PFIQ-7 are among the most widely used and most frequently cited instruments and are recommended by the International Consultation on Incontinence. Across diverse cultural contexts and administration modes (paper-based, telephone, online), they show strong internal consistency, test-retest reliability, and convergent validity, making them suitable for symptom screening, quantification of bother, and outcome evaluation. Brief tools targeting urinary incontinence, such as the ICIQ-UI SF, have also demonstrated acceptable construct validity and responsiveness in perinatal populations, supporting rapid screening and monitoring of intervention effects (Cattani et al., 2024). In addition, brief screening tools tailored to primary care or busy clinical settings have begun to emerge. For example, the Pelvic Floor Health Index (PFHI; 10 items) focuses on key pelvic floor symptoms, genital pain/sensation, and body image. It is suitable for rapid assessment in the immediate postpartum period and for longitudinal follow-up, with reported good test-retest reliability (ICC≈0.78) and convergent validity.

3.2 Objective assessment methods for pelvic floor muscle strength and function

Objective assessment methods are used to quantify pelvic floor muscle (PFM) strength, endurance, coordination, and structural integrity, serving as an important basis for determining injury severity and rehabilitation outcomes, and complementing symptom questionnaires. Common methods include vaginal palpation grading, perineal/vaginal manometry, surface electromyography (EMG), dynamometry, and imaging techniques such as ultrasound (Frazão et al., 2025). In routine postpartum care, standardized digital palpation assessment (e.g., the modified Oxford grading system) is the most accessible and cost-effective approach. Evidence indicates that, when assessors are adequately trained and standardized procedures are followed, palpation-based assessment of maximal voluntary contraction strength and endurance demonstrates moderate to high reliability (kappa ≈ 0.49-0.69), supporting its use as a core bedside indicator. However, agreement for non-voluntary contractions and voluntary relaxation is relatively low (kappa≈0.10-0.51), and these findings should therefore be interpreted cautiously or supplemented with other objective measures.

Surface EMG allows quantification of resting tone, muscle fiber activity, and fatigue characteristics, facilitating classification of functional impairment and supporting individualized rehabilitation planning (Gao et al., 2024). Instrument-based assessments may also extend to overall biomechanics, such as caliper measurement of diastasis recti abdominis (DRA), which has shown acceptable reliability after training (ICC≈0.73-0.83) and is suitable as a supplementary indicator in outpatient follow-up. Overall, objective methods offer good repeatability and are valuable for monitoring rehabilitation progress, but some techniques require specialized equipment and training, potentially increasing costs or psychological burden. Therefore, selection should be guided by care settings and resource availability, with palpation and basic functional tests prioritized in primary care and multimodal tools such as manometry, EMG, and ultrasound introduced when feasible (Frazão et al., 2025).

3.3 Reliability, validity, and nursing applicability of different assessment tools

Reliability and validity are central to the scientific rigor and clinical value of assessment tools. Overall, psychometric evidence for postpartum PFD instruments is increasing, although variability in quality remains and no universal gold standard has been established. Systematic reviews indicate that at least nine validated postpartum PFD questionnaires are currently available, among which the PFDI-20, PFIQ-7, and ICIQ-based instruments are the most frequently used and recommended. These tools demonstrate relatively robust internal consistency, test-retest reliability, and structural validity. Perinatal-specific instruments (e.g., PFQ-PP and its cross-cultural versions) commonly report Cronbach's $\alpha \geq 0.70$ and domain-specific ICCs of approximately 0.73-0.97, effectively distinguishing women with and without symptom-related distress and supporting repeated measurement and trajectory analysis during pregnancy and the postpartum period (Titulaer et al., 2025; Zhu et al., 2025). The brief screening tool PFHI has also shown good convergent validity with established PFD and sexual function measures, as well as satisfactory test-retest reliability, indicating its suitability for rapid screening in primary care settings.

For objective assessments, reliability studies provide critical guidance for routine nursing practice. Digital palpation measures of maximal voluntary contraction and endurance show acceptable consistency and may serve as primary bedside indicators, whereas findings related to non-voluntary contraction and relaxation require cautious interpretation. EMG is considered sensitive to early pelvic floor dysfunction and is useful for refined functional phenotyping and individualized rehabilitation planning, though its application is more common in specialized or research settings due to equipment and training requirements (Gao et al., 2024). Based on current evidence, a "tiered combination strategy" is recommended (Figure 1): nurses should prioritize well-validated multidimensional questionnaires to assess symptoms and quality-of-life impact, then integrate reliable manual grading and, when available, basic instrument-based indicators (e.g., DRA measurement, EMG, manometry, or ultrasound) for functional quantification and outcome tracking. This approach supports efficient screening, risk stratification, and longitudinal follow-up in postpartum pelvic floor care (Frazão et al., 2025) .

4 Case Presentation

4.1 Early postpartum hospitalization assessment

To demonstrate the application of nursing assessment tools in different stages of postpartum pelvic floor function care, Nestor et al. (2025) selected a representative parturient as a case for analysis. The patient underwent routine nursing evaluation during early postpartum hospitalization, followed by systematic assessment at 6 weeks postpartum and subsequent pelvic floor rehabilitation with longitudinal follow-up. During the early postpartum hospitalization period, the patient was in the acute recovery phase following vaginal delivery. At this stage, pelvic floor tissues were likely affected by edema and fatigue, and no overt pelvic floor dysfunction (PFD) symptoms were spontaneously reported. Consistent with clinical practice, the primary nursing objective was not definitive diagnosis, but rapid screening and risk stratification to identify potential PFD risk and guide post-discharge planning (Nestor et al., 2025).

Nurses implemented a brief, low-burden screening approach that could be integrated into routine ward rounds. A short symptom and risk checklist, together with the Pelvic Floor Health Index (PFHI), was administered to screen for urinary incontinence, prolapse-related symptoms, pain, sexual health concerns, and psychosocial impact. The

PFHI is a 10-item self-administered instrument designed for immediate postpartum use and suitable for repeated measurement at 2, 4, and 6 months postpartum, demonstrating good test-retest reliability and responsiveness to change.

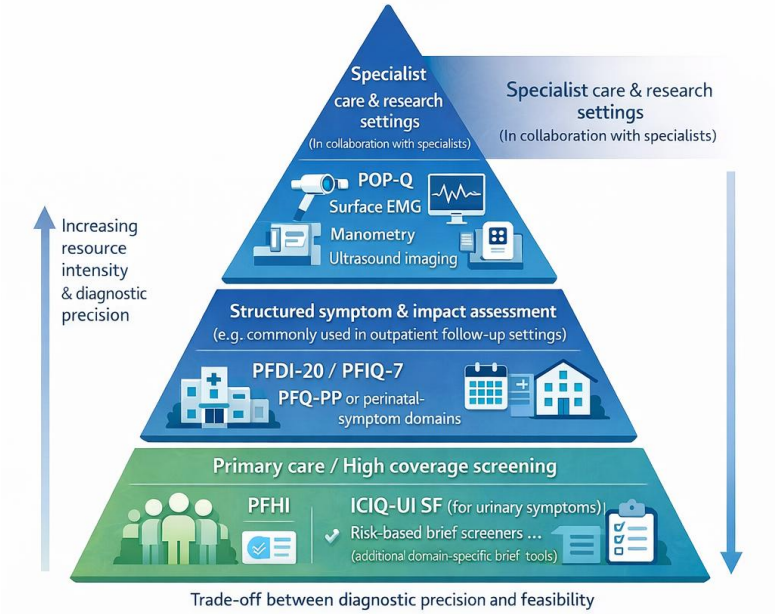

Figure 1 A tool selection framework for nursing-led assessment of postpartum pelvic floor dysfunction

Risk factor assessment was conducted through medical record review and brief bedside inquiry, including maternal age, mode of delivery, operative vaginal delivery, perineal trauma, prolonged second stage of labor, and neonatal birth weight. These factors are consistently associated with increased PFD risk and early pelvic floor muscle weakness detected by surface electromyography (sEMG) at 42-90 days postpartum (Gao et al., 2024; Dong et al., 2025). Based on combined symptom screening and risk profiling, the patient was classified as having moderate PFD risk and was scheduled for a comprehensive nursing assessment at approximately 6 weeks postpartum. Patients presenting with prominent warning signs or multiple risk factors would, in similar circumstances, be referred for earlier reassessment or pelvic floor rehabilitation services (Fertel et al., 2024; Sitaraman et al., 2025).

4.2 Systematic assessment at 6 weeks postpartum

At approximately 6 weeks postpartum, the patient returned for follow-up, marking the transition from acute recovery to the early rehabilitation phase. By this time, pelvic floor edema had largely resolved, and neuromuscular function had stabilized, allowing more accurate symptom reporting and functional evaluation. The focus of nursing assessment shifted from risk screening to evaluation of functional status, classification of dysfunction, and identification of persistent or emerging PFD (Gao et al., 2024).

An integrated assessment strategy was applied, combining subjective questionnaires, structured risk review, and objective measurements. The patient completed validated multidimensional instruments, including the Pelvic Floor Distress Inventory-20 (PFDI-20) and the Pelvic Floor Impact Questionnaire-7 (PFIQ-7), which comprehensively assessed bladder, bowel, prolapse, and sexual function symptoms and their impact on quality of life. The evaluation results in De Amorim et al. (2025) and Nestor et al. (2025) demonstrated that, mild urinary symptoms not previously reported during hospitalization were identified at this stage, illustrating the dynamic nature of postpartum symptom trajectories and the importance of systematic reassessment.

Objective assessment was introduced, including basic pelvic floor muscle examination and pelvic floor sEMG to quantify muscle activation and endurance. Where resources permit, similar cases may incorporate ultrasound or POP-Q assessment to further evaluate early structural changes (Gao et al., 2024). In higher-risk profiles, objective findings may be combined with demographic and obstetric variables to inform predictive models for pelvic floor

muscle weakness and guide individualized rehabilitation planning (Dong et al., 2025). The study cases presented by Titulaer et al. (2025) demonstrates that a comprehensive 6-week postpartum nursing assessment should minimally include a validated questionnaire, structured risk review, and basic pelvic floor muscle evaluation, with referral for advanced testing as indicated (Figure 2).

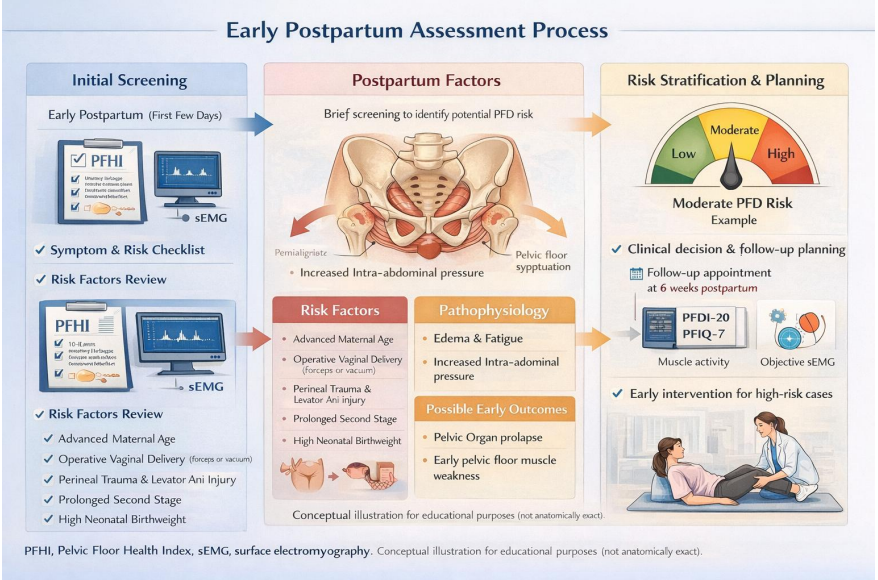

Figure 2 Case-based workflow of early postpartum pelvic floor assessment

4.3 Assessment during pelvic floor rehabilitation and follow-up

Following identification of functional impairment, the patient entered a pelvic floor rehabilitation program. Prior to intervention, nursing assessment established baseline symptom burden and pelvic floor muscle function to support individualized goal setting and outcome evaluation. Standardized, reliable, and change-sensitive tools were selected to ensure comparability across assessment time points (De Amorim et al., 2025). During rehabilitation and follow-up, assessments were conducted at multiple time points, integrating subjective symptom questionnaires with objective indicators such as pelvic floor muscle grading and sEMG parameters. Consistent with existing evidence, improvements in muscle activity were accompanied by reductions in symptom burden and improvements in psychological well-being, highlighting the importance of addressing both physical and psychosocial dimensions in postpartum rehabilitation assessment (Zhao et al., 2025).

In routine nursing practice, the assessment process can be appropriately simplified while ensuring adherence to core principles. A brief, responsive questionnaire was administered before rehabilitation, at program completion, and during follow-up at 3 and 6 months to monitor symptom burden and quality-of-life changes (De Amorim et al., 2025). When feasible, repeated objective measurements provided additional evidence of functional improvement. The iterative process of "assessment-feedback-adjustment-reassessment" enabled individualized nursing guidance and optimized rehabilitation outcomes (Huang et al., 2024). Long-term follow-up using pelvic floor-related instruments facilitated early identification of persistent or late-onset dysfunction and supported timely re-referral to pelvic floor physical therapy or urogynecological services (Nestor et al., 2025; Sitaraman et al., 2025).

5 Application of Nursing Assessment Results in Clinical Practice

5.1 Guiding individualized nursing interventions and rehabilitation programs

Postpartum PFD nursing assessment results serve as a critical basis for developing individualized nursing interventions and rehabilitation programs. By systematically evaluating the type and severity of functional impairment and its impact on quality of life, nurses can identify priority care issues and avoid experience-based or standardized interventions. Evidence indicates that individualized pelvic floor rehabilitation programs are commonly guided by baseline pelvic floor muscle strength, sEMG parameters, ultrasound findings, and symptom questionnaires, with intervention intensity and content tailored according to functional deficits and patient tolerance. In clinical decision-making, marked pelvic floor muscle weakness or abnormal sEMG findings warrant

priority use of device-assisted training, graded pelvic floor muscle training (PFMT), and breathing-based relaxation techniques, whereas women with mild dysfunction and low symptom burden may benefit from home-based PFMT, lifestyle counseling, and reinforced follow-up to enhance adherence and conserve healthcare resources. Risk stratification models incorporating electrophysiological indicators and symptom outcomes, together with predictors such as age, gestational weight gain, and mode of delivery, further support adjustment of intervention intensity, enabling earlier or more intensive rehabilitation for high-risk women (Gao et al., 2024).

Huang et al. (2024) demonstrated that the superiority of assessment-driven care over uniform approaches. Randomized controlled studies show that individualized postpartum nursing guidance based on assessment findings can improve pelvic floor muscle strength, reduce PFD incidence, and increase patient satisfaction (Huang et al., 2024). The Newman nursing model similarly emphasizes tailoring interventions to assessment-identified knowledge gaps, emotional concerns, and life impacts, thereby improving quality of life and pelvic floor recovery (Wang et al., 2024). In postpartum women with comorbid generalized anxiety disorder, integrated interventions guided by anxiety scales, PFDI-20/PFIQ-7, and sEMG assessments have demonstrated concurrent improvements in anxiety levels, pelvic floor function, and quality of life within 12 weeks, highlighting the value of addressing both physical and psychological dimensions in individualized care (Zhao et al., 2025). Overall, systematic use of assessment results promotes a shift from “one-size-fits-all” care to responsive, patient-centered rehabilitation management (Cheredarchuk and Makarchuk, 2025).

5.2 Evaluating the effectiveness of nursing interventions and rehabilitation

Nursing assessment is essential not only for problem identification but also for evaluating the effectiveness of nursing interventions and rehabilitation. Repeated measurements using the same or equivalent tools before and after intervention allow objective comparison of pelvic floor function changes and determination of whether therapeutic goals have been achieved. Multiple randomized and quasi-experimental studies have employed symptom questionnaires, quality-of-life scales, and objective measures (sEMG, manometry, POP-Q, and ultrasound) at baseline and follow-up points (e.g., 6 weeks, 3 months, 6 months, and 1 year) to assess nurse-led postpartum pelvic floor rehabilitation outcomes, providing methodological support for quantifiable efficacy (Mikhelson et al., 2025; Zhao et al., 2025).

Existing evidence indicates that postpartum pelvic floor rehabilitation nursing significantly reduces symptom distress scores and improves patient satisfaction compared with routine care (Zhou and Guo, 2024). sEMG-based monitoring further demonstrates that comprehensive nursing interventions can enhance electromyographic parameters, muscle strength, and fatigue resistance within 3-6 months, offering objective evidence of treatment effects. Assessment data also facilitate comparison of rehabilitation strategies and timing, with early individualized programs and enhanced techniques (e.g., biofeedback) generally yielding superior symptom improvement and response rates. Evidence-based guidelines support PFMT as a core intervention for the prevention and treatment of urinary incontinence, underscoring the importance of establishing repeated-measurement frameworks (baseline-follow-up-outcome) to drive quality improvement in clinical nursing practice (Mikhelson et al., 2025).

5.3 Supporting health education and enhancing self-management capacity

Nursing assessment results play a direct role in health education and the enhancement of postpartum women’s self-management capacity. Communicating assessment findings in an accessible manner helps women understand their pelvic floor function status and the rationale for rehabilitation and lifestyle modification, thereby increasing engagement and adherence. Studies show that integrating structured assessment with targeted health education improves pelvic floor health knowledge, self-efficacy, muscle function, and symptom outcomes (Huang et al., 2024; Wang et al., 2024; Cheredarchuk and Makarchuk, 2025).

The Newman nursing model highlights the importance of designing educational and counseling content based on assessment-identified knowledge gaps and emotional needs, contributing to improved psychological well-being and quality of life (Wang et al., 2024). In programs involving postpartum women with anxiety disorders, repeated use of assessment tools to provide progress feedback and reinforce effective self-care behaviors has proven

effective in enhancing both mental health and pelvic floor outcomes (Zhao et al., 2025). Population-based surveys indicate substantial unmet information needs regarding PFD, with many women self-managing symptoms without professional guidance despite significant distress (Thangarajah et al., 2024). Therefore, incorporating individualized, assessment-based education into routine postpartum discharge counseling and establishing a closed-loop model of "assessment-education-reassessment-re-education" can support sustained prevention and long-term management of postpartum PFD (Rehman et al., 2025).

6 Concluding Remarks

Postpartum pelvic floor dysfunction (PFD) is a significant public health issue that affects women's long-term health and quality of life. Its effective management depends on standardized and systematic nursing assessment. Multidimensional nursing assessment tools provide a structured approach to comprehensively evaluating pelvic floor health in postpartum women, particularly by facilitating the identification of symptoms that may go unreported due to embarrassment, stigma, or limited awareness. This reduces the risk of under-recognition and delayed intervention, underscoring the foundational role of nursing assessment in PFD prevention and management.

Validated subjective questionnaires, including the PFDI-20, PFIQ-7, ICIQ series, and pregnancy-or postpartum-specific instruments, systematically cover key domains such as bladder, bowel, pelvic organ prolapse, and sexual function, while quantifying their impact on quality of life. These tools provide comparable outcome measures for perinatal intervention and longitudinal monitoring. In parallel, objective assessment methods such as surface electromyography (sEMG), manometry, and ultrasound, along with the Pelvic Floor Health Index (PFHI) for rapid screening in primary care settings, enable quantification of pelvic floor muscle function and structural changes. The combined application of subjective and objective tools facilitates a shift in PFD nursing practice from a passive, symptom-driven approach to proactive, evidence-based, and continuous management, thereby reducing the risk of symptom chronicity and promoting overall recovery.

Given the multidimensional and dynamic nature of postpartum PFD, nursing practice should adhere to a "context-goal-tool" alignment strategy, selecting assessment instruments appropriately based on care settings, clinical objectives, and available resources. Brief questionnaires or indices are well suited for rapid screening and referral decision-making in inpatient and primary care settings, whereas comprehensive, reliable, and repeatable tools are more appropriate for specialized clinics and long-term follow-up, with objective assessments integrated when necessary. Future efforts should focus on strengthening nurse training, promoting routine and digitalized use of assessment tools, and continuously improving the evidence base for postpartum-specific instruments. These measures will support early detection, timely intervention, and effective management of PFD, ultimately enhancing women's long-term health outcomes.

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Conflict of Interest Disclosure

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Feature Review Open Access

Genomics-Metabolomics Integration in Neurometabolic and Rare Neurologic Disorders: Diagnostic Pathways and Clinical Impact

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Abstract This study investigates the integrated application of genomics and metabolomics in the field of neurometabolic and rare neurologic disorders, and systematically elaborates on the core causes of neural metabolic imbalance. It also analyzes the application value and challenges in variant interpretation of high-throughput sequencing technology in genomics for the diagnosis of rare neurologic disorders, as well as the advantages of metabolomic technical platforms such as mass spectrometry and nuclear magnetic resonance, the discovery and validation of disease-related markers, and the application value of metabolic monitoring in efficacy evaluation. The study focuses on the integration strategies for genetic and metabolic data, including the functional correlations among genes, proteins and metabolites, analytical methods such as pathway enrichment, and the construction of clinically applicable multi-omics diagnostic workflows. Combined with three clinical cases of mitochondrial encephalopathy, fatty acid oxidation disorders and lysosomal storage disorders, it verifies the practical efficacy of integrated omics diagnosis. In addition, the study points out that this integration model can significantly shorten the diagnostic time and improve the diagnostic rate, facilitate the accurate stratification of patients and the formulation of individualized treatment plans, and optimize prognosis assessment and long-term disease management. Meanwhile, it also analyzes the current challenges faced by omics integration, such as inadequate data standardization, privacy and ethical issues, and the limitations of artificial intelligence in the application of rare disease research and clinical practice. This study aims to provide a comprehensive theoretical and practical reference for the precise diagnosis and treatment of neurometabolic and rare neurologic disorders.

Keywords Genomics-metabolomics integration; Neurometabolic disorders; Rare neurologic disorders; Disease diagnosis; Metabolic markers

1 Introduction

The normal functioning of the nervous system requires a lot of energy. The stable supply of energy to the brain is crucial for the transmission of information by nerve cells. Mitochondria are the "energy factories" of cells, which can provide energy to nerve cells and also regulate calcium ions. If there are problems with mitochondria or abnormal metabolism of energy substances such as glucose, it may damage cells (Xie et al., 2025b). Many studies have found that in the early stages of some neurological diseases, mitochondrial function is abnormal, indicating that metabolism is related to the occurrence of diseases and may become a target for treatment (Zhang et al., 2025a).

Metabolic studies typically employ two techniques. Many rare neurodevelopmental disorders are related to genetics, and the symptoms of such diseases are often quite similar, such as microcephaly and epilepsy. However, even the same genetic changes may manifest differently in different individuals. High-throughput sequencing can help identify the relevant genes and the causes of the diseases, but it also poses certain difficulties for disease diagnosis (Airoldi et al., 2025; Bakare, 2025). Therefore, we need a comprehensive approach that combines genetics, cellular metabolism, and neural network functions for research.

This study focused on how rare and common genetic variations affect neuro-metabolism and the risk of neurodegenerative diseases. Through metabolomics analysis, changes in metabolic pathways can be observed more directly, helping to identify abnormal metabolic patterns. In the research of rare diseases, the combined analysis of genomics and metabolomics has successfully discovered multiple new pathogenic genes, verified the effects of enzyme or transporter protein variations, and also found biomarkers that are helpful for diagnosis.

2 The Fundamental Cause of Neural Metabolic Imbalance

2.1 Energy supply issues

The normal functioning of the brain requires sufficient energy, and mitochondria play a crucial role in this process. If the genes responsible for energy production are abnormal, it will interfere with cellular respiration, leading to reduced energy and the accumulation of harmful substances, thereby damaging nerve cells (Makridou et al., 2025; Pokotylo et al., 2025). Studies have found that in the blood of patients with neurological diseases, substances related to energy metabolism change, indicating that the energy regulation function of the body and the brain has become abnormal (Huang et al., 2025).

When mitochondrial function declines, cells will temporarily replenish energy through glycolysis. Although this can temporarily maintain cell survival, in the long term, it will disrupt the metabolic balance and further aggravate nerve damage (Pokotylo et al., 2025). Currently, the academic community believes that these diseases are not only a problem of insufficient energy supply, but also related to abnormal regulation of the entire metabolic network (Huang et al., 2025).

2.2 Abnormalities in amino acid, organic acid and fat metabolism

Many genetic diseases are related to the metabolism of amino acids or organic acids. If a certain enzyme malfunctions during the metabolic process, certain substances will accumulate in the brain, leading to epilepsy or developmental delays. For example, phenylketonuria occurs because the accumulation of metabolic products interferes with the normal transmission of neural signals.

Apart from common metabolic issues, some rare neurological disorders can also affect the metabolism of amino acids and fats. People with muscle disorders, autism, epilepsy and other conditions often have abnormal amino acid and fat metabolism in their blood (Wijekoon et al., 2025). This indicates that metabolic disorders are closely related to the nervous system and may participate in the occurrence of diseases by affecting signal transmission.

2.3 How genetic mutations trigger metabolic disorders

In neuro-metabolic diseases, genetic mutations often disrupt metabolic balance in several ways. Some mutations directly prevent metabolic enzymes from functioning properly, causing toxic substances to accumulate in the body; some damage transport proteins, depriving the brain of sufficient nutrients; and others interfere with the process of cell waste clearance, preventing damaged mitochondria from being removed in time. These different mechanisms ultimately harm the stability of nerve cells.

Genetic research has revealed that many genes related to metabolism can influence the occurrence of neurodegenerative diseases. For instance, patients with Alzheimer's disease typically have abnormal energy and fat metabolism, which is closely related to the progression of their condition (Pokotylo et al., 2025; Huang et al., 2025). These findings can help us understand these diseases and provide ideas for diagnostic methods.

3 Application of Genomics in the Diagnosis of Rare Neurological Disorders

3.1 Application of high-throughput sequencing technology

The new technology of high-throughput sequencing can simultaneously test multiple genes, significantly changing the diagnostic approach for rare neurological disorders. Currently, whole-exome sequencing is a commonly used method for identifying single-gene neurological diseases (such as abnormal development, epilepsy), and most studies show that its diagnostic probability is approximately between 30% and 45% (Gaouzi et al., 2025). Approximately one-third of patients with developmental problems or epilepsy can find the cause of their illness through this method, and it is more convenient than traditional methods (Chang et al., 2025). Therefore, professional guidelines recommend that for many neurological diseases, whole-exome sequencing or whole-genome sequencing should be prioritized (Assadourian and Martinez-Agosto, 2025). Whole-genome sequencing can discover more types of genetic variations and identify some issues that whole-exome sequencing might miss (Zhang et al., 2025a). As costs continue to decrease, these methods are expected to become routine detection methods for neurological genetic diseases.

3.2 Challenges in the interpretation of genetic variations

High-throughput sequencing technology can help identify genetic variations related to diseases such as intellectual disability and epilepsy. Among the identified genetic variations, approximately one-third are harmful, one-fourth may be harmful, and the effects of the remaining genetic variations are still unclear. This indicates that the interpretation process is very complex (Bedja-Iacona et al., 2025). To make the judgment more accurate, it is necessary to classify the grades according to international standards, combine the patient's onset manifestations, family medical history, and conduct multidisciplinary discussions (Çapan, 2025). How to clarify the meaning of those unexplainable genetic variations is a common problem, especially when many functionally unknown genetic variations are discovered after sequencing. In neonatal screening, the effects of many missense variations are still unclear, and no definite diagnosis can be given. Therefore, it is necessary to continuously update the database and combine metabolic indicators to improve the accuracy of the judgment.

3.3 The role of genetic testing in early screening, diagnosis, and genetic counseling

For patients with rare neurological disorders, genetic testing is very important for early detection and diagnosis. Many children with complex developmental problems have found the cause through exon sequencing, and some treatable diseases have been discovered in time, providing a basis for formulating targeted treatment plans (Gaouzi et al., 2025). Early clarification of genetic diagnosis can also guide the selection of antiepileptic drugs, monitor possible complications, and provide reference for precise treatment (May et al., 2025). For some late-onset neurodegenerative diseases and ataxias, genetic testing also helps to assess the development trend of the disease (Figure 1) (Srinivasan et al., 2025).

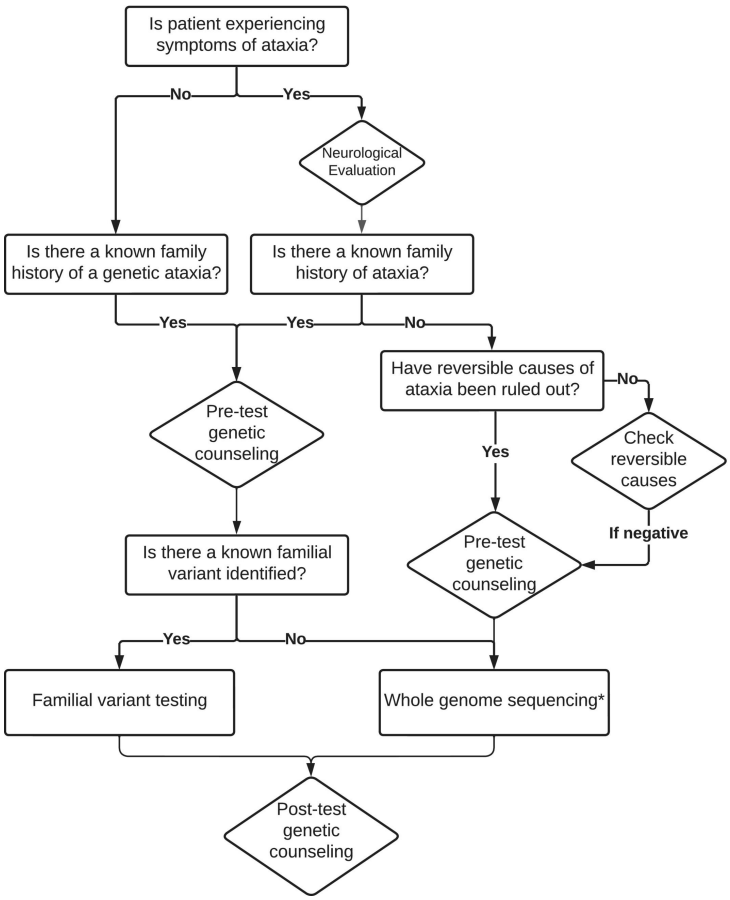

Figure 1 Proposed workflow for evaluation of hereditary ataxia (Adopted from Srinivasan et al., 2025)

Image caption: Genetic counseling may be conducted by a genetic counselor, neurologist with dedicated neurogenetics training, or geneticist based on suspected indication and level of comfort in test selection/interpretation. *Whole genome sequencing (WGS) must include technology capable of reliably detecting repeat expansions. See Recommendation #18 for more details, including alternative testing options such as a dedicated repeat expansion panel (Adopted from Srinivasan et al., 2025)

4 The Unique Advantages of Metabolomics in Disease Identification

4.1 Common metabolomics technology platforms

Metabolic research mainly employs two techniques: mass spectrometry and nuclear magnetic resonance. Mass spectrometry is often used in conjunction with chromatography, and it is highly sensitive, capable of detecting subtle changes in metabolites, which is particularly important for neuro-metabolic diseases as the biochemical changes in these diseases are usually very minor. Liquid chromatography-mass spectrometry is the most commonly used in clinical research, with a wide range of applications, and it can analyze samples such as blood and cerebrospinal fluid (Smusz et al., 2025). Gas chromatography-mass spectrometry has an advantage in separating organic acids, and organic acids are key detection indicators for many congenital metabolic problems (Gątarek and Kałużna-Czaplińska, 2025).

Although the sensitivity of nuclear magnetic resonance is lower than that of mass spectrometry, it is highly accurate in quantification, has good repeatability, and the sample processing is simple, making it suitable for long-term tracking studies. With technological advancements, both methods can detect more metabolites related to the nervous system. Some mass spectrometry platforms specifically designed for rare neuro-metabolic diseases can stably detect hundreds of related metabolites and have begun to be used in clinical testing (Smusz et al., 2025).

4.2 Discovery and validation of disease-related metabolic markers

Metabolomics can reflect the changes brought about by the combined action of genes and the environment. This can help identify the metabolic characteristics related to diseases and provide directions for disease diagnosis and research. Taking Parkinson's disease as an example, many studies have shown that the metabolic substances such as fatty acids and amino acids in patients' bodies have changed. These changes not only distinguish patients from healthy individuals but also indicate possible abnormalities in mitochondrial function. In multiple sclerosis and muscular dystrophy, abnormal energy and lipid metabolism have also been found, providing references for finding disease markers and treatment methods (Wijekoon et al., 2025; Smusz et al., 2025).

The advantage of metabolomics is that it first conducts a broad screening and then focuses on targeted verification. Although this field is still in its early stage of development, some of the identified biomarker combinations can be repeatedly verified in different populations and platforms. In the future, they are expected to be used in clinical treatment. In some rare neuro-metabolic diseases, using high-resolution mass spectrometry to analyze cerebrospinal fluid not only proved the reliability of the known biomarkers but also determined the normal range related to age, laying the foundation for finding new biomarkers (Smusz et al., 2025). In summary, the relationship between metabolites and diseases is gradually becoming clearer, and the role of metabolomics in the development of clinical biomarkers is becoming increasingly important.

4.3 The application value of metabolic monitoring in efficacy evaluation

The sensitivity of metabolic changes is very high, enabling them to promptly reflect the body's condition. This makes metabolomics suitable for assessing treatment efficacy and changes in the condition. In the research on Parkinson's disease, long-term observation revealed that the use of levodopa treatment would alter the metabolic state in patients' plasma, adjust the metabolism of some amino acids, and to a certain extent, improve the imbalance of bile acids. These metabolic changes are more accurate than clinical scores and can better reveal the therapeutic effect of the drugs. In the research on multiple sclerosis, metabolomics also found that after treatment with different drugs, lipid metabolism changed, indicating that some metabolites may become indicators for judging the treatment effect or the condition (Smusz et al., 2025). Incorporating metabolic monitoring into treatment decisions helps predict drug responses, detect neurotoxicity early, and provide references for personalized medication.

For neurodegenerative diseases such as Alzheimer's disease and Parkinson's disease, conventional clinical and imaging indicators often fail to sensitively reflect the early neurological changes. Therefore, metabolomics is highly anticipated. By using high-resolution mass spectrometry and nuclear magnetic resonance technology, only a small amount of blood or cerebrospinal fluid sample is needed to simultaneously determine hundreds of

metabolites. In long-term follow-up, multiple indicator combinations can be constructed to track the disease progression and treatment response with higher temporal resolution. These dynamic metabolic indicators can complement genetic data and comprehensively reflect the effects of genetic background, environment, and treatment factors on cellular metabolism, providing strong support for the research on precise treatment of neurometabolic and rare neurological diseases.

5 Integration Strategy of Genetic and Metabolic Data

5.1 Functional connections among genes, proteins and metabolites

In rare neuro-metabolic diseases, combining genetic data with metabolic data for analysis is intuitive: genetic changes can alter protein functions, thereby affecting the levels of metabolites in the body. Through this correlation, it is possible to determine whether a certain genetic variation truly has an effect. For example, when sequencing reveals suspicious variations in genes related to enzymes, metabolomics can detect an increase or decrease in downstream metabolites, providing more evidence for genetic diagnosis. Studies have shown that in a pair of twins with complex neurodevelopmental problems, whole-genome sequencing identified rare variations in two genes, and at the same time, plasma metabolomics also revealed amino acid metabolism disorders in them. The results of the two methods mutually corroborate, linking genetic variations with clinical symptoms.

Some studies use network analysis to present the relationships between genes, proteins and metabolites graphically. For example, in the animal research of Fragile X syndrome, researchers placed the discovered metabolic changes within the known protein relationship network, clearly showing the impact of the absence of key proteins on processes such as neural signal transmission. In neuromuscular diseases, similar analysis is also used to identify the pathways in which multiple genes work together, providing possible directions for treatment (Figure 2) (García-Criado et al., 2025). In summary, the analytical method from genes to proteins to metabolites provides practical means for the diagnosis of neuro-metabolic diseases.

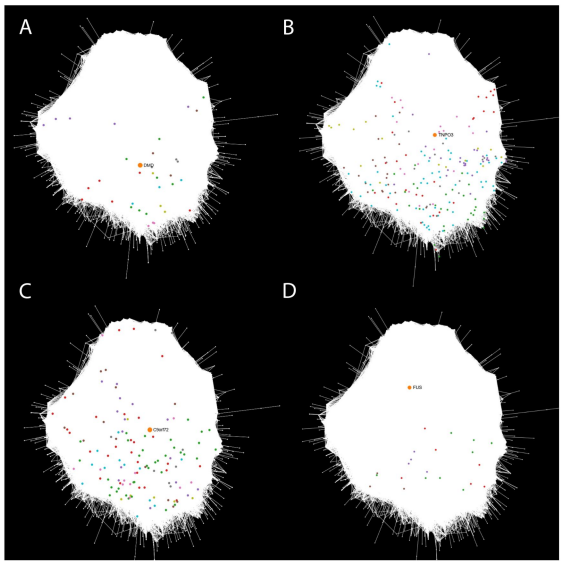

Figure 2 Protein-protein interaction network belonging to the dataset view, based on the union of all expressed genes across all the datasets (white body) (Adopted from García-Criado et al., 2025)

Image caption: Each differentially expressed gene list is represented in different colors, depending on the dataset to which they belonged. Those from the four DMD-related and the two LGMD-related datasets were collapsed into two aggregated DEG lists for visualization clarity. Green: DMD-related datasets; red: LGMD-related datasets; purple: ALS_iN_C9ORF72 dataset; and brown: ALS_fib_FUS dataset. Disease-causal genes (DMD, TNPO3, C9ORF72, and FUS) for all datasets are represented as orange nodes (Adopted from García-Criado et al., 2025)

5.2 Data analysis methods: pathway enrichment, network analysis and artificial intelligence

When analyzing complex data, researchers typically employ two methods: pathway enrichment and network analysis to identify important information. For instance, in the research on Alzheimer's disease, analyzing

metabolic data and genetic data together can help identify lipid metabolism processes related to cognitive ability, track the upstream genes controlling this process, and provide a clearer understanding of the mutual influence between lipid metabolism and amino acid metabolism. Another study detected proteins, metabolites, and inflammatory factors in cerebrospinal fluid, and found that the metabolic levels related to amyloid protein were different. This can help simplify diagnostic indicators. In the research on Fragile X syndrome, metabolic pathway analysis can also assist researchers in identifying clear pathways and potential therapeutic targets from numerous scattered metabolic changes.

After the introduction of artificial intelligence, these analyses have become more efficient. For instance, in the research of multiple sclerosis, using artificial neural networks to analyze blood metabolic data has achieved a very high diagnostic accuracy. In the research of Parkinson's disease, a team developed a model that combines metabolic imaging and clinical indicators, which can help clarify the unique metabolic patterns of this disease and improve the accuracy of early diagnosis (Liu et al., 2025). In the case of Alzheimer's disease, some studies have established a computational platform that integrates multi-omics data and gene metabolic networks to screen therapeutic targets and identify disease characteristics (Yang et al., 2025; Xie et al., 2025a). Applying these methods to rare neuro-metabolic diseases can make variant interpretation and pathway screening more automated and efficient.

5.3 Establishing a clinically applicable multi-omics diagnostic process

Clinically useful genome–metabolome workflows must balance mechanistic depth with feasibility, turnaround time, and interpretability. In rare neurological disease, a practical strategy is to combine WES/WGS with targeted or untargeted metabolomics early in the diagnostic pathway, using genomic data to nominate candidate genes and metabolomics to confirm pathway disruption or to highlight unsuspected metabolic defects. For adult-onset neurometabolic disorders, guidelines already recommend parallel NGS and “deep biochemical phenotyping”; emerging work suggests that untargeted metabolomics can serve as a high-dimensional biochemical screen that both directs further testing and assists in interpreting variants of uncertain significance detected by NGS. Case-based evidence shows that integrated WGS-metabolomics workups in complex pediatric neurogenetic presentations can elucidate composite phenotypes driven by multiple variants and provide pathway-level insights relevant to management.

To make such comprehensive testing a routine procedure, unified sample processing, analysis and reporting steps need to be established. In studies on multi-omics diagnosis of neurodevelopmental disorders and some tumors, some feasible approaches have been used: uniformly collecting samples, simultaneously obtaining multi-omics data, using computational models to identify abnormalities, integrating related pathways, and finally through multidisciplinary discussions, determining the significance of the variations and possible treatment targets (Șerban et al., 2025). Currently, multi-omics data is more suitable for being used in combination, verified through the common involved signaling pathways and candidate markers. The final conclusion still requires comprehensive judgment by experts. With more and more data and the continuous improvement of artificial intelligence models, it is possible in the future to form a standardized gene-pathway-metabolite reporting system, providing more intelligent clinical decision-making assistance for neuro-metabolism and rare neurological diseases.

6 Application Cases of Comprehensive Diagnosis

6.1 Mitochondrial encephalopathy: the interrelationship between metabolomics and genetics

Mitochondrial encephalopathy is a typical example that clearly demonstrates the significant role of metabolic genomics in understanding the impact of genetic changes. Taking MELAS syndrome as an example, researchers analyzed mitochondrial DNA mutations and changes in intracellular metabolites together. They discovered that a metabolite called glutamate showed abnormalities, and its level was closely related to the severity of the genetic mutation. This indicates that glutamate can be used to assess the severity of the disease. Urine analysis also revealed that 36 metabolites in MELAS patients were different from those of healthy individuals, and these changes were mainly related to oxidative imbalance and abnormal fat metabolism. Additionally, some patient indicators (such as FGF21) were significantly elevated, which can serve as an auxiliary method for monitoring

changes in mitochondrial damage. These studies all indicate that in diseases like mitochondrial encephalopathy, combining genetic testing with metabolic indicators can lead to more comprehensive diagnostic results (Zhang et al., 2025b).

6.2 Fatty acid oxidation disorders: association between acylcarnitine profiles and genotypes

Fatty acid oxidation disorders represent another typical case where metabolism is closely linked to genetics. In newborn screening, tandem mass spectrometry is commonly used to detect acylcarnitines in dried blood spots. Different fatty acid oxidation disorders present characteristic profiles, for instance, patients with medium-chain acyl-CoA dehydrogenase deficiency have elevated C8 carnitine, while those with very long-chain acyl-CoA dehydrogenase deficiency show an increase in long-chain acylcarnitines. These metabolic clues can directly guide subsequent genetic testing. Studies in newborn screening cohorts in China and Spain have shown that when the acylcarnitine profile is abnormal, further sequencing of related genes not only enables a clear diagnosis but also establishes the association between genotype and metabolic phenotype (Zhang et al., 2025b; Mayoral et al., 2025).

For example, in primary carnitine deficiency, children carrying a homozygous R254* mutation have significantly lower free carnitine levels than those with compound heterozygous mutations, indicating that the type of mutation directly affects the severity of the metabolism. For multiple acyl-CoA dehydrogenase deficiencies, studies have found that characteristic metabolites may fluctuate over time, so diagnosis requires both genetic testing and multiple metabolic assessments. These experiences demonstrate that in fatty acid oxidation disorders, tandem mass spectrometry provides an efficient initial screening method, while genetic testing is responsible for identifying the cause. The combination of the two can improve diagnostic accuracy and provide a basis for subsequent management.

6.3 Lysosomal storage disorders: multimodal analysis reveals common changes

Lysosomal storage disorders are a group of diseases caused by a single genetic defect. However, the accumulation of substrates triggers a series of secondary changes, such as abnormal autophagy, lipid metabolism disorders, and mitochondrial dysfunction. Recent multimodal studies have begun to systematically depict these downstream effects. For instance, a study simultaneously analyzed the protein and lipid changes in more than twenty types of lysosomal storage disorder mutant cells, revealing that although the pathogenic genes were different, common phenotypes such as autophagy defects and specific lipid elevations were ubiquitous. This provides a new perspective for understanding the disease mechanism and identifying cross-disease treatment targets (Kraus et al., 2025).

Taking Pompe disease as an example, GAA gene mutations not only cause glycogen accumulation but also lead to extensive changes in various metabolites such as sugars, lipids, and amino acids in muscles and body fluids, and different types of patients have different metabolic characteristics. After combining genotype data, these metabolic information helps explain the diversity of clinical manifestations and provides references for the selection of timing for enzyme replacement therapy and efficacy monitoring. Overall, the research on lysosomal storage disorders is shifting from single-gene testing to multimodal integrated analysis. This approach helps shorten the diagnostic cycle, verify the pathogenicity of variations, and discover potential early biomarkers (Yen et al., 2025).

7 Optimization of Diagnostic Procedures and Their Clinical Significance

7.1 Shorten the diagnosis time and increase the diagnosis rate

Many patients with rare neuro-metabolic diseases often spend several years and visit several hospitals before they can be diagnosed. This process is both costly and time-consuming, and sometimes it even delays treatment. If high-throughput genetic testing is adopted at an early stage of the disease, combined with detailed biochemical analysis, the time required for diagnosis can be significantly shortened. For example, for patients with undetermined causes of intellectual disability and metabolic abnormalities, if whole-exome sequencing is used and combined with clinical and biochemical indicators for analysis, the diagnosis rate can reach 68%; while using only genetic testing, the diagnosis rate is only 16%. Studies have pointed out that using whole-exome sequencing as the preferred examination method can eliminate many unnecessary test items, and on average, each patient can save approximately 3,000 euros in costs. In pediatric neuro-metabolic diseases, whole-exome sequencing can help

52% to 68% of patients identify the cause of the disease. It is worth noting that among these patients, over 80% have undergone many tests before but have not been diagnosed (Khudari et al., 2025). Metabolomics can provide more comprehensive biochemical information, which is helpful in explaining those unexplained genetic variations, thereby reducing reliance on a single testing method.

7.2 Precise classification of patients and guidance for individualized treatment

Combining genetic data with metabolic data can lead to more accurate patient classification and enable the formulation of more suitable treatment plans. In many neuro-metabolic diseases, whole exome sequencing combined with detailed symptom analysis not only detects metabolic abnormalities but also provides references for treatment, such as adjusting diet, supplementing coenzymes, or using specific small molecule drugs. A study on neurodevelopmental disorders found that 44% of patients who received molecular diagnostic results later attempted targeted treatment, indicating that this classification method is gradually being applied in actual treatment (Mohammed et al., 2025). For diseases like leukodystrophy, enzyme replacement therapy and gene therapy need to be initiated as early as possible, so the timing of molecular diagnosis is crucial. Additionally, integrating various data can also help us classify diseases more precisely, such as differentiating between typical and mild types based on metabolic characteristics and providing references for medication timing and dosage.

7.3 Improving prognosis assessment and long-term management

The integration of genetic and metabolic data has also had a positive impact on prognosis evaluation and long-term follow-up. In children with neuro-metabolic diseases, molecular diagnosis not only guides current treatment but also changes the prognosis assessment and prevention strategies for 74%-83% of cases, including genetic counseling and family planning (Khudari et al., 2025). For rare cases that have not yet been diagnosed, regular re-analysis of genomic data can also continuously improve the diagnosis rate-with the continuous discovery of new gene-disease relationships and the integration of standardized phenotypic data sharing platforms, approximately 18% of patients can eventually receive a clear diagnosis. This indicates that dynamic updates of clinical and molecular information are valuable for prognosis management. For some slowly-progressing genetic diseases, researchers are attempting to use imaging, blood or skin-derived biomarkers as alternative indicators to capture disease changes in a shorter period of time, making clinical trials more feasible. Once validated metabolic markers are combined with genetic risk information, they can be used for dynamic monitoring of disease activity, warning of complications, and guiding adjustments to treatment plans. It can be said that the integration of genetic testing, metabolic analysis, and data technology is driving the diagnosis and treatment of neuro-metabolic diseases from a single diagnosis to comprehensive and precise management throughout the process.

8 Challenges and Future Perspectives

In the fields of neurometabolism and rare diseases, integrating genomic data and metabolomic data has many practical challenges in actual operation. The data obtained from different technical platforms often do not match, and due to differences in sample batches and inconsistent analysis methods, it is difficult to repeat and verify the results. The current common practice is to analyze each type of data separately before combining them. This approach is prone to subjective judgments and affects the accuracy of the conclusions. Some large-scale collaborative projects have also found that differences in sample sources and clinical information can cause difficulties in subsequent data integration. In the future, it is necessary to establish unified data standards, build shareable databases (such as OmicsDI, MetaboLights, etc.), and rely on cloud computing to efficiently integrate genomic, metabolic, imaging, and clinical data. If these foundations are not laid first, multi-omics analysis will be difficult to truly become a tool that can be used in clinical practice.

The large-scale sharing of data also brings about privacy and ethical issues. Everyone's genetic information is unique. Even if personal information such as names is concealed, it is still possible to identify the corresponding person through these data. The main concerns are how to obtain informed consent, how long the data can be stored, and whether there will be discrimination when applying for insurance or finding a job. Additionally, how to fairly distribute benefits in different regions is also a challenge. Cooperation between developed countries and regions with limited resources requires more reasonable approaches. Although there are currently encryption

technologies and federated learning methods, additional management rules are needed to clearly define who is in charge of the data, who can use the data, and how responsibilities are divided. Patients with rare neurological disorders are already few in number, and the cases are very precious. Therefore, finding a balance between data openness and personal privacy is particularly important.

Artificial intelligence is becoming an important assistant in integrating multi-omics data. It can identify disease characteristics from a large amount of information and also assist in early diagnosis and classification. Currently, some studies have classified neurodegenerative diseases using integrated omics data, and the results are better than traditional methods. However, in the field of rare diseases, the application of artificial intelligence still faces many difficulties. For example, the number of cases is small, the data is complex, and the genomic structure is diverse, which may lead to incorrect judgments. To ensure the reliability of results in clinical applications, high-quality training data, understandable models, and repeated external validation are needed. In the future, if artificial intelligence can be combined with multi-omics, imaging, and wearable device data, it may form a continuously optimized diagnostic and treatment system. But this requires not only technological progress but also meeting requirements in ethics, law, and personnel training.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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Review and Progress Open Access

Research Progress on Psychological Nursing Strategies for Cancer Chemotherapy Patients Based on Humanistic Care

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Abstract This study explores the research progress of psychological nursing strategies for cancer chemotherapy patients based on the concept of humanistic care. Cancer and its treatment impose significant physical and psychological burdens on patients. Individuals undergoing chemotherapy commonly experience anxiety, depression, fear, and fatigue, which further affect treatment adherence, quality of life, and clinical outcomes. This paper systematically reviews the major psychological characteristics of chemotherapy patients and their influencing factors, and summarizes key nursing strategies, including individualized assessment and stratified interventions, communication support and health education, as well as the integration of psychological interventions with social support. It also analyzes the effects of these nursing models on alleviating negative emotions, improving quality of life, enhancing treatment compliance, and optimizing therapeutic outcomes. The findings indicate that humanistic psychological nursing can promote patient recovery from a biopsychosocial perspective and has substantial clinical application value. However, current research is limited by small sample sizes, heterogeneous intervention models, and insufficient evidence on long-term effects. Future studies should strengthen multicenter research, establish standardized nursing pathways, and promote the integration of multidisciplinary collaboration and digital technologies to achieve standardized and continuously optimized psychological care in oncology.
Keywords Humanistic care; Psychological nursing; Cancer chemotherapy; Negative emotions; Quality of life

1 Introduction

Cancer and the treatment process can cause considerable psychological stress for patients, which in turn can further affect their physical and mental health. Many patients undergoing chemotherapy experience symptoms such as anxiety, depression, fear, and fatigue, and these issues may recur during the treatment period. Konieczny et al. (2025) found that approximately one-third to half of the patients have varying degrees of anxiety and depression symptoms, which are also quite common. During the initial stage of chemotherapy, physical discomfort is usually the most obvious, and patients are more likely to worry about the treatment outcome and side effects. Although some physical symptoms gradually improve, many patients' psychological problems persist (Kamimura et al., 2024). Additionally, side effects such as nausea and hair loss can exacerbate negative emotions, making patients more anxious and uneasy (Hu et al., 2025; Yin et al., 2025). If these psychological problems are not promptly identified and addressed, they may persist for a long time, affecting daily life, interpersonal relationships, and overall quality of life (Zhang et al., 2024; Lauter et al., 2025).

The psychological state of patients undergoing chemotherapy not only affects their subjective experience but also directly relates to treatment compliance and clinical outcomes. Emotional problems such as anxiety and depression may make it difficult for patients to adhere to the established treatment plan, reduce their enthusiasm for self-care participation, and even interfere with the smooth progress of treatment (Mustafin, 2025). In patients with gastric cancer and colon cancer, psychological distress is often associated with more severe fatigue, lower quality of life, and may also weaken the chemotherapy effect and shorten the progression-free survival period (Zhang et al., 2023; Rat et al., 2025). A meta-analysis on leukemia also pointed out that if negative emotions are not effectively handled, it will reduce treatment compliance and increase the overall physical and mental burden (Yin et al., 2025). On the contrary, providing targeted psychological support or health education during

chemotherapy can alleviate anxiety and depression, help patients better cope with the disease, enhance confidence and self-care ability, thereby improving compliance and possibly improving treatment outcomes (Poudel et al., 2025). Some studies have also found that the improvement of psychological state is often accompanied by positive changes in immune indicators and symptoms, which further indicates that psychology and physiology interact with each other in cancer treatment (Fu et al., 2024).

In response to the aforementioned issues, in recent years, the "patient-centered" humanistic care-oriented psychological nursing has gradually gained attention. This model emphasizes respecting individual differences of patients, understanding their experiences, and meeting their physical, psychological, social and spiritual needs through empathetic communication. In practice, integrating humanistic care with psychological support, health education and self-efficacy enhancement has achieved good results among chemotherapy patients. Such interventions typically include structured psychological support, communication tailored to needs, family involvement, environment optimization and symptom management guidance, and encouraging patients to actively participate in the treatment process. Studies have shown that these measures can significantly alleviate anxiety and depression, reduce fatigue, enhance self-efficacy and quality of life in patients with lung cancer, leukemia and rectal cancer, without affecting the safety of chemotherapy, and even help improve treatment tolerance (Zhang et al., 2024; Huang et al., 2025). Moreover, the concept of psychological care has gradually shifted from "problem-oriented" to "positive development-oriented", such as interventions based on the PERMA model, which can help enhance patients' sense of hope and psychological growth (Hu et al., 2025). Even in resource-limited conditions, psychological support provided by pharmacists or multidisciplinary teams can also effectively alleviate patients' burdens (Bisht et al., 2025; Mustafin, 2025; Poudel et al., 2025). However, there are significant differences in intervention methods, implementation intensity and theoretical basis among different studies, and there is currently a lack of a unified framework to guide the systematic application of humanistic care in different cancer types and treatment stages.

This study will discuss how to incorporate humanistic care into the nursing of cancer patients. Since these patients often have varying degrees of psychological problems, and these problems can affect the treatment outcome and quality of life, and given that the existing research is scattered, it is necessary to conduct a systematic review. This article summarizes several common nursing methods, such as supportive care, educational care, empowerment care, and methods related to positive psychology, and introduces their main practices. This article will analyze the effects of these methods in alleviating anxiety, depression and pain, enhancing hope and psychological resilience, and paying attention to their impact on treatment compliance and quality of life. It points out some deficiencies in current research and discusses how to better implement humanistic care in actual nursing in the future. By organizing the existing research, this article hopes to provide a reference for improving psychological nursing methods and strengthening patient-centered services, thereby helping to improve patients' treatment experience and overall quality of life.

2 Overview of Humanistic Care

2.1 Basic concepts and meanings of humanistic care

In the field of nursing, humanistic care is a patient-centered approach to nursing. When nurses carry out their work, they will first place the feelings and needs of the patients at the forefront. This nursing approach emphasizes that, first, every patient's uniqueness should be respected, and second, their different needs in terms of physical, psychological, social and spiritual aspects should be paid attention to. In simple terms, when patients receive treatment and care, they will feel respected, understood and cared for. Nurses should regard patients as a complete person, rather than just focusing on the illness itself. They should also use sincerity and patience to help patients. In this way, humanistic care is no longer just completing nursing tasks according to procedures, but integrating professional skills with understanding and respect for people, to help patients better cope with diseases.

In clinical nursing practice, humanistic care places greater emphasis on considering issues from the patient's perspective. Nursing staff should listen carefully to the patient's thoughts, gradually build trust through communication, and interact more with the patient and their family members. They should jointly select more

appropriate nursing methods to make the nursing work not only a task completion but also a manifestation of interpersonal communication and care. At the same time, nursing staff should pay attention to the emotional changes of the patient, protect personal privacy, allow the patient to participate in the treatment decision-making, and promptly provide relevant information and necessary support. In this way, nurses are no longer just handling a "case", but a person with life experiences and emotional needs, and can better meet the actual needs of the patient (Suprajitno and Mugianti, 2025).

2.2 The development and application of humanistic care in nursing

From the perspective of the development of nursing, the concept of humanistic care has been continuously deepening. Initially, people placed more emphasis on the relationship between nurses and patients and nursing ethics; later, the related concepts became clearer, and more systematic evaluation tools and research methods emerged. The research focus has also changed: in the early stage, the main focus was on the caring relationship and professional responsibility, and later, more standardized measurement methods were gradually added. Now, more attention is paid to spiritual support, and it is believed that the nurse's own state and care ability are also part of humanistic care. Currently, it is widely recognized that if nurses have a good physical and mental state, possess reflective awareness, and can take good care of themselves, they are often better able to implement true humanistic care for patients. At the same time, the academic community is also striving to make this concept more specific and clear, so as to provide more explicit basis for teaching, standard formulation, and nursing intervention.

Nowadays, medical care increasingly relies on technology and standardized work processes. This not only enhances work efficiency but also raises concerns that medical services might become too rigid and mechanical, lacking the necessary human touch and the warmth that should exist between people. Therefore, the idea of "more humanistic care" has been brought up again. Some comprehensive studies have found that to incorporate more human elements into nursing work, three things usually need to be done: improving the ward environment, strengthening communication with patients, and encouraging family members to participate in care. This situation is particularly evident in maternity and pediatric wards (Reyes-Téllez et al., 2024). However, some studies have pointed out that it is not easy for nurses to provide good humanistic care in their daily work. They are often troubled by problems such as heavy workloads, insufficient staff, and lack of relevant training. To solve these practical problems, there are several feasible approaches: one is to conduct more training related to humanistic care, the second is to improve the working conditions of nurses, and the third is to reasonably use new technologies, making these technologies become assistants in nursing work rather than replacing the communication and care between people (Yang et al., 2025).

2.3 The value of humanistic care in cancer treatment

During cancer treatment, humanistic care is an important part. Cancer itself and the treatment process not only cause physical pain to patients, but also bring them great psychological pressure. Many patients worry about their future life, fear that the condition will worsen, and feel that they are of no value. Current research and clinical work have shown that cancer treatment cannot be separated from humanistic care. It can shorten the distance between nurses and patients, make patients more willing to cooperate with medical treatment, and can also improve the quality of patients' lives to a certain extent. In daily care, this kind of care is specifically manifested in improving the ward environment, creating a warmer atmosphere, paying attention to each patient's different conditions, and providing more meticulous care, etc. (Tang et al., 2025).

The relevant data and investigation results of the hospital can also prove this point. Liu et al. (2023) stated in their research that patients' feelings about the medical services they receive will affect their satisfaction with the hospital, their sense of security, and their trust in the medical staff. For cancer patients, they are more concerned about these aspects: whether the medical staff's attitude is good, whether they can truly understand their condition, whether the communication is clear and understandable, and whether they are respected. These are all important elements of humanistic care, and they can also reduce patients' fear of the disease and treatment to a certain extent. Integrating genuine humanistic care into cancer treatment can, on the one hand, meet patients' psychological and

social needs, and on the other hand, enhance mutual trust. As a result, patients are more likely to complete chemotherapy successfully and can also play a positive role in the overall treatment effect (Tang et al., 2025).

3 Psychological Characteristics of Cancer Chemotherapy Patients

3.1 The main manifestations include anxiety, depression and fear

Many cancer patients undergoing chemotherapy will experience severe anxiety, fear and depression. Patients with more severe conditions require particular attention. Outpatient surveys show that approximately one quarter to nearly half of the patients have moderate to severe anxiety or depression symptoms, and many patients also have multiple emotional problems. A multi-center study classified the patients' emotional states into different grades, and the results revealed that over 40% of the patients were in a moderately to highly disordered emotional state. This indicates that such emotional problems are very common among chemotherapy patients (Calvo-Schimmel et al., 2025).

These emotional issues are closely related to the patient's physical condition and quality of life. The more severe the patient's anxiety and depression symptoms are, the more likely they are to feel tired, the quality of sleep will deteriorate, pain may worsen, and the quality of life will decline accordingly. There is a mutual influence between emotions and physical reactions. The more severe the problem is, the more obvious this mutual influence becomes (Calvo-Schimmel et al., 2025). Additionally, the study also found that over 80% of the patients experience anxiety or fear, and approximately one-third of the patients have a tendency towards depression. These conditions will affect the patient's daily life, so these emotional issues cannot be ignored.

3.2 Psychological stress caused by chemotherapy side effects

Chemotherapy itself is already a significant source of stress. The side effects caused by chemotherapy do not all manifest at once but accumulate gradually during the treatment process. Patients usually have difficulty predicting when the side effects will occur and how severe they will be. This uncertainty alone is likely to cause anxiety. A study conducted on breast cancer patients found that during chemotherapy, symptoms of fatigue, anxiety, and depression tend to worsen together, and persist for a period before and after the treatment. The more obvious the symptoms are, the faster the quality of life declines. This indicates that emotional changes are closely linked to physical discomfort such as fatigue, nausea, and pain.

Emotional problems and the side effects of chemotherapy are not unrelated; they influence and interact with each other. Physical discomfort makes patients more prone to anxiety and depression; while those with already poor emotional states are more likely to experience more severe chemotherapy side effects. Patients with poor emotional conditions before chemotherapy have a higher probability of experiencing bone marrow suppression. Outpatient research also indicates that patients with more severe levels of anxiety and depression typically have more physical discomfort and weaker daily activity capabilities. Therefore, the side effects of chemotherapy not only impose a burden on the body but also further exacerbate the psychological stress of patients, sometimes even forming a vicious cycle, making both physical and emotional problems become more severe (Papadopoulou et al., 2022).

3.3 Changes in patients' psychological states during different treatment stages

During chemotherapy, the patient's psychological state is not always stable. As the treatment progresses step by step, the patient's emotions will also change. Studies have shown that at the beginning of chemotherapy, the patient's anxiety and depression will become more pronounced; as the treatment continues, these emotions will fluctuate and may gradually ease. One study found that before and after chemotherapy, patients' emotional problems were the most severe. After the first treatment course ended and during subsequent follow-ups, these emotional problems would significantly decrease. However, for those patients who had psychological problems before chemotherapy, they still endured severe psychological distress throughout the treatment process (Kamimura et al., 2024).

The research by Yang et al. (2023) also reached a similar conclusion. Some breast cancer patients had the highest level of anxiety before chemotherapy, and this anxiety would gradually decrease afterwards; while depression may

gradually worsen during the treatment process, and only a little improvement can be seen by the end of the treatment. A study on bladder cancer patients found that the most obvious emotional changes occurred within 1 to 3 months after chemotherapy, and then the emotions would gradually stabilize. Additionally, emotional distress and the patient's subjective well-being are inversely proportional. These research results indicate that at different stages of chemotherapy, patients face different psychological risks, so psychological care cannot remain the same and should provide more targeted support based on the emotional changes at each stage (Figure 1).

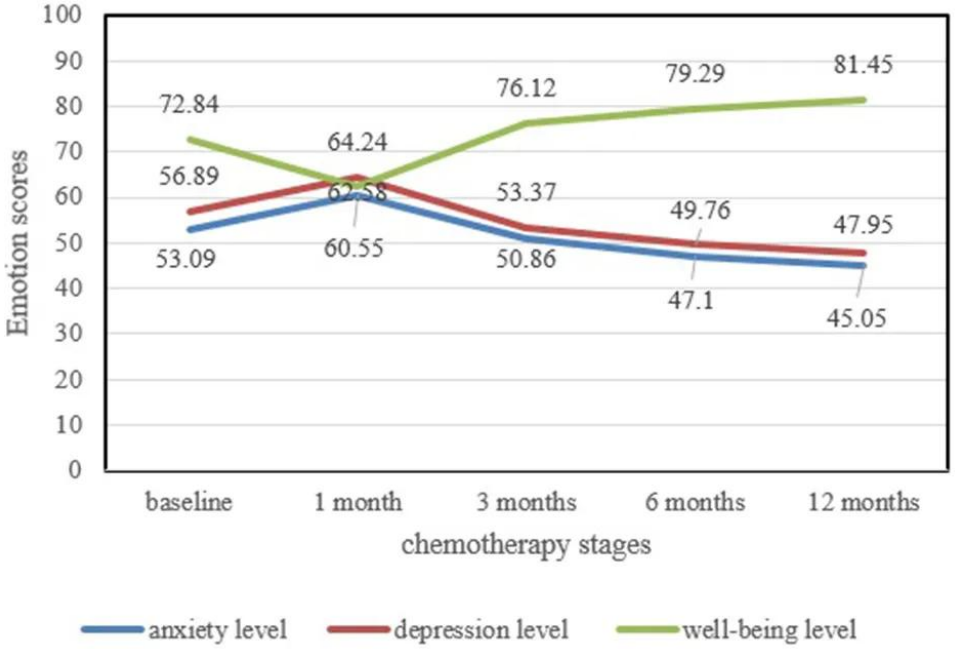

Figure 1 The change in emotion levels and wellbeing levels at different chemotherapy stages (Adopted from Yang et al., 2023)

4 Main Influencing Factors of Psychological Problems

4.1 Factors related to the disease and treatment

The severity of the patient's condition directly determines their psychological state. The development of the disease, the size of the tumor, and the doctor's assessment of the recovery situation all affect the patient's mood. Relevant studies show that patients in the advanced stage, with recurrence, or in stage IV are more likely to experience anxiety and depression compared to those in the early stage (Li et al., 2025). Taking breast cancer patients as an example, those with metastasis, newly diagnosed, or undergoing chemotherapy usually have to endure greater psychological pressure. This indicates that the more severe the disease and the more complex the treatment process, the heavier the psychological burden on the patients (Tang et al., 2024). If patients lack confidence in the treatment and believe that the disease is difficult to cure, they are more likely to feel helpless and worried, which also affects their enthusiasm for cooperating with the treatment.

Among these influencing factors, the treatment method itself, especially chemotherapy, has a more obvious impact on the patient's psychological state. Research has found that patients undergoing chemotherapy have much greater psychological stress than those who have completed treatment (Tang et al., 2024). Compared to other treatment methods, chemotherapy is more likely to cause anxiety and depression in patients (Li et al., 2025). Some studies also mention that knowing whether the patient is undergoing chemotherapy can roughly predict their risk of developing psychological problems (Velasco-Durantez et al., 2024). This indicates that the pressure brought by the disease itself, combined with various physical discomforts during the treatment process, makes patients undergoing chemotherapy more prone to psychological problems.

4.2 Social and family support factors

For patients undergoing chemotherapy, the support from family and friends is particularly important. This support can help patients reduce stress and enable them to better cope with the disease. Studies show that if patients are

satisfied with the help provided by their partners, family members, or friends, their quality of life is usually higher, they experience less physical discomfort, and have less psychological stress. Conversely, if patients feel that no one cares about them, they are more likely to feel helpless and have more difficulty coping with the disease. Similar phenomena exist among breast cancer patients, with more support usually resulting in lower psychological stress. Therefore, good social support can provide protection, while insufficient support increases the risk of anxiety and depression (Figure 2) (Tang et al., 2024).

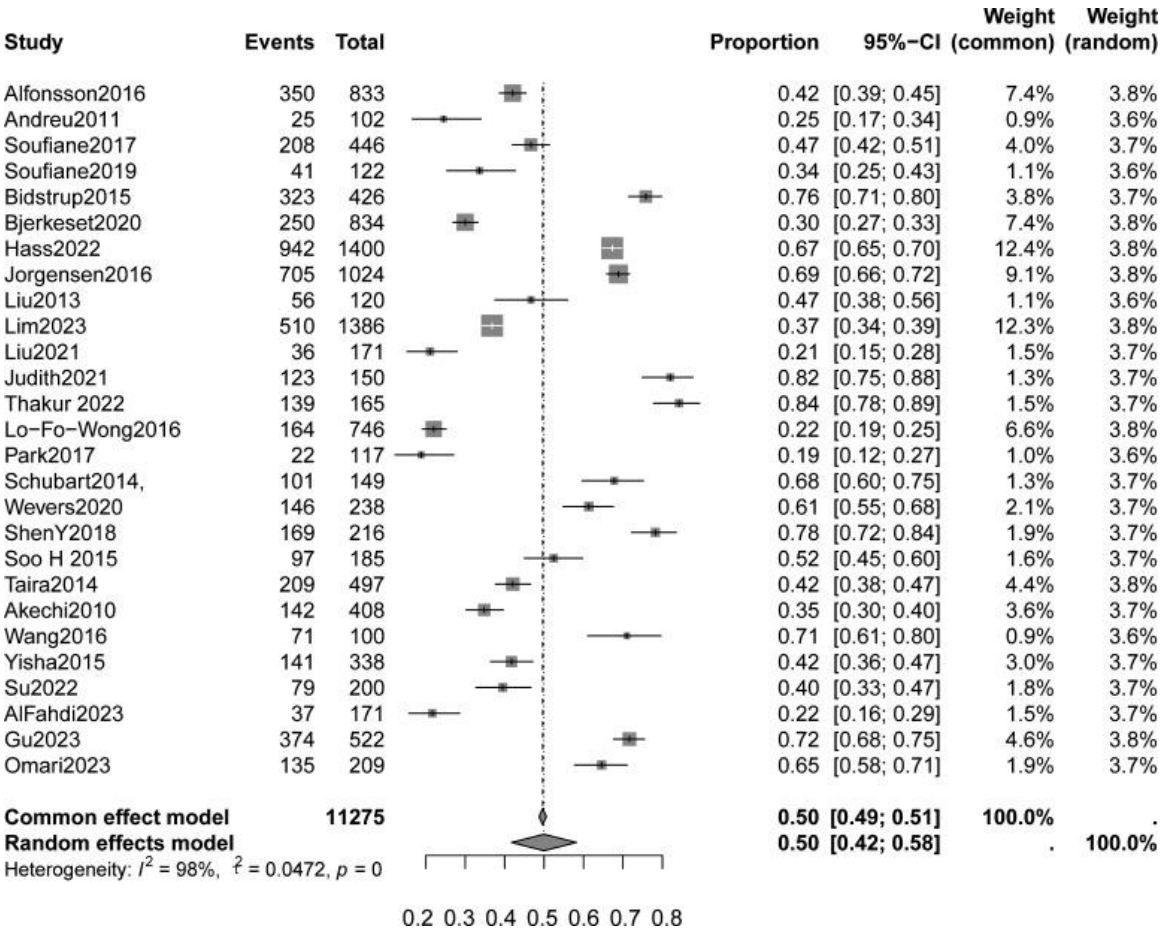

Figure 2 The forest plot of the pooled prevalence of psychological distress in patients with breast cancer (Adopted from Tang et al., 2024)

However, the quality of support is often more crucial than the quantity. If there is always criticism, excessive control, or frequent arguments in life, it not only aggravates the patient's negative emotions but also affects the state of family members themselves. On the contrary, positive and appropriate assistance can significantly reduce the patient's stress (Hermann et al., 2024). At the same time, the fact that family members feel they have made a lot of efforts does not necessarily mean that the patient truly feels supported. This shows that emotions among family members are mutually influential. Therefore, when conducting psychological intervention, caregivers should not only focus on the patient themselves but also consider the patient's family situation, and attach importance to "how to provide support", rather than just focusing on how much support has been given.

4.3 Individual differences

The personalities of different patients vary, which also affects their approaches to dealing with diseases and treatments. Some studies have classified patients into vulnerable, average, and highly adaptable types. The results showed that the more vulnerable patients experienced greater emotional fluctuations and were less willing to address problems head-on. They were more prone to exhibit reactions such as avoidance, denial, and self-blame, and these reactions often intensified feelings of anxiety and helplessness. On the contrary, patients with higher adaptability were more willing to face reality and were better able to adapt to the treatment process. Thus,

personality influences how an individual copes with stress and also affects the likelihood of experiencing emotional problems.

Apart from personality, psychological traits are also very important, such as the strength of psychological adaptability, whether the mindset is positive and optimistic, and the ability of self-regulation. Relevant studies have found that patients with strong psychological adaptability and a more positive and optimistic mindset generally have better overall health and fewer physical discomforts; while patients with weak psychological adaptability often have poorer quality of life and more obvious physical discomforts (Velasco-Durantez et al., 2024). Additionally, even when considering factors such as age and disease status, whether a person has an anxiety tendency can also reflect their psychological state after treatment. Therefore, individual differences, as well as various factors related to the disease and treatment, will affect the probability of patients experiencing anxiety and depression during chemotherapy.

5 Based on the People-Oriented Nursing Concept

5.1 Personalized assessment and stratified intervention

For nursing work to be centered on patients, the first step is to comprehensively understand the actual situation of the patients. Nursing staff need to grasp the details of the patients' conditions and clearly understand their current levels of psychological stress. Nurses can observe the emotional changes of patients during daily interactions. Nurses can also directly ask patients questions to understand if they often feel anxious, depressed, or tired. Nurses can also inquire about patients' views on the disease and their feelings and progress in daily life. After completing these steps, nursing staff can more easily identify patients with higher psychological stress. Nursing staff can provide necessary assistance to these patients as early as possible. Studies show that nursing staff can apply the PERMA model or other systematic assessment methods to the early stage. These methods can help nursing staff more accurately determine the psychological state and severity of symptoms of patients. Nursing staff can provide more appropriate support for patients with higher needs. This support can help patients alleviate negative emotions and improve their overall condition (Hu et al., 2025; Zhang et al., 2025). Moreover, assessment is not a one-time task. Nursing staff need to continuously assess throughout the chemotherapy process. When the patient's condition changes, nursing staff can promptly adjust the nursing plan.

After the initial assessment is completed, the nursing staff can classify the patients based on their specific conditions. During the classification process, factors such as the patients' psychological state, coping ability, and family support can be taken into consideration. For patients with milder emotional problems, the main focus of nursing is on emotional soothing and basic guidance. The nursing staff can help the patients cope with discomfort and stress during the treatment process, which usually helps to reduce anxiety and also helps to maintain the stability of daily life. For patients with more obvious emotional problems, the nursing staff need to take more targeted intervention measures, such as providing cognitive adjustment, relaxation training, and continuous follow-up support, to help the patients gradually alleviate negative emotions and fatigue (Wang et al., 2025; Hu et al., 2025). This stratified intervention approach better meets the actual needs of the patients and also enables more reasonable allocation of nursing resources.

5.2 Communication support and health education

In humanistic nursing, communication plays a crucial role. Firstly, nurses need to listen patiently to the patients' voices and clearly explain the relevant situations, which usually helps patients reduce psychological stress. Secondly, nurses can have more communication with the patients and encourage them to express their concerns and anxieties. Sometimes, even a brief silence can alleviate anxiety and depression. For patients with gynecological cancer and other types of cancer, effective communication can make them feel more at ease and also help improve their sleep quality (Xie et al., 2025). The methods of communication are not limited to one type; face-to-face communication is effective, while remote methods such as phone calls and the internet can also play a role. As long as patients can feel understood and supported, this communication will have a positive impact on their psychological state (Contu et al., 2025).

If health education is also included in the communication process, the effect is usually better. Nurses can explain to patients the methods of psychological support, the condition of the disease, the treatment process, and how to deal with side effects. Through this way, patients can better understand their own situation, feel more relaxed, and are more likely to cooperate with the treatment. Studies have shown that this comprehensive service can reduce anxiety, relieve pain, improve sleep quality, and enhance the quality of life (Fu et al., 2024). When explaining, nurses need to consider the patient's comprehension ability and clarify what they really need to know. They cannot use the same expressions for everyone. This targeted communication is itself a form of respect for the patient.

5.3 Integration of psychological intervention and social support

Patient-centered care mainly focuses on the patient themselves, while also considering their family situation and external support resources. The psychological state of patients is often closely related to the environment they are in. Nowadays, many integrated care models combine psychological intervention, basic treatment, and family support. Nursing staff help patients adjust their mindset, teach them some relaxation techniques, and at the same time, family members also participate in the care process. This integrated care model is usually more effective than traditional care. Studies have found that this model can reduce patients' anxiety and fatigue, improve their physical condition, and enhance their quality of life (Zhu and Liu, 2025). For patients with colon cancer, nursing staff can appropriately increase the frequency of follow-ups and guide family members on how to provide assistance. These practices help patients better adapt to treatment and reduce the risk of complications (Table 1) (Wu and Meng, 2025).

Table 1 Comparison of nutritional status before and after nursing care between the 2 groups (X±SD) (Adopted from Wu and Meng, 2025)

-	Control group (N = 77)	Observation group (N = 80)	t	P-value
Before				
BMI (kg/m²)	22.13 ± 1.86	22.29 ± 3.24	0.378	.706
SGA	12.68 ± 2.12	11.86 ± 3.09	1.932	.055
Serum prealbumin (PA/[mg·L−1])	173.56 ± 12.57	175.08 ± 14.19	0.709	.479
Serum total protein (TP/[g·L−1])	67.88 ± 4.39	68.18 ± 5.26	0.387	.699
Serum albumin (ALB/[g·L−1])	42.73 ± 3.65	43.08 ± 3.82	0.587	.558
triceps skinfold thickness (mm)	13.98 ± 2.11	14.03 ± 2.56	0.133	.894
Post				
BMI (kg/m2)	21.04 ± 1.56	22.01 ± 2.48	2.921	.004
SGA	9.85 ± 2.18	8.13 ± 1.96	8.869	<.001
Serum prealbumin (PA/[mg·L−1])	156.63 ± 13.74	165.88 ± 11.27	4.62	<.001
Serum total protein (TP/[g·L−1])	64.53 ± 3.19	66.05 ± 4.26	2.523	.013
Serum albumin (ALB/[g·L−1])	39.63 ± 3.45	41.13 ± 4.05	2.494	.014
triceps skinfold thickness (mm)	13.01 ± 1.63	13.24 ± 1.96	0.798	.426

Table caption: AL=Serum albumin; BMI=Body mass index, PA=Prealbumin; SGA=Subjective global assessment; SD=Standard deviation, TP=Total protei

In practical work, nurses can also play the role of a "bridge" to help patients establish connections with more support resources, such as community services or patient support groups. In some care plans, encouraging family members to participate in daily care can reduce patients' concerns about their own condition and enhance their confidence (Zhang et al., 2025). At the same time, good communication can also improve family relationships, making it easier for patients to adapt to the treatment process. If patients can continue to receive support after discharge, this will also help stabilize their emotions and enhance their self-management ability (Ye and Zhao, 2025). In summary, integrating psychological intervention with family support and social support usually leads to better nursing outcomes.

6 Nursing Outcomes and Current Issues

6.1 Impact on emotional improvement and quality of life

The nursing approach that combines humanistic care and psychological support can provide significant assistance to chemotherapy patients. Firstly, it can alleviate negative emotions such as anxiety and depression, making patients feel less stressed during the treatment period. For example, a study using the PERMA model for intervention found that patients' anxiety, depression, and fatigue caused by cancer were all reduced, their satisfaction increased, and similar situations occurred in breast cancer patients and other tumor patients (Hu et al., 2025; Wang et al., 2025). Additionally, regular follow-ups, frequent communication with patients, and continuous companionship are also important parts of psychological care. These practices can gradually improve patients' emotions and make them more satisfied. Similar results were also observed in patients with advanced lung cancer and cervical cancer (Lu and Yu, 2024).

Apart from improving mood, systematic psychological care also has many other benefits. The sleep quality of patients usually improves, the feeling of physical discomfort decreases, and people become more confident. These changes, in turn, can help patients stabilize their mood. For example, the MPNFS model combines psychological support, health knowledge explanation, and family participation, which not only reduces anxiety and depression but also improves physical and mental functions, alleviates pain, makes sleep more stable, and reduces fatigue (Zhu and Liu, 2025). For patients with colorectal cancer, combining psychological care with nutritional support can also enhance psychological adaptability and improve quality of life (Wu and Meng, 2025). These results all indicate that humanistic psychological care has positive effects on both the physical and mental aspects of patients.

6.2 Impact on treatment compliance and treatment outcomes

With the help of humanistic psychological care, patients are more willing to cooperate with the treatment, which is particularly crucial for the effectiveness of chemotherapy. For instance, a study on cervical cancer patients found that after receiving online psychological care, the patients' self-management ability improved and they were more willing to continue the treatment. Symptoms such as anxiety, depression, and fatigue were also significantly reduced (Nie, 2024). For rectal cancer patients, comprehensive psychological care not only makes patients more willing to adhere to the treatment but also gives them more hope. Immune indicators such as the CD4+/CD8+ ratio also improved. These changes are beneficial for subsequent recovery. This indicates that psychological care can enhance patients' sense of security and confidence, and reduce the situation where they give up treatment halfway.

When psychological intervention is incorporated into the routine nursing process, patients' physical conditions are usually improved. For example, lung cancer patients using the MPNFS model for care have improved in terms of nutritional status, lung function, and quality of life. Side effects such as nausea, vomiting, bone marrow suppression, and fatigue have also been relatively reduced. The overall effect is better than that of conventional care (Zhu and Liu, 2025). For colorectal cancer patients, combining psychological care with enteral nutrition can also reduce complications and improve nutritional status (Wu and Meng, 2025). Although there are few studies on long-term survival results, from the perspective of improving treatment compliance, reducing side effects, and improving physical functions, humanistic psychological care has positive significance throughout the treatment process.

6.3 Limitations and shortcomings of this study

Although most current studies have yielded relatively positive results, there are still many problems in the practical application of humanistic psychological care. On one hand, many studies are single-center studies or retrospective studies, with relatively small sample sizes, which will affect the persuasiveness of the research results and make it difficult to clearly identify the independent effect of psychological care itself (Nie, 2024; Wu and Meng, 2025). On the other hand, most studies have a relatively short follow-up period, usually only a few weeks to several months. Therefore, it is difficult to determine how long these improvements will last and it is also difficult to clearly determine whether they have a long-term impact on the recurrence rate, survival period, or

chronic symptoms (Wang et al., 2025). Moreover, different studies have significant differences in intervention content, intervention intensity, and assessment indicators, which makes it difficult to directly compare the results and also indicates that there is currently a lack of unified standards. Therefore, although the existing evidence has shown that humanistic psychological care has many positive effects, promoting this care method to a larger scale and forming a more unified and standardized research design still require further research to verify its actual effectiveness.

From a broader perspective, there are still many practical issues that have not been resolved. For instance, the structured psychological intervention training for nurses is not yet mature. The related costs, promotion difficulties, and specific operational methods are all still unclear at present. Current research shows that intervention measures led by nurses can alleviate anxiety and depression to a certain extent, but there is no unified understanding of what role nurses should assume in the clinical environment and how to carry out psychological intervention more systematically. Especially in the care of patients with advanced cancer, such research is still relatively scarce (Malakian et al., 2021). For cancer survivors, the existing care model can only meet some psychological and mental needs, and the effect in improving the quality of life is not yet stable (Song et al., 2024).

7 Future Directions and Conclusions

Looking back, to ensure that psychological care based on humanistic care can play a more stable and clear role in chemotherapy patients, in the future, it cannot only rely on experience to advance, but should gradually move towards standardization and evidence-based approaches. Some initial models have already begun to take shape, such as positive psychological care based on the PERMA model, the nursing method combining self-efficacy and humanistic care, and behavioral nursing plans integrating multiple theories. These methods have shown certain effects in alleviating negative emotions, reducing fatigue, improving self-management ability, and improving quality of life. At the same time, continuous care and empowerment education also demonstrate good long-term value, which can help patients enhance their self-care ability, increase treatment compliance, and make their emotional state more stable. This suggests that contents such as early assessment, individualized psychological support, family participation, and enhancing patient initiative can actually be refined into relatively stable core elements, and further developed into replicable and scalable nursing pathways. In the next step, more multi-center and large-sample studies are needed to improve these key elements, establish more unified operation procedures, clarify when to intervene, what methods to adopt for intervention, and what indicators to use for evaluation, and at the same time, form flexible plans suitable for different cancer types and different treatment stages.

As clinical care increasingly emphasizes holistic care, future psychological nursing cannot be confined to a single nursing behavior, but should be placed within a more comprehensive humanistic care framework, combined more closely with multidisciplinary cooperation and digital means. For example, in patients undergoing chemotherapy for colon cancer, empowerment education involving oncology nurses, doctors, nutritionists, and psychologists has been proven to reduce psychological stress and improve quality of life. This indicates that teamwork, compared to single-position intervention, can better meet the physical, mental, and social needs of patients. Another example is the online psychological care provided to patients with cervical cancer and lung cancer, which not only alleviated anxiety, depression, and fatigue but also enhanced self-management ability, immune level, and quality of life. This also shows that conducting humanistic psychological care in an online format is feasible and has strong potential for promotion. In the future, more methods such as mobile applications, remote care, and data analysis can be combined to achieve more timely psychological assessment and individualized guidance, and connect patients, families, communities, and related support resources. At the same time, psychological doctors, social workers, and hospice care teams can be more deeply involved in chemotherapy care, jointly forming a more complete and patient-centered support system.

Based on the current research, integrating humanistic care into psychological nursing does indeed significantly alleviate patients' negative emotions such as anxiety and depression, enhance their self-confidence, help them cooperate more actively with treatment, reduce the discomfort caused by chemotherapy, improve their quality of life, and to some extent, promote long-term disease control and increase satisfaction. Whether combined with

project-based education, empowerment education, or nursing models constructed based on theories such as Newman's, this kind of humanistic care overall outperforms conventional care in improving the psychological state, physical function, and nurse-patient relationship of patients with different types of cancer and at different treatment stages. However, it should also be noted that there are still some obvious deficiencies in current research, such as small sample size, short follow-up time, inconsistent evaluation indicators, and lack of long-term outcome data. Therefore, the extent of its impact on prognosis and whether the cost-effectiveness is satisfactory still need to be further verified. In the future, if standardized humanistic psychological nursing pathways can be better combined with multidisciplinary collaboration and digital service platforms, and a standardized and continuous assessment mechanism can be established in clinical practice, then the value of this nursing model is expected to be more fully demonstrated, and its effects will no longer be limited to the hospitalization stage but will extend to the entire treatment process, further promoting the development of oncology nursing towards higher quality and greater emphasis on patient feelings.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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