Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Travel Medicine and Infectious Disease 45 (2022) 102246

Contents lists available at ScienceDirect

Travel Medicine and Infectious Disease

journal homepage: www.elsevier.com/locate/tmaid

The emergence of new SARS-CoV-2 variant (Omicron) and increasing calls for COVID-19 vaccine boosters-The debate continues

Naushad Ahmad Khan [a], Hassan Al-Thani [b], Ayman El-Menyar [a,c,*]

[a] Department of Surgery, Trauma and Vascular Surgery Clinical Research, Hamad General Hospital, Doha, Qatar
[b] Department of Surgery, Trauma and Vascular Surgery, Hamad General Hospital, Doha, Qatar
[c] Clinical Medicine, Weill Cornell Medical College, Doha, Qatar

ARTICLE INFO

Keywords:
Omicron
Variant of concern
SARS-CoV-2
Booster dose
Emerging viruses

The emergence of highly mutated severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) variant Omicron (B.1.1.529) has ushered panic responses around the world due to its contagious and vaccine escape mutations. This variant has been designated as a variant of concern (VOC) by the World Health Organization (WHO) [1,2]. Since January 2021, multiple virus variants have emerged and become dominant in many countries [Table 1]. The emergence of these VOCs (Alpha, Beta, Gamma, and Delta) variants was responsible for new waves of infections across the entire world [3]. The Delta variant was reported to have increased transmissibility, higher viral load [4] and high rates of reinfection [5]. Because of its ability to escape from natural immunity [6], it became the globally dominant variant. The emergence of Omicron as a new VOC has transformed the notion of the COVID-19 endgame and created a fresh discussion over-vaccination effectiveness and the ongoing booster campaign in an already COVID-19-weary world. Compared to other the VOCs, this variation unusually carries an exceptionally high number of mutations (50) on the spike (S) protein, the major antigenic target of antibodies produced by infections or immunization. This has led the scientific community to investigate how much this new variant could undermine the existing vaccines. The scientific community knows little about Omicron's infectivity, vaccine breakthrough, and antibody resistance, and reliable experimental results from labs will take a few weeks to come out. Although conclusive immunological and clinical data are not yet available, early genomic data show immune evasion capabilities, fast transmission ability, reinfection rate, and severity [7]. This has triggered the calls to intensify vaccination programmes, including booster doses [8].

1. "Omicron" escalates the COVID-19 vaccine booster debate: to boost or not

So far, the available evidence suggests that booster jabs against COVID-19 provide an extra layer of protection against the illness [9]. However, questions still swirl over how much they will help and how often they will be needed. The evidence that booster jabs improve protection from COVID-19 infections is emerging, but their longevity, impact, and capacity to thwart the new type of infection remain insufficient. The advent of the Omicron variant also has muddled forecasts of how booster efforts would alter the pandemic's trajectory. Even before Omicron arrived, many global-health academics were averse to massive booster campaigns, despite that vaccination rates remain appallingly low in huge swaths of the world [10]. Boosters have already sparked debate over equity issues and the prioritization of limited vaccine resources. Scientists are concerned that wealthy countries rush to provide more boosters in the face of Omicron will exacerbate the global vaccine imbalance, which many health researchers believe contributed to Omicron's emergence and rapid spread.

The scientific rationale for boosters includes concerning evidence regarding declining vaccination protection over time and increased worries about breakthrough infections caused mainly by the SARS-CoV-2 Delta strain. The evidence for boosters comes from a variety of sources, including real-world data from Israel [11–13], the United Kingdom [14],

* Corresponding author. Department of Surgery, Trauma and Vascular Surgery Clinical Research, Hamad General Hospital, Doha, Qatar.
E-mail address: aymanco65@yahoo.com (A. El-Menyar).

https://doi.org/10.1016/j.tmaid.2021.102246
Received 16 December 2021; Accepted 17 December 2021
Available online 21 December 2021

and the USA [15], which showed that a booster dose of one of the commonly used mRNA-based vaccinations significantly reduces a person's chances of contracting SARS-CoV-2 and becoming mildly sick. A recent Pfizer research [16], which included data from over 44 000 people, indicated that after 6 months, vaccination protection dropped from 96.2% to 83.7%. Based on these findings, one can assume that two doses of the Pfizer vaccine give >80% protection against severe sickness and mortality 6 months post vaccination and booster injections enhance protection by 10%. Based on these assumptions, it may be better off delivering injections to unvaccinated persons in poor and developing countries since they will acquire >80% protection against serious disease and death. However, giving the same shot as boosters to fully vaccinated people leads to a 10% increase in benefit.

The fact that antibody levels may be raised in the general population should not be presented as evidence of long-term efficacy, and holistic clinical data are needed to determine whether booster doses are necessary. Booster doses have been also reported to responsible for unusual occurrence of myocarditis and pericarditis following the administration of an mRNA vaccination. According to an Israeli study, those who received the second dose of the vaccine had a rate ratio of 2.35 greater risk of myocarditis than those who did not get the vaccine [17]. Is the benefit-to-risk ratio of the third (booster) dosage different for older and younger people? Concerns have been raised about vaccine-induced thrombotic thrombocytopenia in younger viral vector vaccination users [18]. We are still awaiting data on the safety of third-dose boosters with different vaccines, and a call for booster against the new VOC (Omicron) without substantial scientific data about safety and efficacy can lead to safety concerns.

2. How existing vaccines fare against Omicron: recent research updates

Currently, it appears that the new VOC will alter the existing immunological landscape of COVID-19. Few of Omicron's mutations seems to compromise the T cells capacity to identify the virus and attack infected cells. As a result, we can expect many breakthrough infections. If Omicron can dodge neutralizing antibodies, this does not rule out the possibility that immune responses triggered by vaccination and past infection will provide no protection against this variant. Immunological studies demonstrate that low levels of neutralizing antibodies may protect people against severe COVID-19 infections. One critical aspect of the research will be to monitor T cells activity and another immune player called natural killer cells, which might be especially important for protection against severe COVID-19. Another exciting area of research will be to quantify the level of protection against Omicron provided by the current vaccines and previous infections. Human immune systems produce number of antibodies that target various parts of the spike protein; thus, even if one portion of the spike protein changes, a vaccination will typically still perform well. However, scientists are afraid that this version might be an escape variant because virtually all of the locations that antibodies target differ in the Omicron variant. Early reports suggest that most breakthrough infections with Omicron are mild [19].

On Dec 8, BioNTech and Pfizer claimed a three-shot course of their COVID-19 vaccine could neutralize the new Omicron variant in a laboratory test, an early signal that booster shots could be crucial to protect against infection from the newly identified variant. They claimed that two doses of the vaccine resulted in significantly lower neutralizing antibodies but could still be protective against severe disease [20]. Another study from Israel presented similar findings to BioNTech and Pfizer, indicating that booster doses might be critical in preventing infection from the newly identified variant. The study compared the blood of 20 individuals who had received two vaccination doses 5–6 months earlier to a month prior to the same number of persons who had received a booster dose a month prior. People who took the second dosage 5 or 6 months earlier did not have any neutralization ability against the Omicron. While they still had some against the Delta (strain). The Israeli scientific team worked with the actual virus while the BioNTech and Pfizer companies used what is known as a pseudovirus/or tweaked virus, which was bio-engineered to have the hallmark mutations of Omicron [21].

Recent research from the United States [22], published on medRxiv on December 12, 2021, have reported that vaccine efficacy against symptomatic infection caused by the Omicron variant is expected to be significantly lower than against previous variants. Using previous data on the efficacy of COVID-19 vaccines against earlier variants and preliminary data on the Pfizer/BioNTech vaccine against Omicron, they developed computer models that suggested that after two doses of an mRNA vaccine from Pfizer/BioNTech or Moderna efficacy against symptomatic infection from Omicron is only about 30%, compared to about 87% with the Delta variant.

A contradictory report from South Africa [19], published on Dec 10,

Table 1
Summary of World Health Organization (WHO) designated Variants of Concern (VOC) for SARS-CoV-2.

SARS-CoV-2 variants with Scientific Name	Region/Country first detected	Mutation	Virulence/severity or duration of disease/ reinfection	Transmissibility
Alpha (B.1.1.7)	UK, September 2020	**23,** (17 of which change amino acids) Includes N501Y substitution	Increased risk of hospitalization, possible increased risk of severity and mortality	Reproduction number (Ro) −3.5-5.2 Compared to the wild form, there are higher transmissibility and secondary attacks.
Beta (B.1.351)	South Africa, May 2020	**21,** (8 of which change amino acids) Includes N501Y substitution	Possibility of increased risk of severe disease and in-hospital mortality	Increased transmissibility, estimated to be 2.5 times that of wild type.
Gamma (B.1.1.28.1)	Brazil, November 2020	**17,** (11 of which change amino acids) Includes N501Y substitution	Possible increased risk of hospitalization and severity of disease	Increased transmissibility and secondary attack rate than that of wild type.
Delta (B.1.617.2)	India, October 2020	**12,** Spike mutation profiles L452R, E484Q, and D614G are present. However, there are no mutations at amino acid 501 or 484 in its ACE2 receptor.	Increased risk of emergency care and hospitalization, including higher oxygen requirement, possible admission to an intensive care unit, and increased risk of mortality. Hospitalization rates for unvaccinated individuals are higher compared with vaccinated individuals	The reproduction number (Ro) ranges from 3.2 to 8, with 5.0 being the average. Enhanced transmissibility and Estimated 2.5-fold higher viral loads compared to other variants.
Omicron (B.1.1.529)	Botswana, South Africa November 2021	~**50** mutations, including over 30 mutations on its spike protein and 15 on the receptor-binding domain	Yet unclear if Omicron produces more severe illness than other variants. Early studies imply that hospitalization rates in South Africa are rising. However, this might be attributable to overall rising infection rates rather than an indication of more severe disease. According to preliminary findings, there is a higher chance of reinfection.	Yet not clear whether Omicron is more transmissible. However, some of the mutations observed in Omicron are known to be associated with enhanced transmissibility. Reports suggest high transmissibility due to the presence of D614G and P681H mutations

2021, reported that a cluster of Omicron variant infections in a group of German visitors who had received full primary vaccination series and booster doses with SARS-CoV-2 mRNA vaccines experienced breakthrough infections with the Omicron variant in late November/early December 2021, while in Cape Town, South Africa. They developed symptomatic COVID-19. However, the clinical symptoms were mild to moderate, demonstrating that even three doses of mRNA vaccines may not be enough to prevent infection and symptomatic illness with the Omicron variant. The reported group consisted of seven individuals with an average age of 27.7 years with no relevant medical history. On arrival during the first half of November, all cases provided a negative SARS-CoV-2 PCR test and a complete vaccination record, including booster or third doses. Six cases were fully vaccinated with BNT162b2 (BioNTech). Five of these received a third (booster) dose of BNT162b2 in October or early November 2021, and one received a full dose of mRNA-1273 (Moderna) at the beginning of October. The seventh participant got an initial dose of AstraZeneca's ChAdOx1-S vaccine, followed by a dose of BNT162b2 for primary vaccination completion and a booster dose of the same vaccine. None of them had ever been infected with the SARS-CoV-2 virus [19]. Moreover, recent reports from Singapore showed that their two residents were infected by the omicron variant even after receiving COVID-19 booster shots suggesting its high virulence and uncertain immunological trajectories [23]. These studies prove that, as predicted, the Omicron variant can evade immunity induced by mRNA vaccines in vivo. Nevertheless, the protection from severe disease is probably still intact in individuals who have received complete or booster doses.

3. Will current booster's vaccination improve protection against Omicron?

If shreds of evidence around booster shots to tackle COVID-19 were ambiguous earlier, the emergence of the new variant, Omicron, has ensured that the clamour for booster shots has reached a fever pitch. Nevertheless, new data emerge every day, but the scientific community needs time to complete studies and interpret the results. According to recent reports, booster doses increase neutralizing-antibody levels, which will likely provide a bulwark against Omicron's ability to evade these antibodies. However, it is unclear how well these doses will work against this viral strain. People who have had repeated exposure to SARS-spike CoV-2's protein, whether through infection or a booster dosage, are very likely to have neutralizing antibody activity against Omicron [24–26]. However, a recently published South Africa study shows that even booster doses are insufficient to prevent symptomatic infection and emphasize the need to maintain additional non-pharmaceutical interventions [19]. These findings highlight the need for updated vaccines to protect against symptomatic infection with the Omicron.

While severe illness requiring hospitalization is now seen mostly in unvaccinated individuals, Vaccine-rich nations, in concert with pharmaceutical companies, are implementing strategies to deliver a third so-called booster dose. There is currently no general consensus in any geographic region on when, for whom, or for which vaccines a booster dose is required. Therefore, more clinical studies are needed to understand better the transmissibility, immunity escape potential, clinical presentation and severity of the disease and the role of other available diagnostic and therapeutic countermeasures against Omicron variant before pushing for another booster campaign.

4. Conclusions

The WHO designation of Omicron as a variant of concern has uncovered substantial information gaps and shortcomings in global COVID-19 response and control efforts. To date, the scientific community knows little about Omicron's infectivity, vaccine breakthrough, antibody resistance and efficacy of the ongoing booster doses. Previous experiences with other variants lead us to believe that only time and surveillance will give us more information on transmissibility, vaccine efficacy and severity of the disease caused by this new variant. Whether Omicron will turn out to be an 'a storm in a teacup' or a lethal evolving threat to global health security, its appearance nearly two years after its first discovery serves as a stark reminder that the COVID-19 pandemic is far from over. More affluent countries need to take heed of the WHO slogan that "none of us is safe until all of us are safe". At this point of the pandemic, when the Omicron strain is supercharging the booster debate, global policy must consider the hazards of adopting booster dosages ad libitum across the world.

Funding

None.

All authors have a substantial contribution and approved this submission.

Declaration of competing interest

None.

References

[1] WHO. Classification of omicron (B.1.1.529): SARS-CoV-2 variant of concern. 26 November 2021. Statement, https://www.who.int/news/item/26-11-2021-classification-of-omicron-(b.1.1.529)-sars-cov-2-variant-of-concern. [Accessed 9 December 2021].

[2] GISAID. hCov19 Variants. 2021. https://www.gisaid.org/. [Accessed 9 December 2021].

[3] COVID-19 Genomics UK (COG-UK) consortium Volz E, Mishra S, Chand M, Barrett JC, Johnson R, Geidelberg L, Hinsley WR, Laydon DJ, Dabrera G, O'Toole Á, Amato R, Ragonnet-Cronin M, Harrison I, Jackson B, Ariani CV, Boyd O, Loman NJ, JT McCrone, Gonçalves S, Jorgensen D, Myers R, Hill V, Jackson DK, Gaythorpe K, Groves N, Sillitoe J, Kwiatkowski DP, Flaxman S, Ratmann O, Bhatt S, Hopkins S, Gandy A, Rambaut A, Ferguson NM. Assessing transmissibility of SARS-CoV-2 lineage B.1.1.7 in England. Nature 2021 May;593(7858):266–9. https://doi.org/10.1038/s41586-021-03470-x. Epub 2021 Mar 25. PMID: 33767447.

[4] Luo CH, Morris CP, Sachithanandham J, Amadi A, Gaston D, Li M, Swanson NJ, Schwartz M, Klein EY, Pekosz A, Mostafa HH. Infection with the SARS-CoV-2 Delta variant is associated with higher infectious virus loads compared to the Alpha variant in both unvaccinated and vaccinated individuals. Aug 20: 2021.08.15.21262077. doi: medRxiv 2021. https://doi.org/10.1101/2021.08.15.21262077. PMID: 34462756; PMCID: PMC8404894.

[5] van Kampen JJA, van de Vijver DAMC, Fraaij PLA, et al. Duration and key determinants of infectious virus shedding in hospitalized patients with coronavirus disease-2019 (COVID-19). Nat Commun 2021;12(1):267. https://doi.org/10.1038/s41467-020-20568-4. . [Accessed 11 January 2021].

[6] Townsend JP, Hassler HB, Wang Z, Miura S, Singh J, Kumar S, Ruddle NH, Galvani AP, Dornburg A. The durability of immunity against reinfection by SARS-CoV-2: a comparative evolutionary study. Lancet Microbe 2021 Dec;2(12): e666–75. https://doi.org/10.1016/S2666-5247(21)00219-6. Epub 2021 Oct 1. PMID: 34632431; PMCID: PMC8486316.

[7] Pulliam Juliet RC, van Schalkwyk Cari, Govender Nevashan, von Gottberg Anne, Cohen Cheryl, Groome Michelle J, Dushoff Jonathan, Mlisana Koleka, Moultrie Harry. Increased risk of SARS-CoV-2 reinfection associated with emergence of the Omicron variant in South Africa. 11 medRxiv 2021;11:21266068. https://doi.org/10.1101/2021.11.11.21266068.

[8] Dolgin E. Omicron is supercharging the COVID vaccine booster debate. Nature 2021 Dec 2. https://doi.org/10.1038/d41586-021-03592-2. Epub ahead of print. PMID: 34862505.

[9] Callaway E. COVID vaccine boosters: the most important questions. Nature 2021 Aug;596(7871):178–80. https://doi.org/10.1038/d41586-021-02158-6. PMID: 34354274.

[10] Krause PR, Fleming TR, Peto R, Longini IM, Figueroa JP, Sterne JAC, Cravioto A, Rees H, Higgins JPT, Boutron I, Pan H, Gruber MF, Arora N, Kazi F, Gaspar R, Swaminathan S, Ryan MJ, Henao-Restrepo AM. Considerations in boosting COVID-19 vaccine immune responses. Lancet 2021 Oct 9;398(10308):1377–80. https://doi.org/10.1016/S0140-6736(21)02046-8. Epub 2021 Sep 14. PMID: 34534516; PMCID: PMC8437678.

[11] Bar-On YM, Goldberg Y, Mandel M, Bodenheimer O, Freedman L, Kalkstein N, Mizrahi B, Alroy-Preis S, Ash N, Milo R, Huppert A. Protection of BNT162b2 vaccine booster against covid-19 in Israel. N Engl J Med 2021 Oct 7;385(15): 1393–400. https://doi.org/10.1056/NEJMoa2114255. Epub 2021 Sep 15. PMID: 34525275; PMCID: PMC8461568.

[12] Barda N, Dagan N, Cohen C, Hernán MA, Lipsitch M, Kohane IS, Reis BY, Balicer RD. Effectiveness of a third dose of the BNT162b2 mRNA COVID-19 vaccine for preventing severe outcomes in Israel: an observational study. Lancet 2021 Dec

4;398(10316):2093–100. https://doi.org/10.1016/S0140-6736(21)02249-2. Epub 2021 Oct 29. PMID: 34756184; PMCID: PMC8555967.

[13] Patalon T, Gazit S, Pitzer VE, Prunas O, Warren JL, Weinberger DM. Odds of testing positive for SARS-CoV-2 following receipt of 3 vs 2 doses of the BNT162b2 mRNA vaccine. JAMA Intern Med 2021 Nov 30:e217382. https://doi.org/10.1001/jamainternmed.2021.7382. Epub ahead of print. PMID: 34846533; PMCID: PMC8634151.

[14] Andrews Nick, Julia Stowe, Kirsebom Freja, Gower Charlotte, Ramsay Mary, Lopez Bernal Jamie. Effectiveness of BNT162b2 (Comirnaty, Pfizer-BioNTech) COVID-19 booster vaccine against covid-19 related symptoms in England: test negative case-control study. medRxiv 2021;11(15):21266341. https://doi.org/10.1101/2021.11.15.21266341.

[15] Rosenberg ES, Holtgrave DR, Dorabawila V, Conroy M, Greene D, Lutterloh E, Backenson B, Hoefer D, Morne J, Bauer U, Zucker HA. New COVID-19 cases and hospitalizations among adults, by vaccination status - New York, may 3-July 25, 2021. MMWR Morb Mortal Wkly Rep 2021 Aug 27;70(34):1150–5. https://doi.org/10.15585/mmwr.mm7034e1. PMID: 34437517; PMCID: PMC8389393.

[16] Thomas SJ, Moreira Jr ED, Kitchin N, Absalon J, Gurtman A, Lockhart S, Perez JL, Pérez Marc G, Polack FP, Zerbini C, Bailey R, Swanson KA, Xu X, Roychoudhury S, Koury K, Bouguermouh S, Kalina WV, Cooper D, Frenck Jr RW, Hammitt LL, Türeci Ö, Nell H, Schaefer A, Ünal S, Yang Q, Liberator P, Tresnan DB, Mather S, Dormitzer PR, Şahin U, Gruber WC, Jansen KU. C4591001 clinical trial group. Safety and efficacy of the BNT162b2 mRNA covid-19 vaccine through 6 months. N Engl J Med 2021 Nov 4;385(19):1761–73. https://doi.org/10.1056/NEJMoa2110345. Epub.2021.Sep.15. PMID: 34525277; PMCID: PMC8461570.

[17] Mevorach D, Anis E, Cedar N, Bromberg M, Haas EJ, Nadir E, Olsha-Castell S, Arad D, Hasin T, Levi N, Asleh R, Amir O, Meir K, Cohen D, Dichtiar R, Novick D, Hershkovitz Y, Dagan R, Leitersdorf I, Ben-Ami R, Miskin I, Saliba W, Muhsen K, Levi Y, Green MS, Keinan-Boker L, Alroy-Preis S. Myocarditis after BNT162b2 mRNA vaccine against covid-19 in Israel. N Engl J Med 2021 Dec 2;385(23):2140–9. https://doi.org/10.1056/NEJMoa2109730. Epub 2021 Oct 6. PMID: 34614328; PMCID: PMC8531987.

[18] Cines DB, Bussel JB. SARS-CoV-2 vaccine-induced immune thrombotic thrombocytopenia. N Engl J Med 2021 Jun 10;384(23):2254–6. https://doi.org/10.1056/NEJMe2106315. Epub.2021.Apr.16. Erratum in: N Engl J Med. 2021 Jun 10;384(23):e92. PMID: 33861524; PMCID: PMC8063912.

[19] Kuhlmann Constanze, Mayer Carla Konstanze, Claassen Mathilda, Maponga Tongai G, Sutherland Andrew D, Suliman Tasnim, Shaw Megan, Preiser Wolfgang. Breakthrough infections with SARS-CoV-2 omicron variant despite booster dose of mRNA vaccine. December 9, 2021. https://doi.org/10.2139/ssrn.3981711. Available at: SSRN: https://ssrn.com/abstract=3981711.

[20] Pfizer. Pfizer and BioNTech Provide Update on Omicron Variant. Press release. Wednesday, December 08, 2021 - 06:54am. https://www.pfizer.com/news/press-release/press-releasedetail/pfizer-and-biontech-provide-update-omicron-variant. (Last accessed December 12, 2021.

[21] Reuters. Israeli study finds Pfizer COVID-19 booster protects against Omicron. December 12, 2021. https://www.reuters.com/world/middle-east/israeli-study-finds-pfizer-covid-19-booster-protects-against-omicron-2021-12-11/. [Accessed 13 December 2021].

[22] Gardner Billy J, Marm Kilpatrick A. Estimates of reduced vaccine effectiveness against hospitalization, infection, transmission and symptomatic disease of a new SARS-CoV-2 variant, Omicron (B.1.1.529), using neutralizing antibody titers. medRxiv 2021;12(10):21267594. https://doi.org/10.1101/2021.12.10.21267594.

[23] Fortune. Health COVID-19 Vaccines .Singapore finds two breakthrough Omicron cases in residents who got COVID booster shots. (Last accessed December 12, 2021 . https://fortune.com/2021/12/09/singapore-omicron-variant-covid-cases-breakthrough-vaccine-pfizer-biontech/?queryly=related_article.

[24] Cele S, Jackson L, Khan K, Khoury D, Moyo-Gwete T, Tegally H, Scheepers C, Amoako D, Karim F, Bernstein M, Lustig G, Archary D, Smith M, Ganga Y, Jule Z, Reedoy K, Emmanuel San J, Hwa SH, Giandhari J, Blackburn JM, Gosnell BI, Abdool Karim S, Hanekom W, NGS-SA, COMMIT-KZN Team, von Gottberg A, Bhiman J, Lessells RJ, Moosa MYS, Davenport M, de Oliveira T, Moore PL, Sigal A. SARS-CoV-2 Omicron has extensive but incomplete escape of Pfizer BNT162b2 elicited neutralization and requires ACE2 for infection. Pre-print. https://www.ahri.org/omicron-incompletely-escapesimmunity-induced-by-the-pfizer-vaccine (last accessed December 13, 2021).

[25] Wilhelm A, Widera M, Grikscheit K, Toptan T, Schenk B, Pallas C, Metzler M, Kohmer N, Hoehl S, Helfritz FA, Wolf T, Goetsch U, Ciesek S. Reduced neutralization of SARS-CoV-2 omicron variant by vaccine Sera and monoclonal antibodies. medRxiv 2021;12(7):21267432. https://doi.org/10.1101/2021.12.07.21267432.

[26] Devlin H, Kollewe J. BioNTech says it could tweak Covid vaccine in 100 days if needed. The Guardian(newspaper) https://www.theguardian.com/society/2021/nov/26/biontechsays-it-could-tweak-covid-vaccine-in-100-days-if-needed . (Last accessed December 13, 2021.