May Precision Medicine involve Precision Vaccine?

Yes, **precision medicine** directly involves **precision vaccines** as a core application domain.

Precision vaccinology is explicitly defined as the application of precision medicine to vaccine development, administration, and post-administration analysis (Xie et al., 2020). The terms "precision vaccine" and "personalized vaccine" are treated as synonymous in the literature, with both denoting vaccines tailored to individual or subpopulation characteristics (Xie et al., 2020). This extension from precision medicine to vaccinology parallels the earlier extension from pharmacogenomics to vaccinomics, which applies the same principle of individual variability to vaccine-induced immune responses (Omersel & Kuželički, 2020).

Conceptual Foundations

Precision medicine tailors medical intervention to individual characteristics — genes, environment, and lifestyle — to classify individuals into subpopulations differing in disease susceptibility or treatment response (Marques et al., 2024; Xie et al., 2020). Applied to vaccines, this paradigm replaces the conventional "same dose for everyone" model with strategies that consider the target population, selectively activate specific immune pathways, and incorporate adjuvantation optimized for that population (Soni et al., 2020; Poland et al., 2017). The Precision Vaccines Program at Boston Children's Hospital was established specifically to characterize distinct vaccine-induced immune responses in vulnerable populations such as the very young and elderly, directly embedding precision medicine principles into vaccine research (Soni et al., 2020).

Vaccinomics explores how genetic and non-genetic factors drive heterogeneity in vaccine responses between individuals, while the related field of adversomics addresses vaccine side effects in genetically predisposed individuals (Omersel & Kuželički, 2020). Nearly 90% of measles vaccine response heterogeneity is genetically explainable, demonstrating the magnitude of individual variability that precision approaches aim to address (Xie et al., 2020).

Application Domains

Domain	Approach	Key Evidence
Cancer immunotherapy	Neoantigen-based personalized vaccines from tumor sequencing	(Şahin & Türeci, 2018; , 2023; Kiyotani et al., 2021)
Infectious disease	Adjuvant and formulation matching for vulnerable populations	(Lee et al., 2023)
Perioperative oncology	Genomic profiling + neoantigen vaccines as surgical adjuvants	(Espinal et al., 2025)
Pandemic response	Precision vaccinology informed by COVID-19 variability	(Equils et al., 2023)

FIGURE 1 Application domains where precision medicine principles extend to precision vaccine development

In oncology, personalized cancer vaccines use somatic mutations to generate patient-specific neoantigens that autologous T cells recognize as foreign (Şahin & Türeci, 2018; Kiyotani et al., 2021). First-in-human trials have demonstrated feasibility and immunotherapeutic activity of targeting individual tumor mutation signatures (Şahin & Türeci, 2018). A personalized mRNA vaccine combined with pembrolizumab achieved a 44% higher recurrence-free survival rate versus pembrolizumab alone in resected melanoma, earning FDA breakthrough designation (, 2023).

For infectious diseases, precision vaccinology matches antigen, adjuvant, and formulation to distinct populations — including infants, the elderly, and the immunocompromised — whose immune systems differ phenotypically and mechanistically (Lee et al., 2023; Soni et al., 2020). The COVID-19 pandemic revealed large variability in vaccine response and safety, with approximately 10% of the population — predominantly children, older adults, and the immunocompromised — responding poorly, underscoring the urgent need for precision vaccinology (Equils et al., 2023).

Enabling Technologies and Challenges

- **Multi-omics and systems biology**: Transcriptomics, proteomics, and metabolomics generate vaccine-induced cellular and molecular signatures correlating with immunogenicity (Soni et al., 2020; Poland et al., 2017).
- **AI and computational genomics**: Machine learning enables neoantigen prediction and identification of biological profiles for smaller subgroups within large populations (Xie et al., 2020; Equils et al., 2023; Oh et al., 2026).
- **Nanoplatform engineering**: Lymph node–targeting nanodiscs and biomimetic carriers enhance potency while minimizing off-target effects (Oh et al., 2026; Zhou et al., 2019).
- **Manufacturing scalability**: Individualized vaccine production remains a bottleneck, with each recipient essentially an n-of-1 trial carrying unique toxicity risks (, 2023).

Despite strong scientific momentum, precision vaccinology is far from fully implemented in clinical practice (Omersel & Kuželički, 2020; Jia et al., 2020). Technical, ethical, economic, and regulatory barriers must be addressed to ensure equitable access and safety of personalized vaccination strategies (Montin et al., 2024; Aljabali et al., 2025). Long-term safety of targeting self-antigens in personalized mRNA vaccines requires longitudinal analysis of larger patient cohorts, as follow-up has been short and few patients treated thus far (, 2023). Precision medicine not only may involve precision vaccines — the evidence indicates it already does, across both infectious disease and oncology, with expanding clinical translation.

References

(2023). Precision medicine meets cancer vaccines. *Nature Medicine, 29*, 1287. https://doi.org/10.1038/s41591-023-02432-2

Aljabali, A. A. A., Gammoh, O., Obeid, M. A., Qnais, E., Alqudah, A., El-Tanani, M., & Hatahet, T. (2025). Cancer Vaccines: Mechanisms, Clinical Applications, Challenges, and Future Directions in Precision Medicine.. *Current cancer drug targets*. https://doi.org/10.2174/0115680096381121250628142857

Equils, O., Bakaj, A., Wilson-Mifsud, B., & Chatterjee, A. (2023). Restoring Trust: The Need for Precision Medicine in Infectious Diseases, Public Health and Vaccines. *Human Vaccines & Immunotherapeutics, 19*. https://doi.org/10.1080/21645515.2023.2234787

Espinal, J. A. V., Burgos Mondragón, A., Pérez Aparicio, J. G., Valdez, G. A. A., Arelio, P. R. P., Giles, E. T., & Domínguez Campos, N. A. (2025). Cirugía personalizada en oncología: integración de biomarcadores genómicos y terapias vacunales como adyuvantes quirúrgicos. *Star of Sciences Multidisciplinary Journal*. https://doi.org/10.63969/jatvd658

Jia, S., Li, J.-X., Liu, Y., & Zhu, F. (2020). Precision immunization: a new trend in human vaccination. *Human Vaccines & Immunotherapeutics, 16*, 513 - 522. https://doi.org/10.1080/21645515.2019.1670123

Kiyotani, K., Toyoshima, Y., & Nakamura, Y. (2021). Personalized immunotherapy in cancer precision medicine. *Cancer Biology & Medicine, 18*, 955 - 965. https://doi.org/10.20892/j.issn.2095-3941.2021.0032

Lee, B., Nanishi, E., Levy, O., & Dowling, D. J. (2023). Precision Vaccinology Approaches for the Development of Adjuvanted Vaccines Targeted to Distinct Vulnerable Populations. *Pharmaceutics, 15*. https://doi.org/10.3390/pharmaceutics15061766

Marques, L., Costa, B., Pereira, M., Silva, A. B. A., Santos, J., Saldanha, L. F., Silva, I., Magalhães, P., Schmidt, S., & Vale, N. (2024). Advancing Precision Medicine: A Review of Innovative In Silico Approaches for Drug Development, Clinical Pharmacology and Personalized Healthcare. *Pharmaceutics, 16*. https://doi.org/10.3390/pharmaceutics16030332

Montin, D., Santilli, V., Beni, A., Costagliola, G., Martire, B., Mastrototaro, M. F., Ottaviano, G., Rizzo, C., Sgrulletti, M., Del Giudice, M. M., & Moschese, V. (2024). Towards personalized vaccines. *Frontiers in Immunology, 15*. https://doi.org/10.3389/fimmu.2024.1436108

Oh, J., Cho, H., & Son, S. (2026). Engineering Next Generation Therapeutic Vaccines for Precision Medicine. *KOBRA Reports*. https://doi.org/10.64066/kobrareports.25.0024

Omersel, J., & Kuželički, K. N. (2020). Vaccinomics and Adversomics in the Era of Precision Medicine: A Review Based on HBV, MMR, HPV, and COVID-19 Vaccines. *Journal of Clinical Medicine, 9*. https://doi.org/10.3390/jcm9113561

Poland, G., Ovsyannikova, I., & Kennedy, R. (2017). Personalized Vaccinology: A Review. *Vaccine, 36*, 5350 - 5357. https://doi.org/10.1016/j.vaccine.2017.07.062

Şahin, U., & Türeci, Ö. (2018). Personalized vaccines for cancer immunotherapy. *Science, 359*, 1355 - 1360. https://doi.org/10.1126/science.aar7112

Soni, D., Van Haren, S. V., Idoko, O., Evans, J. T., Diray-Arce, J., Dowling, D. J., & Levy, O. (2020). Towards Precision Vaccines: Lessons From the Second International Precision Vaccines Conference. *Frontiers in Immunology, 11*. https://doi.org/10.3389/fimmu.2020.590373

Xie, J., Zi, W., Li, Z., & He, Y. (2020). Ontology-based Precision Vaccinology for Deep Mechanism Understanding and Precision Vaccine Development. *Current pharmaceutical design, 27*, 900 - 910. https://doi.org/10.2174/1381612826666201125112131

Zhou, J., Kroll, A. V., Holay, M., Fang, R. H., & Zhang, L. (2019). Biomimetic Nanotechnology Towards Personalized Vaccines. *Advanced materials (Deerfield Beach, Fla.), 32*, e1901255 - e1901255. https://doi.org/10.1002/adma.201901255