Review Article

Precision Oncology for Metastatic Cancers: The Essential Role of Multidisciplinary Tumor Boards

Areesha Mansoor[*,1], Muhammad Twaha Zia[2], Dua Ghori[1], Syeda Shahnoor[1], Agha Muhammad Hammad Khan[3]

[1]*Department of Medicine, Dow University of Health Sciences, Karachi, Pakistan.*
[2]*Department of Neurosurgery, Dow University of Health Sciences, Karachi, Pakistan.*
[3]*Department of Radiation Oncology, McGill University, Montreal QC, Canada.*

Abstract: Metastatic cancers are a great challenge in cancer treatment. Due to their vast genetics and aggressive nature these malignancies often develop resistance to standard therapies. Even for advanced tumors healthcare providers are forced to use chemotherapy and radiation to relieve symptoms without being able to address the complex molecular characteristics of metastatic tumors. Precision medicine is an approach that offers tailored cancer treatment to the phenotypic characteristics of each tumor. We conducted a literature review to assess the impact of multidisciplinary collaboration of precision medicine and oncology. The articles extracted from Pubmed, Google Scholar, Scopus and Cochrane supported the use of tumor boards for development of treatment plans. These specialized tumor boards also called Molecular Tumor Boards (MlTBs) use precision medicine tools. MlTBs incorporate advanced technologies, such as genome sequencing and liquid biopsies, which have the ability to significantly enhance and identify actionable genetic changes. These precision tools enable the development of targeted therapies, which are more effective and less toxic than standard chemotherapy/ radiation therapy treatments. With the integration of multiple dataset models MlTBs can help doctors to bridge connections between complex genomic profiles and identify opportunities for precise treatment plans. There are some known drawbacks of MlTBs, namely requirement of a well-oiled system.

Multidisciplinary teams meetings are time consuming and require a lot of planning. However, once incorporated in clinical practice they open opportunities for educational training and clinical trials. MlTBs are new to many physicians and their adaptation might take time, but strong evidence supporting their impact in enhanced treatment precision and improved patient outcomes, highlights their credibility. Making MlTBs a meritorious addition to oncological practice.

Keywords: Molecular Tumor Boards (MlTBs), Radiation therapy, Malignant cells, Metastatic cancers, Heterogeneous lesions, Randomized controlled trials (RCTs).

INTRODUCTION

Metastatic cancers are characterized by presence of multiple secondary tumors. Malignant cells spread from the primary tumor site to other parts of the body creating multiple sites of metastasis with variable tumor characteristics. The variability in characteristics reduces the effectiveness of standard treatment [1]. Conventional chemo and radiotherapies affect each tumor site very differently [2]. In advanced stages where there is presence of multiple heterogeneous lesions, the disease usually has a poor prognosis directing treatments focus towards palliative care. The aggressive nature of metastatic cancer cells promotes drug resistance leading to failure of standard treatment protocols to take effect [3]. This resistance calls for development of more targeted therapies that can effectively address the complexities of metastatic disease [4].

Precision oncology targets the limitations faced by traditional cancer regimes while treating complex malignancies, making it a viable solution. Precision medicine enables healthcare providers to create customized treatment plans. Precision medicine uses molecular data to study tumors in detail, including its genetic and phenotypic characteristics. The treatment plans produced by the help of molecular data are based on the unique nature of each patient's cancer [5]. The personalized approach cuts down on trial-and-error treatments by pinpointing tumor-specific vulnerabilities. Treatment plans tailored to target these susceptibilities, lead to better patient outcomes [6].

Application of precision medicine encounters various systemic and practical challenges. Currently the main issues are; (1) interpretation of complex genomic data, (2) high costs associated with use of advanced diagnostic technology, and (3) timely collaboration across multiple specialties to translate molecular insights into effective clinical solutions [7].

Establishment of Multidisciplinary Tumor Boards (MTBs) is one of the most effective ways to address these challenges. MTBs are teams comprising of a wide range of specialists, including oncologists, surgical oncologists, radiologists, pathologists, molecular

* Address correspondence to this author at the Department of Medicine, Dow University of Health Sciences, Karachi, Pakistan.
Email: itsareeshamansoor@gmail.com

biologists, and genetic counselors, that develop individualized treatment plans for patients with cancer. Through segregated meetings the doctors consider both clinical presentations and molecular profiling data to guide diagnosis and suggest interventions. These suggestions are based on the latest advances in precision oncology. This collaboration enables a comprehensive review of every cancer case presented [8].

MTBs also serve as core areas of information dissemination for ongoing professional development, as these meeting foster knowledge sharing across disciplines [9]. The Next-Generation Sequencing (NGS) breakthrough has transformed oncology. By enabling the creation of genomic profiles a number of critical changes have been unveiled, such as driver mutations and resistance markers [10].

This paper aims to explore, how Multidisciplinary Teams (MDTs) support the successful implementation of personalized therapies within the framework of genomic-guided, targeted cancer treatment. By critically reviewing peer-reviewed research, this paper examines how MDTs facilitate the translation of complex molecular data-particularly from NGS - into practical clinical guidance. The goal is to emphasize the vital role of multidisciplinary approach in developing individualized treatment plans, which will ultimately enhance clinical outcomes in patients with metastatic cancer.

METHODOLOGY

A thorough literature search was done using PubMed, Scopus, Cochrane and MEDLINE databases to select to research studies focusing on the role of MTBs in metastatic cancer treatment and personalized therapy. Search string included terms like 'multidisciplinary tumor board,' 'metastatic cancer,' 'tailored therapy,' 'precision oncology,' and 'personalized cancer treatment. The data was collected from inception to August 2024 from the databases as described. The inclusion criteria for this article included (i) randomized controlled trials (RCTs) (ii) cross-sectional, (iii) cohort, (iv) case-control studies that assessed Articles discussing multidisciplinary tumor boards (MDTs) in treatment decision-making. Eligible studies involved (v) tailored therapy, (vi) personalized treatment, and (vii) precision oncology approaches in metastatic cancer settings. The exclusion criteria for this article focused on ensuring quality and relevance. (i) Studies focusing solely on non-metastatic or early-stage cancers. (ii) Articles that do not address tailored therapy, MDTs, or precision oncology as a central theme. and (iii) Conference abstracts without full-text availability. Lastly, (iv) studies with incomplete data or protocols were not considered, while non-English studies were excluded only if reliable translations were unavailable.

A preliminary literature search using terms such as "multidisciplinary tumor board," "metastatic cancer," "tailored therapy," "precision oncology," and "personalized cancer treatment" revealed a growing body of research, particularly within the last 5–10 years. This reflects an increasing clinical and academic interest in integrating molecular diagnostics with collaborative decision-making frameworks. While numerous studies highlight the benefits of precision oncology in metastatic settings, relatively few focus specifically on the operational and clinical impact of multidisciplinary tumor boards in guiding such individualized approaches. This gap underscores the need to examine how MDTs function as a bridge between genomic data and patient-centered treatment decisions.

ROLE OF PRECISION MEDICINE IN ONCOLOGY

Precision medicine in oncology signals a new approach for handling cancer, pointing to hope for patients and professionals, breaking away from the one-size-fits-all kind of practices. Instead, precision medicine emphasizes on tailoring therapies based on the uniqueness of neoplastic tumors and patients. This leads to discovery of vast possibilities for more efficient and personalized cancer care in the understanding of genetic, environmental, and lifestyle factors that influence the response of a patient to treatment [11]. Genomics and personalized oncology genomic profiling, a cornerstone of precision oncology, has made significant contributions to cancer treatment. Examining the genetic composition of tumors using advance technologies such as Whole Genome Sequencing (WGS) and NGS, enables researchers to pinpoint mutations, Copy Number Variations (CNVs), and gene fusions unique to metastatic neoplasms. In one study, among the sequencing of 2,520 metastatic tumor samples, at least one actionable genetic event was identified in 62% of the samples, this may offer the opportunity for targeted therapies [12].

Emerging non-invasive technologies such as liquids biopsies, assess either circulating tumor cells, or circulating tumor DNA. These non-invasive approaches enable the real-time monitoring of tumor evolution and treatment response, overcoming the limitative nature of traditional biopsies that may not fully capture the heterogeneity of tumors [13]. Targeted therapies are a very potent weapon against cancer. They consist of drugs designed to disrupt specific molecules crucial for the growth and survival of the cancer cell.

Identification of mutations has paved the way for drug-targeting pathways, such as the targeting of pathways such as EGFR gene in non-small cell lung cancer and BRAF gene in melanoma. Such targeted therapies are not mere treatments but game changers to fight the war against cancer. Molecular testing guidelines have become necessary for selecting patients to receive such therapies, particularly those with specific genetic alterations in their tumors.

The fact that targeted therapies can successfully combat cancer indicates the emphasis on the efficacy of targeted therapies in fighting cancer [12, 13]. Basket and Umbrella Trials are novel clinical trial designs. They are a ray of hope for cancer studies as they enable testing of whether the drugs applied work on identical genetic mutations within different types of cancers. Such an approach does promise hope, especially in identifying which patients are likely to benefit from the therapy, particularly

in targeting rare but actionable genetic changes. The potential for targeted treatments offers a favorable perspective for the future of cancer research [14].

Immunotherapy, particularly immune checkpoint inhibitors (ICIs), are considered revolutionary for cancer treatment, however, there is a considerable variability in response to these therapies. Biomarkers such as PD-L1 expressions and tumor mutational burden are being increasingly used to determine which patients are likely to respond to ICIs. High tumor mutation burden (TMB), for example, correlates with a better outcome in patients who have received immunotherapy, as it indicates a higher number of neoantigens that can be targeted by the immune system [15].

Biomarkers help predict responses. However, universal quantitative cutoff values cannot be assigned to TMB. Additionally, resistance to ICIs has also been linked to mutations in antigen-presenting genes, such as B2M and HLA, as well as pathway alterations, including IFN signaling. Therefore, a combination of therapies may be necessary to overcome these hurdles [11, 15]. Epigenetic changes, including DNA methylation and histone modifications are also an area of interest in precision oncology. These changes can inhibit tumor suppressor genes or activate oncogenes, thus promoting cancer. Studies on these changes can not only provide the biology behind cancer but also open up a new landscape of treatment [11, 16]. Metabolic changes in cancer cells are another dimension of personalization. These variations in nucleotide, amino acid, lipid, and carbohydrate metabolites reflect the unique metabolic reprogramming associated with tumors. This can be used in monitoring change, helping in the diagnosis and understanding the pathophysiology of many cancers [16]. Genomic, transcriptomic, and metabolomics data are also applied to shift the practice of oncology. Precision medicine is the approach which provides more effective and less toxic treatments by understanding complex biological networks driving every cancer. As such, the future of care of cancer will most probably be even more dependent on personalized approaches in which every patient's outcomes are maximized based on the particular characteristic of the disease [17].

ROLE OF MTBs IN PRECISION MEDICINE

Precision oncology is conceptualized by a key forum called Molecular Tumor Boards (MlTBs). In fact, MlTBs represent a special kind of MTBs, with genetic and molecular profiling being included in clinical decision-making to formulate tailored therapeutic strategies that can target particular mutations or genomic alterations [18]. Precision medicine is a highly complex field based on several factors, including test sensitivity, specificity, and interpretations of results. Besides this, the landscape of precision medicine is constantly changing with the updates in clinical guidelines, newly approved targeted therapies, and emerging clinical trials [19].

In such a dynamic spectrum, the best way to maximize benefits of precision oncology is by the unification of specialists and experts such as medical oncologists, pathologists, molecular biologists, geneticists, and other relevant physicians to discuss and interpret the clinical history, imaging, pathology, and molecular profiling results to apply appropriately tailored treatment strategies to metastatic cancer patients [20]. Tumor boards, especially MlTBs, are crucial for personalizing advanced cancer treatment plans by using genomics and molecular information to aid therapeutic decisions.

Unlike traditional tumor boards where the focus is limited to histology and pathological findings of tumor coupled with radiological data. MlTBs include molecular data of metastatic tumors. With the help of this data experts are able to consider mutational and other alterations as possible therapeutic targets [19]. Genomic complexities and intra-tumor heterogeneity present significant challenges when treating tumors, with high probability of metastasis. These tumors often harbor multiple mutations, some of which are clinically actionable MTBs bring together oncologists, geneticists, and other specialists to collectively interpret findings including results of NGS, and identify targetable mutations like EGFR, BRCA1/2, ALK, or BCR-ABL [21]. Multidisciplinary discussions ensure that each mutation is accurately assessed in the context of tumor biology, and comorbidities. MTBs facilitate the selection and implementation of personalized therapies, including targeted agents and immunotherapies, thereby optimizing treatment strategies for individual patients [22].

MlTBs are engineered to track a patient's tumor biology at all times through the interfacing of real-time molecular diagnostic tools, like NGS [18] and liquid biopsies [23]. It is, therefore, in the context of metastatic cancer, especially important, as tumors may eventually become selective over time as an evolutionary response to new mutations and resistance. MlTBs can offer such therapeutic counseling by including changing disease profile in the decision-making process by incorporating molecular updates. If a patient initially responds to a targeted therapy but then progresses and becomes resistant, MlTBs can advise evaluation of the basic genetic structure of the tumor [22]. Based on updated information, novel alternative targeted therapies can be suggested, enabling in-time adjustment of therapeutic regimens, aiding in the control of resistance, and thereby controlling the disease. Incorporation of MlTBs for planning treatment of an advanced disease has also been associated with positive patient outcomes, such as endpoints like progression-free survival, were improved in patients harboring targetable mutations [24].

MlTBs might open opportunities for clinical trials and new therapies for advanced disease patients [25]. Since the field of precision medicine is moving rapidly, there will always be new targeted therapies and immunotherapies that need to be tested in a clinical trial. MlTBs acts as an intermediary between the patients who would most likely benefit from those novel and advanced treatments, especially in the case of rare mutations that have not been approached by common therapies yet. For most patients with metastatic cancer, participation in clinical trials offers the greatest hope for a better prognosis-especially when all conventional treatment options have been exhausted. Thus, MlTBs can assist in matching a patient with a clinical trial based

on their genetic profile so that they can accesses targeted therapies compatible with their tumor biology. Along the technical and scientific aspects, MTBs are also emphasize the importance of patient-centered care. MlTBs enhance clinical decision-making by incorporating molecular data into therapeutic discussions, thereby enabling patient-informed treatment planning [26].

DISCUSSION

Multidisciplinary teams create individualized treatment plans based on the specific genetic and molecular features of each patient's tumor to improve clinical outcomes [21]. Results suggest that a customized intervention developed based on genomic changes can improve clinical outcomes, with precision medicine playing a crucial role in improving patients' survival rates and quality of life [22]. These boards leverage genomic and molecular data to propose tailored therapies that offer hope, even for advanced and resistant cancers.

Molecular tumor boards have huge potential for implementing precision medicine in clinical practice. However, despite the growing potential of precision oncology, several systemic and operational challenges still hinder the widespread adoption and effectiveness of molecular tumor boards [23]. A major obstacle is the poor coordination between departments and institutions, which can cause delays in data dissemination leading to inconsistent clinical decision-making, and limited access to genomic resources [24]. It should be noted that there's still a significant gap in standardized protocols for incorporating molecular data into molecular tumor board workflows, which erodes the consistency and reproducibility of treatment recommendations.

A lack of comprehensive genomic knowledge among clinicians, particularly those outside molecular oncology, continues to limit the smooth implementation of precision medicine in clinical cancer care. Without ongoing, structured interdisciplinary training, many professionals struggle to interpret next-generation sequencing results or follow rapidly changing treatment guidelines in real-time [23]. Additionally, the ever-changing field of precision medicine requires continuous Quality Improvement (QI) systems that can quickly update clinical protocols based on new evidence and emerging biomarkers. Without real-time knowledge updating platforms, even well-meaning molecular MTBs risk using outdated information, which could negatively affect patient outcomes.

Time constrictions and high patient volumes also put significant stress on MTBs. The intense review process required for precision oncology cases often overwhelms the resource capabilities of institutions, particlarly those that do not have special bioinformatics support or effective case management systems [27, 28]. Limited institutional interaction, especially between academic institutions and community hospitals, undermines the equitable implementation of MTB in cases involving precision medicine, especially for patients in low-resource settings [28]. Precision medicine aims to maximize treatment outcomes by tailoring treatments to molecular profiles obtained from various omics data from the patient's specimen before, during, and after treatment. However, obtaining this data is very costly [29] and timely access to detailed and accurate patient information is essential for making informed decisions. Moreover, much of the healthcare infrastructure needed to support MTBs is lacking [30]. Patient heterogeneity and treatment resistance complicate the work of multidisciplinary tumor boards, requiring complex decision-making for cancer care [31]. In low- and middle-income countries (LMICs) like Pakistan, access to diagnostics and affordable drugs is limited, especially immunological and advanced oncology drugs due to high costs [32, 33]. Genome databases can aid LMICs in improving the implementation of precision oncology [34].

Precision medicine and metastatic cancer are shaped by advances that are rapidly changing clinical and research landscapes, particularly the integration of artificial intelligence (AI) and the development of personalized cancer vaccines. The rapid advancements in AI have urged its adoption in most fields with oncology being no exception, this has led to AI-powered platforms gaining popularity as tools for analyzing high-throughput genomic and clinical data. These tools enable tumor boards to identify actionable mutations, predict treatment responses, and optimize therapeutic strategies with greater speed. Decision-support tools such as IBM Watson for Oncology and Tempus have been promising to improve clinical practices. The programs analyze complicated molecular data and recommend treatments, thus ensuring that the recommendations are in line with the latest clinical literature and international guidelines.

Personalized cancer vaccines represent a promising frontier in immunotherapy. These vaccines are designed to provoke an immune response against neoantigens-tumor-specific mutations unique to each patient. Clinical trials such as the Moderna–Merck mRNA-4157/V940 vaccine in combination with pembrolizumab [35, 36], have shown encouraging results, including reduced recurrence risk. Other trials, like BioNTech's individualized neoantigen-specific immunotherapies (iNeST platform) [37], are exploring similar approaches in multiple solid tumors.

Collectively these innovations enhance the capacity of multidisciplinary tumor boards to deliver truly personalized care, paving the way for improved treatment efficacy, reduced toxicity, and better long-term outcomes in patients with advanced malignancies [38]. This is different from conventional therapies in that these cancer vaccines exploit the body's immune system to recognize and eliminate cancerous cells with much specificity, which can lead to effective long-term tumor control [39]. The inclusion of these vaccines in discussions in tumor boards may offer the possibility of introducing new treatments in patients with metastatic cancers, which are usually unresponsive to standard therapies [40]. Since the research and clinical work in this area is still at an early stage, there is much promise that further development will increase the number of possible treatments that can be opened through tumor boards.

For better access to immuno-oncology drugs and to address cancer care disparities in LMICs, several strategies are neces-

sary. A patient registry for people receiving lower doses of IO drugs may provide real-world efficacy data, while analyses of cost-effectiveness may show benefits at the population level, even though individual survival may be decreased. Informed consent for lower doses would have to be ensured, and such randomized trials would be required to confirm the dose equivalence, but funding and pharmaceutical challenges may arise [39]. Improving coordination among stakeholders is also important for enhancing early detection, cancer registries, and control programs. Developing guidelines specific to the region, ensuring affordable access to such targeted therapies, and regularly reviewing the access programs would optimize patient outcomes. Cancer treatment is recognized as a priority public health issue, which will further improve prevention and timely treatment in respect to improved access and equity in cancer care [40-42].

CONCLUSION

MTBs are the heart of metastatic cancer management and serve as the foundation for precision oncology by bringing together multiple forms of clinical expertise and complex genomic information. Within the setting of tumor heterogeneity and the quickly changing therapeutic landscape, MTBs facilitate personalized, evidence-based treatment planning through shared decision-making. MTBs' role is most critical in actionable mutation interpretation and coordination of targeted therapies with patient-specific variables, ultimately enhancing metastatic disease outcomes.

In the future, MTB efficiency can be optimized further by encouraging standardized data-sharing policies between institutions to enable more synergy and access to complete datasets. Coordination with research centers to optimize clinical trial accrual and prioritizing patient preference and quality-of-life issues at the forefront of care planning are also important. Lastly, ongoing multidisciplinary integration in education and training will solidifying MTB as a dynamic and essential part of cancer treatment today.

ABBREVIATIONS

AI: Artificial Intelligence.

CNV: Copy Number Variations.

ICI: Immune Checkpoint Inhibitors.

LMICs: Low Middle Income Countries.

MITB: Molecular Tumor Boards.

MTB: Multidisciplinary Tumor Board.

NGS: Next-Generation Sequencing.

QI: Quality Improvement.

STAMP: Solid Tumor Actionable Mutation Panel.

TMB: Tumor Mutation Burden.

WGS: Whole Genome Sequencing.

AUTHORS' CONTRIBUTION

Areesha Mansoor: Conceptualization, Study Design, Writing Draft, Critical review and revision the manuscript.

Muhammad Twaha Zia: Writing Draft, Critical review and revision the manuscript.

Dua Ghori and **Syeda Shahnoor**: Writing draft.

Agha Muhammad Hammad Khan: Methodology, Data analysis and interpretation, Critical review and revision the manuscript.

ACKNOWLEDGEMENTS

Declared none.

ETHICAL DECLARATIONS

Data Availability

Not applicable.

Ethical Approval

Not applicable.

Consent to Participate

Not applicable.

Consent to Publication

Consented.

Conflict of Interest

Declared none.

Competing Interest/Funding

Declared none.

Use of AI-Assisted Technologies

The authors declare that no generative artificial intelligence (AI) or AI-assisted technologies were utilized in the writing of this manuscript, in the creation of images/graphics/tables/captions, or in any other aspect of its preparation.

REFERENCES

[1] Esposito M, Ganesan S, Kang Y. Emerging strategies for treating metastasis. Nat Cancer 2021; 2(3): 258-70.

[2] Liu B, Zhou H, Tan L, Siu KTH, Guan XY. Exploring treatment options in cancer: Tumor treatment strategies. Signal Transduct Target Ther 2024; 9(1): 175.

[3] Gouldthorpe C, Power J, Taylor A, Davies A. Specialist palliative care for patients with cancer: More than end-of-life care. Cancers (Basel) 2023; 15(14): 3551.

[4] Gote V, Nookala AR, Bolla PK, Pal D. Drug resistance in metastatic breast cancer: Tumor targeted nanomedicine to the rescue. Int J Mol Sci 2021; 22(9): 4673.

[5] Hoeben A, Joosten EAJ, van den Beuken-van Everdingen MHJ. Personalized medicine: Recent progress in cancer therapy. Cancers (Basel) 2021; 13(2): 242.

[6] Tsimberidou AM, Fountzilas E, Nikanjam M, Kurzrock R. Review of precision cancer medicine: Evolution of the treatment paradigm. Cancer Treat Rev 2020; 86: 102019.

[7] Naithani N, Atal AT, Tilak T, Vasudevan B, Misra P, Sinha S. Precision medicine: Uses and challenges. Med J Armed Forces India 2021; 77(3): 258-65.

[8] Lowes M, Kleiss M, Lueck R, Detken S, Koenig A, Nietert M, *et al.* The utilization of multidisciplinary tumor boards (MDT) in clinical routine: Results of a health care research study focusing on patients with metastasized colorectal cancer. Int J Colorectal Dis 2017; 32(10): 1463-9.

[9] Patel M, Kato SM, Kurzrock R. Molecular tumor boards: Realizing precision oncology therapy. Clin Pharmacol Ther 2018; 103(2): 206-9.

[10] Specchia ML, Frisicale EM, Carini E, Di Pilla A, Cappa D, Barbara A, *et al.* The impact of tumor board on cancer care: Evidence from an umbrella review. BMC Health Serv Res 2020; 20(1): 73.

[11] Zugazagoitia J, Guedes C, Ponce S, Ferrer I, Molina-Pinelo S, Paz-Ares L. Current challenges in cancer treatment. Clin Ther 2016; 38(7): 1551-66.

[12] Lindeman NI, Cagle PT, Aisner DL, Arcila ME, Beasley MB, Bernicker EH, *et al.* Updated molecular testing guideline for the selection of lung cancer patients for treatment with targeted tyrosine kinase inhibitors: Guideline from the College of American Pathologists, the International Association for the Study of Lung Cancer, and the Association for Molecular Pathology. Arch Pathol Lab Med 2018; 142(3): 321-46.

[13] Jones AS. Chaos, cancer, the cellular operating system and the prediction of survival in head and neck cancer. In: Outcome Prediction in Cancer. Netherland: Elsevier 2007; pp. 101-43.

[14] Haslam A, Olivier T, Tuia J, Prasad V. Umbrella review of basket trials testing a drug in tumors with actionable genetic biomarkers. BMC Cancer 2023; 23(1): 46.

[15] Looney AM, Nawaz K, Webster RM. Tumour-agnostic therapies. Nat Rev Drug Discov 2020; 19(6): 383-4.

[16] Toufektchan E, Toledo F. The guardian of the genome revisited: p53 downregulates genes required for telomere maintenance, DNA repair, and centromere structure. Cancers (Basel) 2018; 10(5): 135.

[17] Raphael BJ, Dobson JR, Oesper L, Vandin F. Identifying driver mutations in sequenced cancer genomes: computational approaches to enable precision medicine. Genome Med 2014; 6(1): 5.

[18] Irelli A, Chiatamone Ranieri S, Di Giacomo D, Malatesta S, Patruno LV, Tessitore A, *et al.* Role of the molecular tumor board for the personalized treatment of patients with metastatic breast cancer: A focus on the state of the art in Italy. Cancers (Basel) 2023; 15(6): 1727.

[19] Liu A, Vicenzi P, Sharma I, Orr K, Teller C, Koentz M, *et al.* Molecular tumor boards: the next step towards precision therapy in cancer care. Hematol Rep 2023; 15(2): 244-55.

[20] Luchini C, Lawlor RT, Milella M, Scarpa A. Molecular tumor boards in clinical practice. Trends Cancer 2020; 6(9): 738-44.

[21] Ballatore Z, Bozzi F, Cardea S, Savino FD, Migliore A, Tarantino V, *et al.* Molecular tumour board (MTB): From standard therapy to precision medicine. J Clin Med 2023; 12(20): 6666.

[22] Boos L, Wicki A. The Molecular Tumor Board—A Key Element of Precision Oncology. USA: Springers 2024.

[23] Nikanjam M, Kato S, Kurzrock R. Liquid biopsy: Current technology and clinical applications. J Hematol Oncol 2022; 15(1): 131.

[24] Miller RW, Hutchcraft ML, Weiss HL, Wu J, Wang C, Liu J, *et al.* Molecular tumor board-assisted care in an advanced cancer population: results of a phase II clinical trial. JCO Precis Oncol 2022; 6: e2100524.

[25] Tamborero D, Dienstmann R, Rachid MH, Boekel J, Lopez-Fernandez A, Jonsson M, *et al.* The molecular tumor board portal supports clinical decisions and automated reporting for precision oncology. Nat Cancer 2022; 3(2): 251-61.

[26] Ott PA, Hu Z, Keskin DB, Shukla SA, Sun J, Bozym DJ, *et al.* An immunogenic personal neoantigen vaccine for patients with melanoma. Nature 2017; 547(7662): 217-21.

[27] Kim SY, Kim JH, Kim TY, Park SR, Yoon S, Lee S, *et al.* Pragmatic nationwide master observational trial based on genomic alterations in advanced solid tumors: Korean Precision Medicine Networking Group Study of Molecular profiling guided therapy based on genomic alterations in advanced solid tumors (KOSMOS)-II study protocol. KCSG AL-22-09. BMC Cancer 2024; 24(1): 574.

[28] Lajmi N, Alves-Vasconcelos S, Tsiachristas A, Haworth A, Woods K, Crichton C, *et al.* Challenges and solutions to system-wide use of precision oncology as the standard of care paradigm. Camb Prism Precis Med 2024; 2: e4.

[29] Andi A. Precision medicine approaches in oncology: Current trends and future directions. Adv Healthc Res 2024; 2(1): 36-48.

[30] Yang HT, Shah RH, Tegay D, Onel K. Precision oncology: Lessons learned and challenges for the future. Cancer Manag Res 2019; 11: 7525-36.

[31] Saunders NA, Simpson F, Thompson EW, Hill MM, Endo-Munoz L, Leggatt G, *et al.* Role of intratumoural heterogeneity in cancer drug resistance: Molecular and clinical perspectives. EMBO Mol Med 2012; 4(8): 675-82.

[32] Aziz Z, Naseer H, Altaf A. Challenges in access to new therapeutic agents: Marginalized patients with cancer in Pakistan and the need for new guidelines. JCO Glob Oncol 2022; 8: 1-7. https://doi.org/10.1200/GO.21.00132

[33] Mathew Thomas V, Linden H, Gralow J, Van Loon K, Williams L, Dubard-Gault M, *et al.* Precision medicine in low- and middle-income countries. Int J Cancer Care Deliv 2023; 3(2): 73-7. https: //doi.org/10.53876/001c.88504.

[34] Rathnasamy N, Mullapally S, Sirohi B. Precision oncology in low- and middle-income countries: a word of caution. Int J Cancer Care Deliv 2021; 1(1): 27-31. https: //doi.org/10.53876/001c.29768.

[35] ClinicalTrials.gov. An efficacy study of adjuvant treatment with the personalized cancer vaccine mRNA-4157 and Pembrolizumab in participants with high-risk melanoma (KEYNOTE-942). 2023; Available at: https: //clinicaltrials.gov/study/NCT03897881 [Accessed 28 May 2025].

[36] Chen JH, Asch SM. Machine learning and prediction in medicine -beyond the peak of inflated expectations. New Engl J Med 2017; 376(26): 2507-9. Available at: https: //doi.org/10.1056/NEJMp1702071

[37] Moderna, Inc. and Merck & Co., Inc. Moderna and Merck Announce Positive Phase 2 Data for mRNA-4157/V940 in Melanoma. Press Release 2023; Available at: https: //investors.modernatx.com [Accessed 28 May 2025].

[38] Dolgin E. How personalized cancer vaccines could keep tumors from coming back. Nature 2024; 630(8016): 290-2.

[39] Secli L, Leoni G, Ruzza V, Siani L, Cotugno G, Scarselli E, *et al.* Personalized cancer vaccines go viral: Viral vectors in the era of personalized immunotherapy of cancer. Int J Mol Sci 2023; 24(23): 16591.

[40] Fan T, Zhang M, Yang J, Zhu Z, Cao W, Dong C. Therapeutic cancer vaccines: Advancements, challenges, and prospects. Signal Transduct Target Ther 2023; 8(1): 450.

[41] Patel A, Goldstein DA, Tannock IF. Improving access to immunotherapy in low- and middle-income countries. Ann Oncol 2022; 33: 360-1.

[42] Ball J, Thompson J, Wulff-Burchfield EM, Ellerbeck EF, Kimminau KS, Brooks J, *et al.* Precision community: A mixed methods study to identify determinants of adoption and implementation of targeted cancer therapy in community oncology. Implement Sci Commun 2020; 1: 72. https://doi.org/10.1186/s43058-020-00064-y

Received: October 02, 2024 Revised: June 04, 2025 Accepted: June 04, 2025