

MRNA VACCINES: SAFETY, EFFICACY, FUTURE APPLICATIONS, AND ADDRESSING MISCONCEPTIONS

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ABSTRACT

Messenger RNA (mRNA) vaccines have transformed vaccinology, achieving unprecedented success during the COVID-19 pandemic. This review synthesises evidence on their safety, efficacy, and potential applications beyond infectious diseases, while addressing common misconceptions. Over 13 billion doses administered globally to date demonstrates a robust safety profile, with rare serious adverse events. Effectiveness against severe COVID-19 has been demonstrated with real-world evidence, with significant reductions in hospitalisations and mortality. Future applications include vaccines for infectious diseases and personalised therapies, with promising clinical trials underway. Misconceptions, such as DNA alteration and infertility, are debunked using peer-reviewed data. This article underscores mRNA vaccines' transformative potential and the critical role of physicians in combating misinformation to promote public health.

Keywords: Messenger RNA vaccines, COVID-19 vaccines, Vaccine safety, Vaccine hesitancy, Public health communication, Personalised therapeutics

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INTRODUCTION

The advent of mRNA vaccines marks a pivotal advancement in medical science, driven by decades of research and accelerated by the urgent need to address the COVID-19 pandemic. Pioneered by scientists like Katalin Karikó and Drew Weissman, who were awarded the 2023 Nobel Prize for their work on lipid nanoparticles, mRNA technology enables rapid, precise, and adaptable vaccine development.¹ Unlike traditional vaccines, which use inactivated or live-attenuated pathogens, mRNA vaccines deliver synthetic mRNA to instruct cells to produce pathogen-specific proteins, eliciting robust immune responses without infectious agents.² By 2025, over 13 billion doses have been administered globally, primarily for COVID-19, with emerging applications in other diseases.³ This article reviews the safety profile, clinical benefits, and future potential of mRNA vaccines, while

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systematically addressing misconceptions that fuel vaccine hesitancy. Through evidence-based insights, we aim to equip medical professionals with the knowledge to advocate for this transformative technology.

SAFETY PROFILE OF MRNA VACCINES

The safety of mRNA vaccines has been rigorously evaluated through clinical trials, real-world studies, and continuous global surveillance. Since their introduction in 2020, mRNA vaccines have been administered to billions. In Singapore, the rates of serious adverse events after the third mRNA COVID-19 dose was reported at <0.001 percent.⁴ Common side effects, including injection-site soreness, fatigue, and low-grade fever, are transient, typically resolving within 1–3 days.⁵ These effects reflect the immune system's activation and are consistent with other vaccines.

Severe adverse events, such as myocarditis and anaphylaxis, are rare but warrant attention due to their clinical significance. Myocarditis, primarily observed in young males after the second dose, occurs at an incidence of 1–2 per 100,000 doses, with most cases being mild and resolving with rest or minimal intervention.^{6,7} In contrast, COVID-19 infection poses a significantly higher risk of myocarditis, with rates of 2.8 per 1,000 infections.⁷ This stark difference underscores the protective benefit of vaccination. Anaphylaxis, another rare event, occurs at a rate of 0.55 to 0.67 per 100,000 administered doses of mRNA COVID-19 vaccines and can be mitigated with timely medical intervention.⁸ Screening for allergies and post-vaccination observation further mitigate this risk.

A critical aspect of mRNA vaccine safety is the transient nature of the mRNA itself. After translation into proteins, mRNA degrades within 24–48 hours.⁹ This rapid degradation eliminates concerns about long-term persistence or genomic integration, as mRNA operates exclusively in the cytoplasm and does not enter the nucleus.^{1,10,11} Long-term safety data, now spanning over five years, confirm no significant adverse effects, with ongoing monitoring through systems like the Vaccine Adverse Event Reporting System (VAERS) and V-safe.⁵ A 2025 study by the Center for Infectious Disease Research and Policy (CIDRAP) found no safety issues with the latest mRNA vaccine formulations, reinforcing their reliability.¹²

mRNA vaccines are also safe in special populations, such as pregnant women. Recent evaluation by the CDC in 2025 found no increased risk of poorer maternal, pregnancy, or infant outcomes from analyses taken from the COVID-19 Vaccine Pregnancy Registry and the Vaccine Safety Datalink.¹³ Similarly, fertility studies, such as Wesselink et al,¹³ found no difference in conception rates between vaccinated and unvaccinated individuals, debunking

infertility concerns.¹⁴ Regulatory oversight by the FDA, European Medicines Agency (EMA), and World Health Organization (WHO) ensures rigorous testing and post-market surveillance, establishing mRNA vaccines as among the safest in vaccinology.¹⁵

CLINICAL BENEFITS OF MRNA VACCINES

The clinical efficacy of mRNA vaccines has been a cornerstone of their success. Clinical trials for mRNA-COVID-19 vaccines demonstrated over 90 percent efficacy against severe COVID-19 outcomes, including hospitalisation and death.¹⁰ Real-world data further validate these findings, with an estimated 80 percent reduction in hospitalisations and 20 million lives saved globally.^{15,16} The vaccines induce robust humoral and cellular immunity, producing high levels of neutralising antibodies and T-cell responses that persist with booster doses.^{17,18} This immunogenicity is particularly valuable in immunocompromised patients, where adjusted dosing regimens enhance protection.¹⁷

The adaptability of mRNA vaccines is a key advantage. The platform allows rapid modification to target emerging variants, as demonstrated by Omicron-specific variant vaccines developed within months.¹⁹ This flexibility contrasts with traditional vaccines, which require years to develop due to reliance on cultured pathogens.²⁰ By protecting vulnerable populations, such as the elderly and those with comorbidities, mRNA vaccines have alleviated strain on healthcare systems, facilitating economic and social recovery during the COVID-19 pandemic.³ These benefits underscore the platform's transformative impact on global health.

FUTURE APPLICATIONS OF MRNA TECHNOLOGY

The versatility of mRNA technology extends far beyond COVID-19, with a robust pipeline targeting infectious diseases, cancer, and rare disorders.²¹ The platform's rapid design and scalability make it ideal for addressing emerging pandemics, such as potential H5N1 outbreaks.²² It may be possible for mRNA technology to be used for universal vaccines (e.g., pan-coronavirus) or personalised therapies in the near future.

DEBUNKING COMMON MYTHS

Misinformation has significantly contributed to vaccine hesitancy, necessitating evidence-based rebuttals to common myths. One pervasive myth is that mRNA vaccines alter DNA. This is scientifically implausible, as mRNA operates in the cytoplasm, degrades within 24–48 hours, and does not enter the nucleus where DNA resides.^{1,10,11} Studies, including Pardi et al,¹ confirm no evidence of genomic integration, and regulatory agencies have reiterated this finding.²³ Concerns about long-term harm are equally unfounded. Over five years of data, including a 2025 CIDRAP study, show no significant long-term adverse

effects, with global surveillance systems like VAERS and V-safe ensuring ongoing safety.¹²

The myth that mRNA vaccines cause infertility has been thoroughly debunked. Wesselink et al¹³ found no difference in conception rates between vaccinated and unvaccinated individuals, and studies of over 500,000 pregnant women confirm no increased risk of miscarriage or fertility issues.¹⁴ Claims that mRNA vaccines are “experimental” ignore over 30 years of research, starting in the 1990s, and the administration of over 13 billion doses safely.^{3,24} The 2023 Nobel Prize for mRNA technology underscores its established scientific foundation.¹ Other misconceptions, such as vaccines causing widespread severe side effects, are contradicted by data showing adverse events are rare and manageable.⁶⁻⁸ Addressing these myths with clear, evidence-based communication is essential for building public trust and encouraging vaccine uptake.

CONCLUSION

mRNA vaccines have redefined vaccinology, offering an effective, tolerable, and versatile platform for combating infectious diseases and beyond. With a safety profile demonstrating rare adverse events (<0.01%), robust efficacy against severe COVID-19, and a promising platform for infectious diseases and therapeutics, mRNA technology is poised to transform medicine. By debunking myths with robust evidence, physicians can counter misinformation and promote vaccine confidence. Ongoing research and global initiatives to expand access will further amplify the impact of mRNA vaccines. Medical professionals are urged to be updated with the knowledge of the mRNA platform to better educate patients, and support continued innovation to realise the full potential of this revolutionary technology.

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LEARNING POINTS

- **Proven Safety:** mRNA degrades in 24–48 hours with no DNA integration; serious adverse events are rare (<0.01 percent), far lower than disease risks (e.g., myocarditis from COVID-19 is 10–100 times higher).
 - **High Efficacy & Adaptability:** >90 percent protection against severe COVID-19; platform enables rapid variant updates and strong antibody/T-cell responses, saving ~20 million lives globally.
 - **Future Potential:** Versatile for infectious diseases (e.g., RSV, HIV trials), cancer immunotherapy (e.g., personalised melanoma vaccines), and rare disorders like cystic fibrosis.
 - **Myth Debunking:** No evidence of infertility (studies show no conception impact) or long-term harm (5+ years of data); mRNA is established tech, not experimental, with 13B+ safe doses.
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