Journal of Drug Development and Clinical Therapeutics
Content Available at www.uniquepubinternational.com
(An online peer reviewed Journal) ISSN (O): XXXX-XXXX

Review Article
OPEN ACCESS

MRNA VACCINE PLATFORM FOR NON-COVID DISEASES: UPDATES IN CANCER, HIV, AND INFLUENZA THERAPEUTICS

NAGASUBRAHMANYA SATUPATHI

Department of Pharmacy Practice, Vishwa Bharathi College of Pharmaceutical Sciences, Guntur

*Corresponding Author
Dr. Nagasubrahmanya Satupathi

Article History: Received: 14 Feb 2026, Revised: 04 Mar 2026, Accepted: 09 Apr 2026

Abstract: Messenger RNA (mRNA) vaccine technology has emerged as one of the most transformative biomedical innovations of the twenty-first century, particularly following the global success of mRNA vaccines during the COVID-19 pandemic. Beyond SARS-CoV-2 prevention, mRNA vaccine platforms are increasingly being investigated for numerous non-COVID diseases including cancer, human immunodeficiency virus (HIV), influenza, and other infectious and chronic disorders. Unlike conventional vaccine technologies, mRNA vaccines provide rapid design flexibility, scalable manufacturing, enhanced immunogenicity, and precise antigen targeting while avoiding risks associated with live attenuated pathogens. Advances in lipid nanoparticle delivery systems, nucleoside modifications, computational immunology, and synthetic biology have significantly expanded the therapeutic potential of mRNA-based platforms. Cancer immunotherapy represents one of the most promising applications of mRNA vaccines due to their ability to encode tumor-associated antigens and stimulate adaptive immune responses. Personalized neoantigen-based cancer vaccines are currently under clinical evaluation for melanoma, lung cancer, colorectal cancer, and other malignancies. Similarly, HIV vaccine development has benefited from mRNA technologies capable of generating broadly neutralizing antibodies and enhancing cellular immunity. Influenza vaccine research also increasingly utilizes mRNA systems to improve strain adaptability, immunogenicity, and pandemic preparedness. Pharmacists contribute significantly to mRNA vaccine implementation through medication management, vaccine storage optimization, patient counseling, pharmacovigilance, public health education, and interdisciplinary collaboration. Despite remarkable progress, several challenges remain regarding long-term stability, manufacturing scalability, cold-chain logistics, vaccine hesitancy, regulatory pathways, and equitable global distribution. This manuscript reviews recent updates in mRNA vaccine platforms for non-COVID diseases with emphasis on cancer therapeutics, HIV prevention, influenza vaccines, pharmacist interventions, technological innovations, clinical applications, safety considerations, and future perspectives in precision immunotherapy and global healthcare.

Keywords: *mRNA vaccines; Cancer vaccines; HIV vaccines; Influenza vaccines; Lipid nanoparticles; Immunotherapy; Precision medicine; Vaccine technology; Pharmacist interventions; Messenger RNA therapeutics.*

1. INTRODUCTION

Messenger RNA vaccine technology has revolutionized modern vaccinology and immunotherapy through its ability to induce potent immune responses using synthetic genetic material encoding target antigens [1]. Although mRNA-based therapeutics have been investigated for several decades, the rapid global development and successful deployment of COVID-19 vaccines significantly accelerated scientific, clinical, and industrial interest in mRNA platforms [2]. The unprecedented effectiveness, scalability, and adaptability of these vaccines demonstrated the immense therapeutic potential of mRNA technology beyond infectious disease outbreaks. Traditional vaccine platforms including live attenuated vaccines, inactivated pathogens, viral vectors, and protein subunit vaccines possess several limitations related to manufacturing complexity, long development timelines, limited adaptability, and safety concerns [3]. In contrast, mRNA vaccines provide rapid and flexible vaccine design, scalable production, improved safety profiles, and strong immunogenicity without requiring integration into host genomes. Synthetic mRNA molecules instruct host cells to transiently produce antigenic proteins capable of stimulating adaptive immune responses. Advances in lipid nanoparticle delivery systems, nucleoside modifications, molecular engineering, computational biology, and synthetic immunology have substantially improved the stability, translational efficiency, and therapeutic efficacy of mRNA vaccines [4]. Lipid nanoparticles protect mRNA molecules from enzymatic degradation and facilitate intracellular delivery into antigen-presenting cells. Modified nucleosides reduce excessive innate immune activation while improving protein expression and vaccine tolerability. Beyond COVID-19 prevention, mRNA vaccine platforms are increasingly being explored for numerous non-COVID diseases including cancer, HIV infection, influenza, respiratory syncytial virus, cytomegalovirus, and rare genetic disorders [5]. Personalized cancer vaccines targeting tumor neoantigens represent among the most promising applications of precision immunotherapy. Similarly, HIV vaccine research increasingly utilizes mRNA technologies to induce broadly neutralizing antibodies and robust cellular immune responses capable of overcoming viral diversity and immune evasion mechanisms [6].Influenza vaccine development also benefits significantly from mRNA technology due to the rapid mutational evolution of influenza viruses and the need for seasonal vaccine reformulation. mRNA systems provide accelerated manufacturing capabilities and improved pandemic preparedness [7].Pharmacists play increasingly important roles in vaccine implementation through patient counseling, immunization services, cold-chain management, adverse event monitoring, public health education, and pharmacovigilance activities [8]. Despite substantial progress, important challenges remain regarding manufacturing scalability, storage stability, global accessibility, vaccine hesitancy, regulatory frameworks, and long-term safety monitoring.This manuscript discusses recent advances in mRNA vaccine platforms for non-COVID diseases, focusing on cancer therapeutics, HIV prevention, influenza vaccine development, pharmacist interventions, technological innovations, clinical applications, safety considerations, and future perspectives within precision medicine and global immunization strategies.

2. HISTORICAL EVOLUTION OF MRNA VACCINE TECHNOLOGY

The concept of utilizing messenger RNA as a therapeutic platform emerged several decades ago following discoveries regarding gene expression and protein synthesis mechanisms [9]. Early experimental studies demonstrated that exogenous mRNA molecules could direct protein production within mammalian cells. However, clinical translation initially faced major challenges related to mRNA instability, rapid enzymatic degradation, inefficient delivery systems, and excessive inflammatory responses. Significant breakthroughs occurred during the 1990s and early 2000s with the development of nucleoside-modified mRNA molecules and advanced lipid-based delivery systems [10]. Modified nucleosides such as pseudouridine reduced innate immune activation while improving translational efficiency and molecular stability. Simultaneously, lipid nanoparticle technologies significantly enhanced intracellular delivery and protection of mRNA constructs. The COVID-19 pandemic represented a historic turning point in mRNA vaccine development. Rapid authorization and global deployment of mRNA vaccines demonstrated remarkable clinical efficacy and safety while validating decades of foundational research [11]. Pharmaceutical industries, academic institutions, and biotechnology companies subsequently accelerated development of mRNA therapeutics targeting numerous infectious diseases, cancers, and genetic disorders. Today, mRNA technology is recognized as one of the most versatile and rapidly adaptable platforms within precision medicine and immunotherapy research.

3. MECHANISM OF ACTION OF MRNA VACCINES

mRNA vaccines function by delivering synthetic messenger RNA molecules encoding specific antigenic proteins into host cells [12]. Following cellular uptake, host ribosomes translate the mRNA sequence into antigenic proteins that stimulate adaptive immune responses. Lipid nanoparticles serve as the primary delivery vehicles for most clinically advanced mRNA vaccines. These nanoparticles protect fragile mRNA molecules from degradation and facilitate endocytosis into antigen-presenting cells such as dendritic cells [13]. Following intracellular release, translated antigens are processed and presented through major histocompatibility complex pathways, activating both humoral and cellular immunity. mRNA vaccines stimulate production of neutralizing antibodies while simultaneously inducing CD4+ helper T-cell and CD8+ cytotoxic T-cell responses. This dual immunological activation contributes to robust and durable immunity.

Unlike DNA-based therapies, mRNA vaccines do not integrate into host genomes, thereby reducing risks of insertional mutagenesis [14]. Additionally, transient expression of antigens minimizes long-term toxicity concerns.

4. **LIPID NANOPARTICLE DELIVERY SYSTEMS**

Lipid nanoparticles remain central to successful mRNA vaccine delivery and therapeutic efficacy. These nanoparticles typically contain ionizable lipids, phospholipids, cholesterol, and polyethylene glycol-modified lipids that collectively stabilize and protect mRNA molecules [15]. Ionizable lipids facilitate endosomal escape and intracellular release of mRNA payloads. Cholesterol and phospholipids improve nanoparticle stability and membrane fusion properties. Polyethylene glycol components enhance circulation time and reduce aggregation. Recent advances in lipid nanoparticle engineering have significantly improved tissue targeting, immunogenicity, and safety profiles. Novel biodegradable lipids and organ-specific delivery systems are currently under investigation for personalized therapeutic applications [16]. Microfluidic manufacturing technologies further improve nanoparticle reproducibility, scalability, and formulation consistency within industrial production systems.

5. mRNA VACCINES IN CANCER IMMUNOTHERAPY

Cancer immunotherapy represents among the most promising applications of mRNA vaccine technology. Conventional cancer treatments including chemotherapy and radiation therapy frequently produce systemic toxicity and limited specificity [17]. mRNA vaccines offer personalized and targeted immunotherapeutic strategies capable of stimulating antitumor immune responses. Cancer mRNA vaccines typically encode tumor-associated antigens or patient-specific neoantigens derived from tumor genomic sequencing [18]. Following vaccination, antigen-presenting cells stimulate cytotoxic T lymphocytes capable of recognizing and eliminating malignant cells. Personalized neoantigen vaccines are currently under clinical investigation for melanoma, colorectal cancer, pancreatic cancer, lung cancer, breast cancer, and glioblastoma [19]. Early clinical studies demonstrate promising immune activation and tumor regression outcomes.Combination therapies integrating mRNA vaccines with immune checkpoint inhibitors, monoclonal antibodies, and adoptive cell therapies may further enhance therapeutic efficacy. Personalized mRNA vaccines represent an important advancement within precision oncology.

6. PERSONALIZED NEOANTIGEN VACCINES

Personalized cancer vaccines utilize genomic sequencing technologies to identify unique tumor-specific mutations within individual patients [20]. Computational algorithms predict neoantigens capable of stimulating robust immune responses. Synthetic mRNA molecules encoding selected neoantigens are subsequently manufactured and administered to patients.Clinical trials involving melanoma patients demonstrated that personalized neoantigen vaccines can induce durable T-cell responses and reduce tumor recurrence risks [21]. Similar approaches are currently being explored for gastrointestinal cancers, ovarian malignancies, and hematological disorders.

Artificial intelligence increasingly supports neoantigen prediction, vaccine design optimization, and individualized therapeutic planning.

7. HIV MRNA VACCINE DEVELOPMENT

Human immunodeficiency virus remains among the most challenging infectious diseases for vaccine development due to rapid viral mutation, immune evasion mechanisms, and extensive genetic diversity [22]. Conventional vaccine approaches have demonstrated limited success in generating broadly protective immunity.

mRNA vaccine platforms provide several advantages for HIV prevention due to their rapid adaptability and capacity to encode multiple viral antigens. Current research focuses on generating broadly neutralizing antibodies capable of targeting conserved viral epitopes [23]. Germline-targeting strategies utilize mRNA vaccines to stimulate precursor B cells capable of developing broadly neutralizing antibody responses. Sequential immunization approaches aim to guide antibody maturation toward highly protective immune profiles. Clinical studies involving HIV mRNA vaccines have demonstrated encouraging immunogenicity and T-cell activation outcomes. Lipid nanoparticle-based mRNA vaccines may substantially improve future HIV prevention strategies.

8. INFLUENZA MRNA VACCINES

Influenza viruses undergo frequent antigenic drift and shift, necessitating annual vaccine reformulation and rapid pandemic response capabilities [24]. Conventional influenza vaccine production relies heavily on egg-based manufacturing systems that require prolonged production timelines. mRNA vaccine technology significantly improves influenza vaccine adaptability by enabling rapid redesign and scalable manufacturing. Synthetic mRNA constructs encoding hemagglutinin and neuraminidase antigens stimulate protective immune responses without requiring viral culture systems [25].

Preclinical and clinical studies demonstrate that mRNA influenza vaccines induce strong neutralizing antibody responses and cellular immunity. Multivalent mRNA vaccines capable of targeting multiple influenza strains simultaneously are currently under investigation. Universal influenza vaccine development also represents an important research objective. mRNA technologies may facilitate generation of broadly protective immunity against conserved influenza antigens [26].

9. mRNA VACCINES FOR EMERGING INFECTIOUS DISEASES

Beyond HIV and influenza, mRNA platforms are increasingly investigated for several infectious diseases including respiratory syncytial virus, cytomegalovirus, Zika virus, rabies, Ebola virus, and malaria [27].

Rapid vaccine development capability makes mRNA systems particularly valuable during infectious disease outbreaks and pandemic emergencies. Flexible antigen redesign and scalable manufacturing improve preparedness for future global health threats. Combination vaccines and multivalent formulations may further expand preventive capabilities against multiple pathogens simultaneously.

10. SAFETY AND ADVERSE EFFECTS

mRNA vaccines generally demonstrate favorable safety profiles compared to live attenuated vaccines and viral vector systems [28]. Common adverse effects include injection-site reactions, fatigue, headache, fever, myalgia, and transient inflammatory symptoms. Rare adverse events such as myocarditis and hypersensitivity reactions have been reported following COVID-19 mRNA vaccination, particularly among younger populations [29]. Ongoing pharmacovigilance and long-term safety monitoring remain essential. Lipid nanoparticle components may contribute to inflammatory responses and allergic reactions in susceptible individuals. Continued optimization of nanoparticle formulations aims to improve tolerability and reduce reactogenicity.

11. PHARMACIST INTERVENTIONS IN MRNA VACCINE PROGRAMS

Pharmacists play critical roles in mRNA vaccine implementation and public health immunization programs. Community and hospital pharmacists contribute to vaccine storage, preparation, cold-chain management, administration, patient counseling, and pharmacovigilance activities [30].

mRNA vaccines often require specialized storage conditions due to molecular instability. Pharmacists ensure maintenance of appropriate refrigeration and ultra-cold storage systems necessary for preserving vaccine efficacy [31]. Patient education represents another essential pharmacist responsibility. Pharmacists provide counseling regarding vaccine mechanisms, safety profiles, adverse effects, immunization schedules, and public health benefits. Pharmacist-led educational initiatives significantly improve vaccine confidence and reduce misinformation. Pharmacists additionally participate in adverse event monitoring, immunization documentation, and interdisciplinary vaccination campaigns. Clinical pharmacists contribute to therapeutic research, vaccine policy development, and precision immunotherapy implementation.

12. MANUFACTURING CHALLENGES AND SCALABILITY

Despite substantial scientific progress, several manufacturing challenges remain regarding widespread implementation of mRNA therapeutics. Large-scale production requires sophisticated infrastructure, specialized equipment, and high-quality raw materials [32].Cold-chain logistics represent among the most significant barriers for global distribution, particularly within low-resource settings. Improving thermostability and developing room-temperature formulations remain important research priorities. Manufacturing consistency, quality assurance, and regulatory standardization are additionally essential for ensuring vaccine safety and efficacy. Supply chain disruptions involving lipid nanoparticle components and nucleoside materials may further complicate industrial production.

13. ETHICAL AND GLOBAL HEALTH CONSIDERATIONS

Global inequities in vaccine distribution became highly apparent during the COVID-19 pandemic [33]. High-income countries obtained greater access to advanced mRNA vaccines while many low-resource regions experienced delayed immunization availability. Future mRNA vaccine implementation strategies must prioritize equitable access, affordable manufacturing, technology transfer, and international collaboration. Ethical concerns regarding intellectual property rights, vaccine nationalism, and healthcare disparities remain significant global health challenges. Public trust and vaccine confidence also remain essential for successful immunization programs. Combating misinformation and strengthening public health communication are critical responsibilities for healthcare professionals and policymakers.

14. ARTIFICIAL INTELLIGENCE AND FUTURE INNOVATIONS

Artificial intelligence increasingly supports mRNA vaccine research through antigen prediction, molecular modeling, immunogenicity analysis, and therapeutic optimization [34]. Machine learning algorithms accelerate vaccine design and personalized immunotherapy development. Self-amplifying RNA vaccines represent an emerging innovation capable of enhancing antigen expression while reducing dosage requirements. Circular RNA technologies may further improve molecular stability and translational efficiency [35]. Personalized cancer vaccines, therapeutic HIV vaccines, universal influenza vaccines, and gene-editing delivery systems are expected to expand significantly over the coming decade.

15. FUTURE PERSPECTIVES

The future of mRNA therapeutics extends far beyond infectious disease prevention. Personalized cancer vaccines, autoimmune disease therapies, regenerative medicine applications, and protein replacement therapies are increasingly under investigation [36].

Integration of nanotechnology, artificial intelligence, computational immunology, and genomic medicine will likely accelerate development of next-generation mRNA therapeutics. Decentralized manufacturing systems and thermostable formulations may improve global accessibility and pandemic preparedness. Continued interdisciplinary collaboration among immunologists, pharmacists, molecular biologists, clinicians, engineers, and public health experts will remain essential for advancing mRNA medicine.

16. CONCLUSION

mRNA vaccine technology has emerged as a transformative platform within modern medicine with applications extending far beyond COVID-19 prevention. Advances in lipid nanoparticle delivery systems, nucleoside modifications, computational biology, and synthetic immunology have significantly expanded the therapeutic potential of mRNA-based vaccines for cancer, HIV, influenza, and numerous emerging diseases. Cancer immunotherapy represents one of the most promising applications through personalized neoantigen vaccines capable of stimulating targeted antitumor immune responses. HIV vaccine research increasingly benefits from mRNA platforms designed to induce broadly neutralizing antibodies and enhanced cellular immunity. Influenza vaccine development similarly utilizes mRNA technology to improve strain adaptability, immunogenicity, and pandemic preparedness. Pharmacists continue to play essential roles in vaccine storage management, patient counseling, immunization services, pharmacovigilance, and public health education. Despite remarkable progress, significant challenges remain regarding manufacturing scalability, storage stability, equitable global distribution, regulatory frameworks, and vaccine hesitancy. Continued technological innovation, interdisciplinary collaboration, and global healthcare investment will remain critical for advancing mRNA therapeutics and expanding precision immunotherapy applications within future healthcare systems.

17. FUNDING

Nil

18. INFORM CONSENT AND ETHICAL STATEMENT

Not applicable

19. ACKNOWLEDFEMENT

Not Declared

20. REFERENCES

1. Pardi N, Hogan MJ, Porter FW, Weissman D. mRNA vaccines-a new era in vaccinology. *Nat Rev Drug Discov*. 2018;17(4):261-279.
2. Sahin U, Karikó K, Türeci Ö. mRNA-based therapeutics-developing a new class of drugs. *Nat Rev Drug Discov*. 2014;13(10):759-780.
3. Plotkin SA. Vaccines: past, present and future. *Nat Med*. 2005;11(4 Suppl):S5-S11.
4. Hou X, Zaks T, Langer R, Dong Y. Lipid nanoparticles for mRNA delivery. *Nat Rev Mater*. 2021;6(12):1078-1094.
5. Verbeke R, Lentacker I, De Smedt SC, Dewitte H. Three decades of messenger RNA vaccine development. *Nano Today*. 2019;28:100766.
6. Corey L, Mascola JR, Fauci AS, Collins FS. A strategic approach to COVID-19 vaccine R&D. *Science*. 2020;368(6494):948-950.
7. Feldman RA, Fuhr R, Smolenov I, et al. mRNA vaccines against H10N8 and H7N9 influenza viruses of pandemic potential are immunogenic and well tolerated in healthy adults. *Lancet*. 2019;394(10205):1210-1217.
8. Isenor JE, Edwards NT, Alia TA, et al. Impact of pharmacists as immunizers on vaccination rates: a systematic review and meta-analysis. *CMAJ*. 2016;188(4):E146-E152.
9. Wolff JA, Malone RW, Williams P, et al. Direct gene transfer into mouse muscle in vivo. *Science*. 1990;247(4949 Pt 1):1465-1468.
10. Karikó K, Buckstein M, Ni H, Weissman D. Suppression of RNA recognition by Toll-like receptors: the impact of nucleoside modification and the evolutionary origin of RNA. *Immunity*. 2005;23(2):165-175.
11. Baden LR, El Sahly HM, Essink B, et al. Efficacy and safety of the mRNA-1273 SARS-CoV-2 vaccine. *N Engl J Med*. 2021;384(5):403-416.
12. Verbeke R, Hogan MJ, Loré K, Pardi N. Innate immune mechanisms of mRNA vaccines. *Immunity*. 2022;55(11):1993-2005.
13. Cullis PR, Hope MJ. Lipid nanoparticle systems for enabling gene therapies. *Mol Ther*. 2017;25(7):1467-1475.
14. Sahin U, Türeci Ö. Personalized vaccines for cancer immunotherapy. *Science*. 2018;359(6382):1355-1360.
15. Hassett KJ, Benenato KE, Jacquinet E, et al. Optimization of lipid nanoparticles for intramuscular administration of mRNA vaccines. *Mol Ther Nucleic Acids*. 2019;15:1-11.
16. Hou X, Kubanek J, et al. Emerging advances in lipid nanoparticles for drug delivery applications. *Adv Mater*. 2021;33(49):e2008364.
17. Ribas A, Wolchok JD. Cancer immunotherapy using checkpoint blockade. *Science*. 2018;359(6382):1350-1355.
18. Ott PA, Hu Z, Keskin DB, et al. An immunogenic personal neoantigen vaccine for patients with melanoma. *Nature*. 2017;547(7662):217-221.
19. Sahin U, Derhovanessian E, Miller M, et al. Personalized RNA mutanome vaccines mobilize poly-specific therapeutic immunity against cancer. *Nature*. 2017;547(7662):222-226.
20. Keskin DB, Anandappa AJ, Sun J, et al. Neoantigen vaccine generates intratumoral T cell responses in phase Ib glioblastoma trial. *Nature*. 2019;565(7738):234-239.
21. Hilf N, Kuttruff-Coqui S, Frenzel K, et al. Actively personalized vaccination trial for newly diagnosed glioblastoma. *Nature*. 2019;565(7738):240-245.
22. Burton DR, Walker LM. Rational vaccine design in the time of COVID-19. *Nat Immunol*. 2020;21(11):1303-1304.
23. Saunders KO, Wiehe K, Tian M, et al. Targeted selection of HIV-specific antibody mutations by engineering B cell maturation. *Immunity*. 2019;50(3):567-576.e6.
24. Krammer F. The human antibody response to influenza A virus infection and vaccination. *Nat Rev Drug Discov*. 2018;17(3):167-182.
25. Bahl K, Senn JJ, Yuzhakov O, et al. Preclinical and clinical demonstration of immunogenicity by mRNA vaccines against H10N8 and H7N9 influenza viruses. *Mol Ther*. 2017;25(6):1316-1327.
26. Erbelding EJ, Post DJ, Stemmy EJ, et al. A universal influenza vaccine: the strategic plan for the National Institute of Allergy and Infectious Diseases. *J Infect Dis*. 2018;218(3):347-354.
27. Pardi N, Hogan MJ, Weissman D. Recent advances in mRNA vaccine technology. *Curr Opin Immunol*. 2020;65:14-20.
28. Polack FP, Thomas SJ, Kitchin N, et al. Safety and efficacy of the BNT162b2 mRNA Covid-19 vaccine. *N Engl J Med*. 2020;383(27):2603-2615.

29. Mevorach D, Anis E, Cedar N, et al. Myocarditis after BNT162b2 mRNA vaccine against Covid-19 in Israel. *N Engl J Med*. 2021;385(23):2140-2149.
30. Burson RC, Buttenheim AM, Armstrong A, Feemster KA. Community pharmacies as sites of adult vaccination: a systematic review. *Vaccine*. 2016;34(45):593-599.
31. Knezevic I, Liu MA, Peden K, Zhou T, Kang HN. Development of mRNA vaccines: scientific and regulatory issues. *NPJ Vaccines*. 2021;6(1):83.
32. Kis Z, Kontoravdi C, Dey AK, et al. Rapid development and deployment of high-volume vaccines for pandemic response. *NPJ Vaccines*. 2020;5:78.
33. Bollyky TJ, Bown CP. The tragedy of vaccine nationalism. *N Engl J Med*. 2020;383(5):408-410.
34. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. *Nat Med*. 2019;25(1):44-56.
35. Blakney AK, McKay PF, Yus BI, Aldon Y, Shattock RJ. Inside out: optimization of lipid nanoparticle formulations for exterior complexation and in vivo delivery of saRNA. *Nat Commun*. 2021;12(1):4463.
36. Schlake T, Thess A, Fotin-Mleczek M, Kallen KJ. Developing mRNA-vaccine technologies. *RNA Biol*. 2012;9(11):1319-1330.