

COVID-19 vaccines: comparison of biological, pharmacological characteristics and adverse effects of Pfizer/BioNTech and Moderna Vaccines

S.A. MEO¹, I.A. BUKHARI², J. AKRAM³, A.S. MEO⁴, D.C. KLONOFF⁵

¹Department of Physiology, ²Pharmacology, College of Medicine, King Saud University, Riyadh, Saudi Arabia

³Department of Medicine, University of Health Sciences, Lahore, Pakistan

⁴Army Medical College, National University of Medical Sciences, Rawalpindi, Pakistan

⁵Diabetes Research Institute, Mills-Peninsula Medical Center, San Mateo, CA, USA

Abstract. – OBJECTIVE: The “Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2)” disease has caused a worldwide challenging and threatening pandemic (COVID-19), with huge health and economic losses. The US Food and Drug Administration, (FDA) has granted emergency use authorization for treatment with the Pfizer/BioNTech and Moderna COVID-19 vaccines. Many people have a history of a significant allergic reaction to a specific food, medicine, or vaccine; hence, people all over the world have great concerns about these two authorized vaccines. This article compares the pharmacology, indications, contraindications, and adverse effects of the Pfizer/BioNTech and Moderna vaccines.

MATERIALS AND METHODS: The required documents and information were collected from the relevant databases, including Web of Science (Clarivate Analytics), PubMed, EMBASE, World Health Organization (WHO), Food and Drug Authorities (FDA) USA, Local Ministries, Health Institutes, and Google Scholar. The key terms used were: Coronavirus, SARS-COV-2, COVID-19 pandemic, vaccines, Pfizer/BioNTech vaccine, Moderna vaccine, pharmacology, benefits, allergic responses, indications, contraindications, and adverse effects. The descriptive information was recorded, and we eventually included 12 documents including research articles, clinical trials, and websites to record the required information.

RESULTS: Based on the currently available literature, both vaccines are beneficial to provide immunity against SARS-CoV-2 infection. Pfizer/BioNTech Vaccine has been recommended to people 16 years of age and older, with a dose of 30 µg (0.3 m) at a cost of \$19.50. It provides immunogenicity for at least 119 days after the first vaccination and is 95% effective in preventing the SARS-COV-2 infection. However, Moderna Vaccine has been recommended to people 18 years of age and older, with a dose of

50 µg (0.5 mL) at a cost of \$32-37. It provides immunogenicity for at least 119 days after the first vaccination and is 94.5% effective in preventing the SARS-CoV-2 infection. However, some associated allergic symptoms have been reported for both vaccines. The COVID-19 vaccines can cause mild adverse effects after the first or second doses, including pain, redness or swelling at the site of vaccine shot, fever, fatigue, headache, muscle pain, nausea, vomiting, itching, chills, and joint pain, and can also rarely cause anaphylactic shock. The occurrence of adverse effects is reported to be lower in the Pfizer/BioNTech vaccine compared to the Moderna vaccine; however, the Moderna vaccine compared to the Pfizer vaccine is easier to transport and store because it is less temperature sensitive.

CONCLUSIONS: The FDA has granted emergency use authorization for the Pfizer/BioNTech and Moderna COVID-19 vaccines. These vaccines can protect recipients from a SARS-CoV-2 infection by formation of antibodies and provide immunity against a SARS-CoV-2 infection. Both vaccines can cause various adverse effects, but these reactions are reported to be less frequent in the Pfizer/BioNTech vaccine compared to the Moderna COVID-19 vaccine; however, the Moderna vaccine compared to the Pfizer vaccine is easier to transport and store because it is less temperature sensitive.

Key Words:

SARS-CoV-2 vaccine, Pfizer/BioNTech, Moderna vaccine, Pharmacology, Adverse effects.

Introduction

The “Severe Acute Respiratory Syndrome Corona virus 2 (SARS-CoV-2)” disease has caused

a challenging and threatening pandemic globally (COVID-19). This virus is highly contagious and has caused disruption of the world's health and economy¹. The prevalence and mortality rates of SARS-CoV-2 are changing on a daily basis². According to World Health Organization (WHO) as of December 25, 2020, the COVID-19 pandemic involved 216 countries, and had affected 80,161,578,00 people with a fatality rate of 1,756,379,00 (2.19%)³.

During the COVID-19 pandemic, globally people are facing major health care challenges, lockdowns, anxiety and stress⁴, as there is no specific treatment and vaccination for this pandemic. Given the lack of specific therapy for and the rapid spread of this virus, vaccination would be a significant tool in the fight against the SARS-CoV-2 pandemic. More recently, on December 11, 2020 and December 18, 2020, respectively, the US Food and Drug Administration (FDA), granted emergency authorization to the Pfizer/BioNTech^{5,6} and Moderna COVID-19 vaccines⁷. These two COVID-19 vaccines were developed quickly to benefit humanity and arrest the rise in the number of SARS-CoV-2 cases. From the time when the SARS-CoV-2 genome was released in early 2020⁸ until these two vaccines received EUA status, less than one year passed. The fastest any vaccine had previously been developed, from viral sampling to approval, was four years, for mumps in the 1960s⁹. There have been some concerns about potential adverse effects of these vaccines. The present study aims to highlight evidence about the pharmacological characteristics, indications, contraindications and adverse effects of Pfizer/BioNTech and Moderna vaccines.

Materials and Methods

The required informations were collected from relevant databases, regarding the pharmacology, indications, contraindications, and adverse effects of Pfizer/BioNTech and Moderna vaccines. We reviewed the literature from various databases including "Web of Science Clarivate Analytics"¹⁰, PubMed¹¹, "Medline, EMBASE, World Health Organization (WHO), US Food and Drug Administration (FDA), Centers for Disease Control and Prevention (CDC), regional ministries, health institutes, and Google Scholar. The literature was searched by using the key terms: Coronavirus, SARS-CoV-2, COVID-19 pandemic, vaccines, Pfizer/BioNTech vaccine, Moderna vaccine,

pharmacological characteristics, benefits, allergic responses, indications, contraindications, and adverse effects. The descriptive information was recorded and 42 articles, documents were identified. The studies, international organizations, and weblinks in which SARS-CoV-2 and COVID-19 pandemic Vaccine were discussed were eligible for inclusion. No limitations on publication status, study design, or language of publication were imposed. The descriptive information was retrieved from the selected literature. Two co-authors reviewed the literature, and their findings were entered into tabular form. After that, a third co-author rechecked the literature and their findings. From the 24 identified documents, finally we included 12 documents including publications and few organizations such as "World Health Organization (WHO), US Food and Drug Administration (FDA), Centers for Disease Control and Prevention (CDC).

Data extraction and Ethics statement

The findings were documented by using a standardized form including a full description of the study characteristics. In this study we recorded the publicly available database literature on coronavirus, SARS-CoV-2, COVID-19 vaccine, Pfizer/BioNTech and Moderna vaccines; hence, Ethical approval was not required.

Results

Table I presents a comparison between the pharmacology, indications, and adverse effects of Pfizer/BioNTech and Moderna vaccines. The US Food and Drug Authorities (FDA) have granted emergency authorization for use of the Pfizer/BioNTech and Moderna vaccines. Pfizer/BioNTech Vaccine has been recommended to people 16 years of age and older, with a dose of 30 µg (0.3 ml) at a cost of \$19.50. It provides immunogenicity for at least about 119 days after the first vaccination and is 95% effective in preventing the SARS-CoV-2 infection. However, Moderna Vaccine has been recommended to people 18 years of age and older, with a dose of 50 µg (0.5 mL) at a cost of \$32-37. It provides immunogenicity for at least 119 days after the first vaccination and is 94.5% effective in preventing the SARS-CoV-2 infection (Table I). Based on the currently available literature, both vaccines are beneficial to provide immunity against a SARS-CoV-2 infection. However, some allergic responses have been reported.

SARS-CoV-2 vaccine

Table I. Comparison between pharmacology, indications, and adverse effects of Pfizer/BioNTech and Moderna Vaccines.

Characteristics	Pfizer/BioNTech Vaccine	Moderna Vaccine
General name	Pfizer/BioNTech Vaccine ¹² .	Moderna Vaccine ¹³ .
Generic name	Tozinameran, brand name Comirnaty ¹² .	Moderna COVID-19 Vaccine ¹³ .
Manufacturer	Pfizer, Inc and BioNTech ¹² .	ModernaTX, Inc ¹³ .
Type of vaccine	mRNA (BNT162b2) ¹² .	mRNA (mRNA-1273) ¹³ .
FDA Approval	Emergency authorization Dec 11, 2020 ¹² .	Emergency authorization Dec 18, 2020 ¹³ .
Dose	Each dose contains 30 µg (0.3 mL) ^{14,15} .	Each dose contains 50 µg (0.5 mL) ^{16,17} .
Number of injections	2 shots, given 21 days apart ¹⁴ .	2 shots, given 28 days apart ¹⁶ .
Route of administration	Intramuscular-deltoid muscle ¹² .	Intramuscular-deltoid muscle ¹³ .
Booster shots	Further research is needed to determine, whether shots will be required over the year to maintain immunity, or to be given annually like the flu shot.	Further research is needed to determine whether booster shots will be required over the year to maintain immunity, or to be given annually like the flu shot.
Age group for vaccination	16 years of age and older ¹⁴ .	18 years of age and older ¹⁷ .
Effectiveness	95% in preventing the SARS-COV-2 infection ¹⁴ .	94.5% in preventing the SARS-COV-2 infection ¹⁶ .
Approximate cost per dose	Freely available in many developed nations. However, \$19.50 per dose excluding taxes, distribution, storage and health care services cost ¹⁸ .	Free available in many developed nations. However, \$32-37 per dose excluding taxes, distribution, storage and health care services cost ¹⁸ .
Storage	Multiple dose vials are stored between -80°C and -60°C (-112°F to -76°F). Thaw and store undiluted vials in the refrigerator [2°C to 8°C (35°F to 46°F)] for up to 5 days (120 hours). For immediate use thaw undiluted vials at room temperature [up to 25°C (77°F)] for 30 minutes. Undiluted vials may be stored at room temperature for no more than 2 hours ¹⁹ .	Multiple-dose vials are stored between -25° and -15°C (-13° to 5°F). Vials can be stored refrigerated between 2°C and 8°C (36° to 46°F) for up to 30 days prior to first use. After the first dose has been withdrawn, vial should be held between 2° and 25°C (36° to 77°F), discard the vial after 6 hours ²⁰ .
Transportation / Distribution	Complicated, difficult distribution particularly in low-income and hot climate countries.	Complicated, difficult distribution particularly in low-income and hot climate countries.
Mechanism of action	The vaccine is formulated in lipid particles, which enable delivery of the RNA into host cells to allow expression of the SARS-CoV-2 S antigen. It elicits an immune response to the S antigen, which protects against COVID-19 ^{21,22} .	The nucleoside-modified mRNA vaccine is formulated in lipid particles. It enables delivery of the nucleoside-modified mRNA into host cells to allow expression of the SARS-CoV-2 S antigen. The vaccine elicits an immune response to the S antigen, which protects against COVID-19. The antibodies are specific to the SARS-CoV-2 virus, to protect against a future infection ^{21,22} .

COVID-19 vaccine can cause mild adverse effects after the first or second dose, including pain, redness or swelling at the site of vaccine inject, fever, fatigue, headache, muscle pain, nausea, vomiting, itching, chills, muscle pain, and joint pain, and can also rarely cause anaphylactic shock. A comparison between pharmacology, indications, and adverse effects of Pfizer/BioNTech and Moderna Vaccines is presented in Table I. A compari-

son between the immunogenicity, adverse effects, risks, and contraindications between Pfizer/BioNTech and Moderna Vaccines reported by each of the two manufacturers is presented in Table II. The percentage of these adverse effects is reported to be lower with the Pfizer/BioNTech vaccine than with the Moderna vaccine (Figure 1), however the Moderna vaccine compared to the Pfizer vaccine is easier to transport and store because it

Table II. Comparison between immunogenicity, adverse effects, risks, and contraindications between Pfizer/BioNTech and Moderna Vaccines.

Immunogenicity	Immunogenicity persisted over a median of 2 months ¹⁴ .	Immunogenicity persisted for at least 3 months. 119 days after first vaccination 90 days after the second vaccination ¹⁶ .
Adverse events	Pain, swelling, redness, fever, fatigue, headache, chills, vomiting, diarrhea, muscle pain, joint pain, lymphadenopathy, shoulder injury, right axillary lymphadenopathy, paroxysmal ventricular arrhythmia, syncope, and right leg paresthesia ¹⁴ .	Pain, swelling, redness at the site of vaccine, fever, fatigue, headache, chills, vomiting, arthralgia, myalgia, urticaria. These clinical symptoms were mild to moderate after the first dose of vaccine. However, after the second dose of vaccine the clinical symptoms were moderate to severe ¹⁷ . Moreover, facial swelling and Bell's palsy has also been reported ²⁰ .
Anaphylaxis Reaction	CDC has identified 6 case of anaphylaxis reaction following Pfizer-BioNTech vaccine ²³ .	No such reports in the peer reviewed medical literature, and so for in the trial ²⁴ .
Risks in pregnancy, infant and children	Not Known: the prevention of COVID-19 is not addressed in younger adolescents, children and pregnant women ¹⁴ .	Not Known.
Contraindication	Individuals with a known history of severe allergic reactions, including anaphylaxis, immunocompromised persons, and individuals receiving immunosuppressive therapy ¹⁹ .	Individuals with a known history of severe allergic reactions including anaphylaxis, immunocompromised persons, and individuals receiving immunosuppressive therapy ²⁰ .

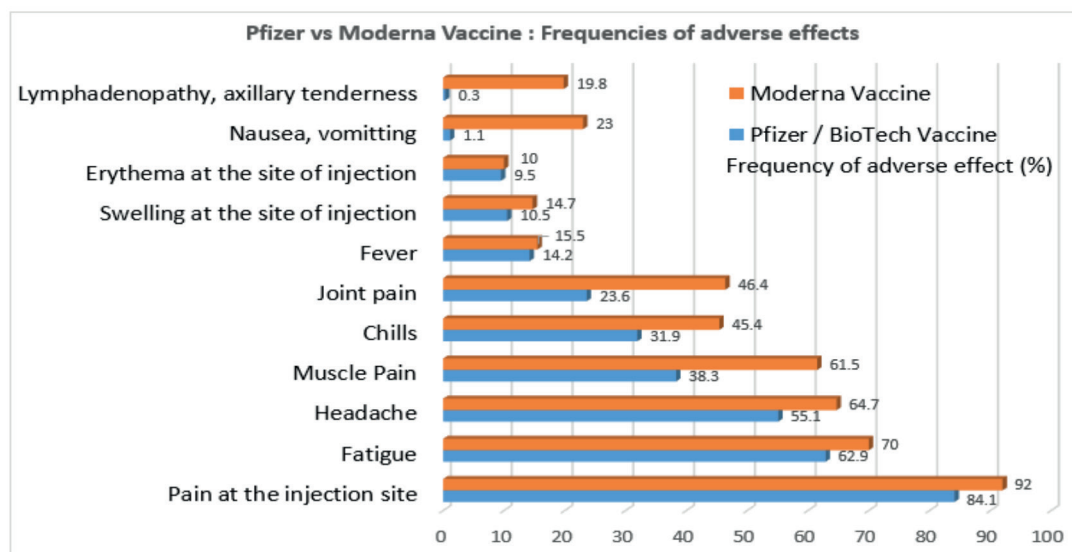


Figure 1. Comparison between frequencies of adverse effects of Pfizer/BioNTech and Moderna Vaccines^{12,13,20}.

is less temperature sensitive. It must be noted that because clinical trials are conducted under widely varying conditions, adverse reaction rates observed in the clinical trials of a vaccine cannot be directly compared with rates in the clinical trials of another vaccine and may not reflect the rates observed in practice.

Discussion

The novel coronavirus, SARS-CoV-2 infection is an emerging global health concern and has infected a significant portion of the world's population². During the COVID-19 pandemic, people worldwide are facing major health care challeng-

es, anxiety and stress⁴, because there has been no specific treatment, and until December 2020 no vaccination for this pandemic. In mid-December 2020, the US Food and Drug Authority, (FDA), granted emergency authorization for the use of the Pfizer/BioNTech^{5,6} and Moderna COVID-19 vaccines⁷. There is reasonable evidence that both Pfizer-BioNTech COVID19 Vaccine and Moderna COVID-19 Vaccine may be effective to combat the COVID-19 pandemic. In this study we compared the pharmacology, indications, contraindications, and adverse effects of Pfizer/BioNTech and Moderna vaccines.

It has been more than one year since the Coronavirus outbreak began and the pandemic became a global catastrophe. With a global lockdown amidst a fear of increasing morbidity and mortality, countries have witnessed their economies collapse and health systems devolve in crisis while hoping for a miraculous cure in the form of a vaccine for this new ailment. After a year, the authorization of the Pfizer vaccine on Dec 11, 2020⁵ and Moderna vaccine on Dec 18, 2020⁶ have brought forth a global ray of optimism for ending the fight against COVID-19.

Both authorized vaccines use modified RNA to encode the SARS-CoV-2 spike protein along with mutations in the mRNA added to lock the spike proteins into a three-dimensional shape that it naturally assumes just before it binds to the human ACE-2 receptors on cells with which elicited virus-neutralizing antibodies must interact²⁵. Both also use lipid nanoparticle (LNP) delivery system²⁶. These represent a new class of vaccine, which offer potential advantages, compared to traditional replicating or non-replicating viral vector vaccines, in that RNA vaccines are very potent and can be manufactured rapidly and at a relatively low cost. They have a good safety profile, compared to viral vaccines, since they are not made with an actual pathogen and do not integrate into host DNA. Both are administered in two doses into the deltoid muscle. A disadvantage of this class of vaccines is that because RNA is unstable, they require extreme refrigeration for stability during distribution.

The two approved vaccines, made available after thorough testing at almost the same time, have certain differences in their properties and actions on the body. The Pfizer vaccine is given in two slightly smaller dosages of 30 µg^{14,15}, whereas the Moderna vaccine is given in two 50 µg dosages^{16,17}. The Pfizer vaccine is approved for ages 16 years up, whereas the Moderna vaccine is

approved for ages 18 years and up. The efficacy reported for the Pfizer vaccine, at 95%¹⁴ is very slightly more than that reported for the Moderna vaccine at 94.5%¹⁶.

However, differences between the two arise when their factors of cost, storage requirements, and beneficial or adverse effects are considered. The Pfizer vaccine is significantly less costly than the Moderna vaccine, and their costs are \$19.50 USD and \$32-37 USD, respectively¹⁸. While certain developed nations are vaccinating their citizens free of charge, others are charging the public and must consider whether the vaccine is affordable by all the citizens, because the health and lives of all individuals of a society are equally important and universal vaccination is an excellent way to reach herd immunity. Special consideration must be taken by low-income countries where the average person can simply afford the vaccine or not, and if so, then cost would be a consideration. However, despite its lower cost, the Pfizer vaccine's major issue lies with its storage temperature between -80°C and -60°C (-112°F to -76°F)¹⁹, whereas the Moderna vaccine is stored at a relatively much higher temperature between -25° and -15°C²⁰ that is easier to maintain. This temperature requirement can pose a challenge to low-income countries, many of which also face an energy crisis, as to how they will manage such low storage temperature conditions to ensure the promising results of both the vaccines, especially the Pfizer vaccine, with although cheaper, requires much lower and more difficult to maintain storage temperatures. Published data has shown that both vaccines elicit a similar humoral response, and the published literature reports no difference in cellular immunity. There is, however, preliminary unpublished evidence that Pfizer's COVID-19 vaccine may trigger stronger CD8 T-cell responses than Moderna's vaccine²⁷. This cellular response might provide added protection against an infection.

Regarding their adverse effects, both vaccines have in some cases produced serious adverse effects, and in rare cases, have produced severe allergic reactions, including anaphylaxis. Despite these issues that concern the vaccines, to date, Pfizer and Moderna vaccine are the only widely available vaccinations in the fight against corona. Countries, despite cost, are trying their best to vaccinate their citizens as early as possible, but further research is required to ensure that potential adverse effects are not triggered by any COVID-19 vaccines²⁸ and that planned phase 4 post marketing trials are also

complete for the vaccines to ensure their safety. So far, both COVID-19 vaccines have their own pros and cons and appear to be effective. The incidence of adverse effects is reported to be lower with the Pfizer/BioNTech vaccine than with the Moderna vaccine; however, the Moderna vaccine compared to the Pfizer vaccine is easier to transport and store because it is less temperature sensitive. With further research, the science community will hopefully bring forth new radical measures to fight this disease and finally bring an end to this pandemic.

Study Strengths and Limitations

This is the first study in the literature, to our knowledge, to highlight a comparison between the biology, pharmacology, indications, contraindications and adverse effects of the Pfizer/BioNTech and Moderna vaccines for a better understanding of these two vaccines.

Conclusions

The FDA has authorized, on an emergency basis, the Pfizer/BioNTech and Moderna vaccines. These two vaccines can provide protection from SARS-COV-2 infection by formation of antibodies, to provide immunity against a SARS-COV-2 infection, with humoral as well as possibly cellular immunity, which has led to great hope for ending the COVID-19 pandemic. The available evidence supports the conclusion that both vaccines are beneficial, but may cause some adverse effects including pain, redness or swelling at the site of vaccine shot, nausea, vomiting, fever, fatigue, headache, muscle pain, itching, chills, and joint pain, as well as in rare cases they may cause an anaphylactic reaction. The occurrence of these adverse effects is reported to be lower with the Pfizer/BioNTech vaccine than with the Moderna vaccine. However, the Moderna vaccine compared to the Pfizer vaccine is easier to transport and store because it is less temperature sensitive. It must be noted that because clinical trials are conducted under widely varying conditions, adverse reaction rates observed in the clinical trials of a vaccine cannot be directly compared with rates in the clinical trials of another vaccine and may not reflect the rates observed in practice.

Acknowledgement

Thanks to “Researchers Supporting Project Number (RSP-2019/47), King Saud University, Riyadh, Saudi Arabia”.

Conflict of Interest

The Authors declare that they have no conflict of interests.

References

- 1) Meo SA, Alhowikan AM, Al-Khlaiwi T, Meo IM, Halepoto DM, Iqbal M, Usmani AM, Hajjar W, Ahmed N. Novel coronavirus 2019-nCoV: prevalence, biological and clinical characteristics comparison with SARS-CoV and MERS-CoV. *Eur Rev Med Pharmacol Sci* 2020; 24: 2012-2019.
- 2) Meo SA, Al-Khlaiwi T, Usmani AM, Meo AS, Klonoff DC, Hoang TD. Biological and Epidemiological Trends in the Prevalence and Mortality due to Outbreaks of Novel Coronavirus COVID-19. *J King Saud Univ Sci* 2020; 32: 2495-2499.
- 3) World Health Organization (WHO). Coronavirus disease (COVID-19) outbreak situation. Available at: <https://www.who.int/emergencies/diseases/novel-coronavirus-2019>. cited date Dec 25, 2020.
- 4) Meo SA, Abukhalaf AA, Alomar AA, Sattar K, Klonoff DC. COVID-19 pandemic: impact of quarantine on medical students' mental wellbeing and learning behaviors. *Pak J Med Sci* 2020; 36: S43-S48.
- 5) US Food and Drug Administration. Pfizer-BioNTech COVID-19 Vaccine. Available at: <https://www.fda.gov/emergency-preparedness-and-response/coronavirus-disease-2019-covid-19/pfizer-biontech-covid-19-vaccine>. Cited date Dec 24, 2020.
- 6) US Food and Drug Ad. Available at: <https://www.fda.gov/media/144412/download>. Cited date Dec 24, 2020.
- 7) US Food and Drug Ad. Moderna COVID-19 Vaccine. Available at: <https://www.fda.gov/emergency-preparedness-and-response/coronavirus-disease-2019-covid-19/moderna-covid-19-vaccine>. Cited date, Dec 24, 2020.
- 8) Zhu N, Zhang D, Wang W, Li X, Yang B, Song J, Zhao X, Huang B, Shi W, Lu R, Niu P, Zhan F, Ma X, Wang D, Xu W, Wu G, Gao GF, Tan W; China Novel Coronavirus Investigating and Research Team. A Novel Coronavirus from patients with pneumonia in China, 2019. *N Engl J Med* 2020; 382: 727-733.
- 9) Philip Ball. The lightning-fast quest for COVID vaccines - and what it means for other diseases. *Nature* 2021; 589: 16-18.
- 10) Web of Science, Clarivate Analytics. Available at: <https://apps.webofknowledge.com>. Cited Dec 24, 2020.
- 11) Pub Med. Available at: <https://pubmed.ncbi.nlm.nih.gov/>. Cited date Dec 24, 2020.
- 12) Centre for Disease Control Prevention (CDC). Information about the Pfizer-BioNTech COVID-19 Vaccine. Available at: <https://www.fda.gov/emergency-preparedness-and-response/coronavirus-disease-2019-covid-19/pfizer-biontech-covid-19-vaccine#additional>. Cited dated, Dec 24, 2020.
- 13) Centre for Disease Control Prevention (CDC). Information about the Moderna COVID-19 Vaccine.

- Available <https://www.fda.gov/media/144638/download>. Cited Date Dec 24, 2020.
- 14) Polack FP, Thomas SJ, Kitchin N, Absalon J, Gurtman A, Lockhart S, Perez JL, Pérez Marc G, Moreira ED, Zerbini C, Bailey R, Swanson KA, Roychoudhury S, Koury K, Li P, Kalina WV, Cooper D, Frenck RW Jr, Hammitt LL, Türeci Ö, Nell H, Schaefer A, Ünal S, Tresnan DB, Mather S, Dormitzer PR, Şahin U, Jansen KU, Gruber WC; C4591001 Clinical Trial Group. Safety and efficacy of the BNT162b2 mRNA Covid-19 vaccine. *N Engl J Med* 2020; 383: 2603-2615.
 - 15) Oliver SE, Gargano JW, Marin M, Wallace M, Curran KG, Chamberland M, McClung N, Campos-Outcalt D, Morgan RL, Mbaeyi S, Romero JR, Talbot HK, Lee GM, Bell BP, Dooling K. The Advisory Committee on Immunization Practices' Interim Recommendation for Use of Pfizer-BioNTech COVID-19 Vaccine - United States, December 2020. *MMWR Morb Mortal Wkly Rep* 2020; 69: 1922-1924.
 - 16) Widge AT, Roupshael NG, Jackson LA, Anderson EJ, Roberts PC, Makhene M, Chappell JD, Denison MR, Stevens LJ, Puijssers AJ. mRNA-1273 study group. Durability of responses after SARS-CoV-2 mRNA-1273 vaccination. *N Engl J Med* 2021; 384: 80-82.
 - 17) Jackson LA, Anderson EJ, Roupshael NG, Roberts PC, Makhene M, Coler RN, McCullough MP, Chappell JD, Denison MR. mRNA-1273 Study Group. An mRNA vaccine against SARS-CoV-2 - preliminary report. *N Engl J Med* 2020; 383: 1920-1931.
 - 18) Katie Jennings. Forbes. How much will it cost to get a COVID-19 vaccine? Available at: www.healthline.com/health-news/how-much-will-it-cost-to-get-a-covid-19-vaccine#What-we-know-about-distribution-and-administration-costs. Cited date Dec 24, 2020
 - 19) Pfizer-BioNTech COVID-19 Vaccine. Facts sheet. Available at: <https://www.fda.gov/media/144413/download>. Cited date Dec 25, 2020.
 - 20) Moderna COVID-19 Vaccine. Facts Sheets. Available at: <https://www.idsociety.org/covid-19-real-time-learning-network/vaccines/moderna-covid-19-vaccine/>. Cited date Dec 25, 2020.
 - 21) Dong Y, Dai T, Wei Y, Zhang L, Zheng M, Zhou F. A systematic review of SARS-CoV-2 vaccine candidates. *Signal Transduct Target Ther* 2020; 5: 237.
 - 22) Anderson EJ, Roupshael NG, Widge AT, Jackson LA, Roberts PC, Makhene M, Chappell JD, Denison MR, Stevens LJ, Puijssers AJ. mRNA-1273 Study Group. Safety and Immunogenicity of SARS-CoV-2 mRNA-1273 Vaccine in Older Adults. *N Engl J Med* 2020; 383: 2427-2438.
 - 23) Thomas Clark. Anaphylaxis Following m-RNA COVID-19 Vaccine Receipt. <https://www.cdc.gov/vaccines/acip/meetings/downloads/slides-2020-12/slides-12-19/05-COVID-CLARK.pdf>. Cited date Dec25, 2020.
 - 24) Ledford H. Moderna COVID vaccine becomes second to get US authorization. *Nature* 2020 Dec 18. doi: 10.1038/d41586-020-03593-7. Epub ahead of print.
 - 25) Walsh EE, Frenck RW Jr, Falsey AR, Kitchin N, Absalon J, Gurtman A, Lockhart S, Neuzil K, Mulligan MJ, Bailey R, Swanson KA, Li P, Koury K, Kalina W, Cooper D, Fontes-Garfias C, Shi PY, Türeci Ö, Tompkins KR, Lyke KE, Raabe V, Dormitzer PR, Jansen KU, Şahin U, Gruber WC. Safety and immunogenicity of two RNA-based Covid-19 vaccine candidates. *N Engl J Med* 2020; 383: 2439-2450.
 - 26) Dolgin E. COVID-19 vaccines poised for launch, but impact on pandemic unclear. *Nat Biotechnol* 2020 Nov 25. doi: 10.1038/d41587-020-00022-y. Epub ahead of print.
 - 27) Taylor NP. Pfizer reports strong T-cell response to COVID-19 vaccine. Fierce Biotech. Available at: <https://www.fiercebiotech.com/biotech/pfizer-reports-strong-t-cell-response-to-covid-19-vaccine>. Cited date Dec 26, 2020.
 - 28) Vashishtha VM, Kumar P. Development of SARS-CoV-2 vaccines: challenges, risks, and the way forward. *Hum Vaccin Immunother* 2020 Dec 3:1-15. doi: 10.1080/21645515.2020.1845524. Epub ahead of print.