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BREAST

Frequency and outcomes of MRI-detected axillary adenopathy following COVID-19 vaccination

Joao V. Horvat[1] · Varadan Sevilimedu[2] · Anton S. Becker[1] · Rocio Perez-Johnston[1] · Randy Yeh[1] · Kimberly N. Feigin[1]

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Abstract

Objectives To assess the frequency of ipsilateral axillary adenopathy on breast MRI after COVID-19 vaccination. To investigate the duration, outcomes, and associated variables of vaccine-related adenopathy.

Methods In this retrospective cohort study, our database was queried for patients who underwent breast MRI following COVID-19 vaccination from January 22, 2021, to March 21, 2021. The frequency of ipsilateral axillary adenopathy and possible associated variables were evaluated, including age, personal history of ipsilateral breast cancer, clinical indication for breast MRI, type of vaccine, side of vaccination, number of doses, and number of days between the vaccine and the MRI exam. The outcomes of the adenopathy were investigated, including the duration of adenopathy and biopsy results.

Results A total of 357 patients were included. The frequency of adenopathy on breast MRI was 29% (104/357 patients). Younger patients and shorter time intervals from the second dose of the vaccine were significantly associated with the development of adenopathy (p = 0.002 for both). Most adenopathy resolved or decreased on follow-up, with 11% of patients presenting persistence of adenopathy up to 64 days after the second dose of the vaccine. Metastatic axillary carcinoma was diagnosed in three patients; all three had a current ipsilateral breast cancer diagnosis.

Conclusions Vaccine-related adenopathy is a frequent event after COVID-19 vaccination; short-term follow-up is an appropriate clinical approach, except in patients with current ipsilateral breast cancer. Adenopathy may often persist 4–8 weeks after the second dose of the vaccine, thus favoring longer follow-up periods.

Key Points

- *MRI-detected ipsilateral axillary adenopathy is a frequent benign finding after mRNA COVID-19 vaccination.*
- *Axillary adenopathy following COVID-19 vaccination often persists > 4 weeks after vaccination, favoring longer follow-up periods.*
- *In patients with concurrent ipsilateral breast cancer, axillary adenopathy can represent metastatic carcinoma and follow-up is not appropriate.*

Keywords Vaccines · Pandemic · Lymphadenopathy · Magnetic resonance imaging · Breast neoplasms

Abbreviations

CDC	Centers for Disease Control and Prevention
CNB	Core needle biopsy
FDA	Food and Drug Administration
FNA	Fine needle aspiration
IQR	Interquartile range
SLNB	Sentinel lymph node biopsy

✉ Joao V. Horvat
machadoj@mskcc.org

[1] Department of Radiology, Memorial Sloan Kettering Cancer Center, 300 E 66th St, New York, NY 10065, USA

[2] Department of Epidemiology and Biostatistics, Memorial Sloan Kettering Cancer Center, New York, NY, USA

Introduction

New challenges emerged from the devastating effects of the COVID-19 pandemic. The novel pathogenicity of the SARS-COV-2 virus as well as its associated mortality and morbidity rate started a worldwide effort to find measures to remediate the disease and control the spread of infection [1]. The

development of vaccines that could reduce the infection rate and lethality of the virus brought hope to billions of people worldwide [2]. While the vaccination process has been viewed with great enthusiasm, constant monitoring is still necessary to detect possible adverse events from these new vaccines [3].

In December 2020, the Food and Drug Administration (FDA) in the USA authorized the emergency use of the first two COVID-19 vaccines, produced by Pfizer-BioNTech (BNT162b2) and Moderna (mRNA-1273), respectively [4, 5]. These vaccines present new biotechnology that consists of an injection of mRNA that is capable of inducing human cells to produce viral proteins that can be detected by the immune system, starting a reaction chain that ultimately leads to immune protection. The third vaccine to receive emergency use authorization by the FDA is produced by Janssen (Ad26.COV2.S) and has a different approach of triggering an immune response [6]. In this case, the immune response is mediated by an adenovirus encoding the coronavirus S protein that infects human cells. The aforementioned vaccines were subsequently approved for use in the European Union by the European Medicines Agency [7]. Other vaccines currently not available in the USA or European Union have different approaches, such as the injection of attenuated SARS-COV-2 particles [8].

Axillary lymph nodes are the most common site of metastatic infiltration from breast tumors [9, 10]. During the nationwide SARS-COV-2 vaccination campaign, a number of studies were published associating mRNA-mediated vaccines with axillary adenopathy [11–15]. Vaccine-related adenopathy may be confounded with malignant infiltration of axillary lymph nodes [16, 17]. This distinction is particularly difficult in patients with a diagnosis of current or previous breast cancer. A number of authors and medical associations have recommended short-term follow-up of patients with adenopathy ipsilateral to the arm that received the vaccination dose to ensure benignity [16, 18–24]. Nevertheless, little is known regarding the frequency and duration of imaging-detected adenopathy in patients after the COVID-19 vaccination [21].

In this study, we evaluated the frequency of ipsilateral axillary adenopathy following COVID-19 vaccination in patients who underwent breast MRI at a comprehensive cancer center. Additionally, we investigated possible variables associated with the incidence of adenopathy and the outcomes of patients with abnormal lymph nodes.

Materials and methods

Population

In this Health Insurance Portability and Accountability Act–compliant and Institutional Review Board–approved study, we retrospectively searched our database for patients who underwent breast MRI at our institution, a tertiary care cancer center, after receiving the COVID-19 vaccine. Consecutive cases within a 2-month period were queried from January 22, 2021, to March 21, 2021, starting from when the cataloging of the vaccination status began at our institution. The necessity for patient informed consent was waived by the Institutional Review Board. The exclusion criteria were as follows: (1) vaccine not received in the arm and (2) MRI study considered non-diagnostic due to the presence of artifacts. A total of 357 patients were included in our study sample. The flow of patient inclusion is presented in Fig. 1.

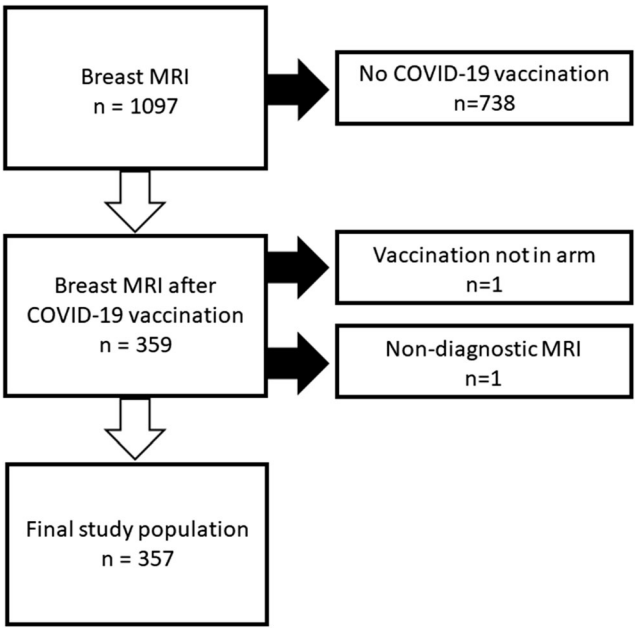

Fig. 1 Patient accrual diagram

Clinical information

The health information system was queried for patients' clinical information, including age, biological sex, and previous history of or current presence of known breast cancer. Clinical indication for breast MRI was also annotated and classified into a screening or diagnostic exam. COVID-19 vaccination history was also queried, including the type of vaccine, number of doses received before the MRI study, dates of the doses, and arm side that received the vaccine.

Breast MRI

Breast MRI reports were searched for information on the presence of abnormal axillary lymph nodes. Patients with abnormal lymph nodes ipsilateral to the arm that received one of the doses of the vaccine were considered positive for adenopathy. The presence of adenopathy was described by breast imaging specialist radiologists based on morphological features,

including cortical thickening (> 3 mm), lack or effacement of a fatty hilum, size, decreased long/short axis ratio, or irregular contours. Patients with one or more abnormal lymph nodes were considered positive for adenopathy, even if additional normal-appearing lymph nodes were identified within the axilla. Patients with axillary adenopathy presumed to be vaccine-related were recommended for follow-up 4–8 weeks after the second vaccination dose following our breast imaging service recommendations at the time.

Outcomes

The outcomes of all patients were annotated on September 1, 2021. Patients with adenopathy for which follow-up was recommended were scheduled for a targeted axillary ultrasound to be performed at 4–8 weeks after the completion of the vaccination regimen. If for various reasons a breast MRI, PET-CT, or chest CT was performed before the follow-up ultrasound showing the decrease or resolution of the adenopathy, the follow-up ultrasound was considered unnecessary and canceled.

The nodal status on imaging follow-up of patients with adenopathy was annotated and classified into three categories: persistent, decreased, and resolved. Patients with persistent adenopathy were either recommended for an additional follow-up 4 weeks later or recommended for fine-needle aspiration (FNA) or core needle biopsy (CNB). Patients with current ipsilateral breast cancer who underwent sentinel lymph node biopsy were also cataloged and the results were annotated.

Statistical analysis

The results were expressed as medians and interquartile ranges (IQR) for continuous variables and proportions for categorical variables. Clinical, temporal, or vaccine-related characteristics such as age, presence of ipsilateral current breast cancer, history of ipsilateral treated breast cancer, clinical indication for breast MRI, type of vaccine, side (left or right) of vaccination, number of doses received before the exam, number of days between the first dose of the vaccine and the MRI exam, number of days between the second dose of the vaccine and the MRI exam, and number of days between the latest dose of the vaccine and the MRI exam were compared between groups with and without adenopathy on MRI. Continuous covariates were compared using the Wilcoxon rank-sum test and categorical covariates were compared using the chi-square test of independence or Fisher's exact test. Multiple comparison adjustment was made using the Benjamini–Hochberg (false discovery rate) procedure. The adjusted type I error rate was set to 0.05 (α).

Results

Study sample

Of the 357 patients that underwent breast MRI after the COVID-19 vaccination, 356 (> 99%) were female. The median age of the patients was 55 years (IQR 45, 65). There were 16/357 (4%) patients with current ipsilateral breast cancer and 57/357 (16%) patients with a history of treated ipsilateral breast cancer.

The clinical indication for the breast MRI exam was screening in 219/357 (61%) patients and diagnostic in 138/357 (39%) patients, including 44 to evaluate breast implants, 42 to evaluate a known cancer, 27 for short-term follow-up of a probably benign finding, 13 for a breast symptom, 9 to evaluate a breast lesion identified by another imaging modality, 2 to evaluate a surgical bed, and 1 for palpable axillary adenopathy.

The Pfizer-BioNTec vaccine was administered in 175/357 (49%) patients, the Moderna vaccine was administered in 137/357 (38%) patients, the Janssen vaccine was administered in 1/357 (< 1%) patients, and in 44/357 (12%) patients the type of vaccine was unknown. The vaccine was administered in the left arm in 268/357 (75%) patients, in the right arm in 69/357 (19%) patients, one dose in each arm in 12/357 (4%) patients, and in 8/357 (2%) patients the laterality was unknown. The number of doses received before the MRI exam was one dose for 173/357 (48%) patients and two doses for 184/357 (52%) patients. The median number of days was 26 days (IQR 14, 44) between the first dose of the vaccine and the exam date, 18 days (IQR 7, 29) between the second dose and the exam, and 15 days (IQR 8, 24) between the latest dose (either first or second dose) and the exam. Patient information is summarized in Table 1.

COVID-19 vaccination and adenopathy

There were 104/357 (29%; 95% CI: 25, 34) patients with ipsilateral axillary adenopathy after COVID-19 vaccination. Of these, 13/104 (13%) presented with adenopathy beyond 4 weeks following completion of vaccination. Patients with only one dose of the vaccine presented adenopathy between 4 and 30 days after the vaccine, while patients with two doses presented adenopathy between 1 and 62 days after the second dose of the vaccine. Younger age was statistically significantly associated with the development of adenopathy ($p = 0.002$). This was confirmed after false discovery rate adjustment (adjusted p value = 0.012). The median age of patients with adenopathy was 51 years (IQR 41, 59) in comparison with 57 years (IQR 46, 67) of patients without adenopathy. The presence of either a current ipsilateral breast cancer or a history of a treated ipsilateral breast cancer was not associated with the development of adenopathy (p = 0.087 and 0.5,

Table 1 Patient characteristics, breast MRI details, and vaccine information

Characteristics of patients	*n*	%
Patient median age = 55 years (range, 25–82)		
Total number of patients	357	100
Patient biological sex		
Female	356	99
Male	1	1
History of ipsilateral breast cancer		
Current cancer	16	4
Previous cancer	57	16
Breast MRI technique		
With contrast	313	88
Without contrast	44	12
Clinical indication for breast MRI		
Screening	219	61
Diagnostic	138	39
Type of vaccine		
Pfizer-BioNTec	175	49
Moderna	137	38
Janssen	1	1
Unknown	44	12
Side of vaccine		
Left arm	268	75
Right arm	69	19
Bilateral	12	4
Unknown	8	2
Number of doses of the vaccine		
1 dose	173	48
2 doses	184	52
Median days between dose and breast MRI		
Days since the first dose	26	
Days since the second dose	18	
Days since the latest dose	15	

respectively). Of patients with concurrent ipsilateral breast cancer, 8/104 (8%) had adenopathy in comparison to 8/253 (3%) without adenopathy and among patients with a personal history of ipsilateral breast cancer, 14/104 (13%) developed adenopathy while 43/253 (17%) did not. Similarly, the clinical indication of the exam, either screening or diagnostic, was not associated with adenopathy (p = 0.9). Contralateral axillary adenopathy was not associated with COVID-19 vaccination and was only identified in patients with contralateral breast cancer and metastatic adenopathy.

A slightly larger proportion of patients who received the Moderna vaccine developed adenopathy 47/137 (34%) in comparison with the proportion of patients who received the Pfizer-BioNTec vaccine and who subsequently developed adenopathy 44/175 (25%), but this difference was not statistically significant (p = 0.12). Only one patient in our study population had received the Janssen vaccine, and this patient did not develop adenopathy. The comparison of types of vaccine between groups with and without adenopathy is demonstrated in Table 2.

Table 2 Type of vaccine compared between patients with and without axillary adenopathy on breast MRI (p = 0.12)

Type of vaccine	Adenopathy	No adenopathy	Total
Pfizer-BioNTec	44 (25%)	131 (75%)	175
Moderna	47 (34%)	90 (66%)	137
Janssen	0 (0%)	1 (100%)	1
Total	91	222	313

Of the patients who received only one dose of the vaccine, 50/173 (29%) developed adenopathy; similarly, this finding was observed in 54/184 (29%) of patients who received two doses of the vaccine. No association was found between adenopathy and the number of doses of the vaccine prior to the MRI ($p > 0.9$). Likewise, the side where the vaccine was administered was not associated with adenopathy (p = 0.4).

The time between the second dose of the vaccine and the MRI exam was inversely associated with the development of adenopathy (p = 0.002). This was confirmed after false discovery rate adjustment (adjusted p value = 0.012). The time between the first dose or the latest dose and the exam were not associated with the development of adenopathy. The median time interval between vaccination doses and the presence of adenopathy on breast MRI exams are demonstrated in Table 3.

Outcomes

Of 104 patients with ipsilateral axillary adenopathy on breast MRI following COVID-19 vaccination, 74/104 (71%) had imaging follow-up performed at least 4 weeks after the second dose of the vaccine. All patients underwent an axillary ultrasound on follow-up, except for three who underwent PET-CT, two who underwent breast MRI, and one who underwent chest CT. In 8/74 (11%) patients, imaging follow-up performed at least 4 weeks after the second dose of the vaccine (ranging between 29 and 64 days after the last dose) demonstrated persistence of adenopathy. In 72/74 (97%) patients, the adenopathy was deemed resolved or decreased on follow-up, including 6 patients with persistent adenopathy on initial follow-up. Adenopathy was considered resolved in 57/74 (77%) patients (ranging between 31 and 130 days after vaccination) while in 15/74 (20%) patients, it was considered still abnormal but decreased in correlation with the breast MRI exam (ranging between 28 and 104 days after vaccination). Two patients were lost to follow-up after an axillary ultrasound performed more than 4 weeks after vaccination demonstrated persistence

Table 3 Days after the COVID-19 vaccine compared between patients with and without adenopathy on breast MRI

Vaccine dose (days, IQR)	Adenopathy	No adenopathy	*p* value (adjusted)
First dose	26 (15, 36)	28 (14, 47)	0.6
Second dose	14 (4, 24)	20 (9, 32)	0.012
Latest dose	14 (7, 20)	16 (8, 24)	0.2

of adenopathy. The range of days after vaccination on imaging follow-up of patients with persistent, decreased, and resolved adenopathy is demonstrated in Table 4.

An interventional procedure was performed in 10/104 (10%) patients with adenopathy, including four FNAs, one CNB, and five sentinel lymph node biopsies (SLNBs). The results were positive for metastatic carcinoma in 3/104 (3%) patients, all of whom had concurrent ipsilateral breast cancer. These three patients represent 38% of a total of eight patients with axillary adenopathy and concurrent ipsilateral breast cancer. Two patients without ipsilateral breast cancer underwent FNA that yielded benign results. One additional patient had a previously diagnosed chronic lymphocytic leukemia and underwent an axillary CNB that yielded the same diagnosis.

Discussion

The frequency of ipsilateral axillary adenopathy on breast MRI following COVID-19 vaccination was 29%. Adenopathy was detected on MRI up to 62 days after the second dose of the vaccine. Younger patients were more prone to develop adenopathy. The type of vaccine, laterality of administration, and number of doses received before the exam were not associated with adenopathy. The number of days after the second dose of the vaccine was found to be statistically significant; patients who recently received the second dose of the vaccine were more likely to demonstrate adenopathy. Adenopathy resolved or decreased on follow-up in the majority of cases, but some patients demonstrated persistent adenopathy up to 64 days after the second dose of the vaccine. Metastatic adenopathy was only detected in patients with known ipsilateral breast cancer and in one patient with chronic lymphocytic leukemia.

The presence of ipsilateral axillary adenopathy on breast MRI after recent COVID-19 mRNA vaccination is very frequent, as observed in this study. On MRI, it was detected in the first week after the first dose of the vaccine and up to more than 8 weeks after the second dose. The frequency was found to be higher than on previous reports that noted the presence of clinically-evident adenopathy in 0.3% of patients who received the Pfizer-BioNTec vaccine and in up to 16% of patients who received the Moderna vaccine, in comparison with the 29% frequency observed in our study [11, 12, 14, 15]. This higher frequency may be because breast MRI allows for the detection of adenopathy that is not clinically apparent to the patient or physician on examination. On the other hand, our findings were less frequent than in a previous report on PET/CT by Cohen et al that identified hypermetabolic adenopathy in 46% of patients after the Pfizer-BioNTec vaccine [25]. Given the high proportion of patients who developed abnormal lymph nodes in our study, the finding of ipsilateral axillary adenopathy on breast MRI after recent COVID-19 mRNA vaccination should be considered probably benign in patients with negative breast imaging studies and with low suspicion for cancer recurrence. This result favors the recommendation for follow-up instead of an interventional procedure for these patients.

Younger patients were more likely to develop adenopathy than older patients. A previous report by the US Centers for Disease Control and Prevention (CDC) had also identified that young adult patients who received the Moderna vaccine were more prone to develop adenopathy [12]. In a study by Eifer et al on PET-CT after COVID-19 vaccination, age was also found to be inversely associated with increased rates of fluorodeoxyglucose (18F) uptake in ipsilateral axillary lymph nodes, corroborating our findings [26].

A slightly larger proportion of patients who received the Moderna vaccine (34%) developed ipsilateral axillary adenopathy than patients who received the Pfizer-BioNTec vaccine (25%), but this difference was not statistically significant in our study. The number of doses received prior to the MRI exam was also not statistically significantly different between patients with and without adenopathy. The number of days after the second vaccine dose was significantly inversely associated with adenopathy while the number of days after the first dose was not. Since patients usually receive a second dose of the vaccine within 3 to 5 weeks after the first dose, these findings suggest that most patients who develop adenopathy after the first dose will sustain this finding until the date of the second dose. This is in contrast with previous reports that mentioned the resolution of clinically evident adenopathy in most cases in 10 days or less [11, 12]. On the

Table 4 Status of axillary adenopathy on imaging follow-up

Status of adenopathy	Number of patients	Range (days)
Persistent	8	29–64
Decreased	15	28–104
Resolved	57	31–130

other hand, time after the second dose was, as expected, inversely associated with the presence of adenopathy, with a median of 14 days after the vaccine in patients with adenopathy in comparison with 20 days in patients without adenopathy.

For most patients who demonstrate vaccine-related adenopathy on breast MRI, this finding decreased or resolved on imaging follow-up within 4–8 weeks after the second dose of the vaccine, proving benignity. Yet, a significant portion (11%) of patients still demonstrated persistent adenopathy during this period. Given the frequency of persistent adenopathy 4–8 weeks after the second dose of the vaccine, follow-up periods that are equal to or greater than 8 weeks may be preferable to shorter follow-ups, in contrast with previous recommendations [16, 18–24]. Furthermore, in patients with persistent adenopathy 4–8 weeks after the second dose of the vaccine, an additional follow-up in 4 or more weeks may be preferable to an interventional procedure. This is in agreement with the European Society of Breast Imaging that recommended follow-up at least 12 weeks after COVID-19 vaccination when clinically indicated [27]. Future studies will clarify when an interventional procedure should be performed in patients without a suspicious breast lesion but with persistent adenopathy, as this can represent recurrence from a treated breast cancer, occult primary breast cancer, lymphoproliferative disorders, or metastatic disease from other solid tumors [28].

In our study sample, metastatic carcinomatous adenopathy was detected in only patients with current ipsilateral breast cancer. In patients with known ipsilateral cancer, adenopathy after the COVID-19 vaccination may represent malignant infiltration and biopsy should be recommended. Sampling is usually performed during surgery with SLNB but may be performed preoperatively in selected cases if clinically indicated. COVID-19 vaccination should not change the standard management of the axilla in patients with breast cancer as follow-up is not adequate for this population, in agreement with the European Society of Breast Imaging recommendations [27].

Our study is not devoid of limitations. First, we included only patients who received the vaccine in the first few months of the vaccination campaign. It is expected that in future studies, the frequency of adenopathy will decrease in populations who receive the second dose of the vaccine longer before an imaging exam. Second, only one patient in our population received the Janssen vaccine; thus, no conclusions could be made regarding this type of vaccine. Third, MRI images were not reviewed and the presence of adenopathy was based solely on the report. Lastly, follow-up was not standardized, with patients having a follow-up exam at different time points while a few were not followed at all.

In conclusion, ipsilateral axillary adenopathy after COVID-19 mRNA-based vaccination is a frequent event that was observed in 29% of patients after either the first or second dose. Younger patients are more prone to develop adenopathy while its frequency reduces as time goes by after the second dose of the vaccine. Adenopathy may often persist 4–8 weeks after the second dose of the vaccine, thus favoring follow-up periods that are equal to or greater than 8 weeks. Short-term follow-up is an appropriate clinical approach in most cases, except in patients with current ipsilateral breast cancer for which standard management of the axilla is still recommended.

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Declarations

Guarantor The scientific guarantor of this publication is Joao V. Horvat, MD.

Conflict of interest The authors of this manuscript declare relationships with the following companies: Dr. Kimberly N Feigin is a paid clinical advisor to Covera Health, Inc. The company had no participation in this study.

Statistics and biometry One of the authors (Varadan Sevilimedu) has significant statistical expertise.

Informed consent Written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Methodology
- retrospective
- observational
- performed at one institution

References

1. Domingo P, Mur I, Pomar V, Corominas H, Casademont J, de Benito N (2020) The four horsemen of a viral Apocalypse: the pathogenesis of SARS-CoV-2 infection (COVID-19). EBioMedicine 58:102887
2. Singh JA, Upshur REG (2021) The granting of emergency use designation to COVID-19 candidate vaccines: implications for COVID-19 vaccine trials. Lancet Infect Dis 21:e103–e109
3. Menni C, Klaser K, May A et al (2021) Vaccine side-effects and SARS-CoV-2 infection after vaccination in users of the COVID Symptom Study app in the UK: a prospective observational study. Lancet Infect Dis 21:939–949
4. Pfizer-BioNTech COVID-19 Vaccine. United States Food and Drug Administration. Available via https://www.fda.gov/emergency-preparedness-and-response/coronavirus-disease-2019-covid-19/pfizer-biontech-covid-19-vaccine. Accessed 21 June 2021

5. Moderna COVID-19 Vaccine. United States Food and Drug Administration. Available via https://www.fda.gov/emergency-preparedness-and-response/coronavirus-disease-2019-covid-19/moderna-covid-19-vaccine. Accessed 21 June 2021
6. Janssen COVID-19 Vaccine. United States Food and Drug Administration. Available via https://www.fda.gov/emergency-preparedness-and-response/coronavirus-disease-2019-covid-19/janssen-covid-19-vaccine. Accessed 21 June 2021
7. Agency EM COVID-19 Vaccines. Available via https://www.ema.europa.eu/en/human-regulatory/overview/public-health-threats/coronavirus-disease-covid-19/treatments-vaccines/covid-19-vaccines. Accessed 16 Jan 2022
8. Creech CB, Walker SC, Samuels RJ (2021) SARS-CoV-2 Vaccines. JAMA 325:1318–1320
9. Giuliano AE, Ballman KV, McCall L et al (2017) Effect of axillary dissection vs no axillary dissection on 10-year overall survival among women with invasive breast cancer and sentinel node metastasis: the ACOSOG Z0011 (Alliance) Randomized Clinical Trial. JAMA 318:918–926
10. Mamounas EP, Kuehn T, Rutgers EJT, von Minckwitz G (2017) Current approach of the axilla in patients with early-stage breast cancer. Lancet. https://doi.org/10.1016/S0140-6736(17)31451-4
11. Local reactions, systemic reactions, adverse events, and serious adverse events: Pfizer-BioNTech COVID-19 Vaccine. Centers for Disease Control and Prevention. Available via https://www.cdc.gov/vaccines/covid-19/info-by-product/pfizer/reactogenicity.html. Accessed 21 June 2021
12. Local reactions, systemic reactions, adverse events, and serious adverse events: Moderna COVID-19 Vaccine. Centers for Disease Control and Prevention. Available via https://www.cdc.gov/vaccines/covid-19/info-by-product/moderna/reactogenicity.html. Accessed 21 June 2021
13. Lehman CD, Lamb LR, D'Alessandro HA (2021) Mitigating the impact of coronavirus disease (COVID-19) vaccinations on patients undergoing breast imaging examinations: a pragmatic approach. AJR Am J Roentgenol. https://doi.org/10.2214/AJR.21.25688
14. Baden LR, El Sahly HM, Essink B et al (2021) Efficacy and safety of the mRNA-1273 SARS-CoV-2 vaccine. N Engl J Med 384:403–416
15. Polack FP, Thomas SJ, Kitchin N et al (2020) Safety and efficacy of the BNT162b2 mRNA Covid-19 vaccine. N Engl J Med 383:2603–2615
16. Becker AS, Perez-Johnston R, Chikarmane SA et al (2021) Multidisciplinary recommendations regarding post-vaccine adenopathy and radiologic imaging: Radiology Scientific Expert Panel. Radiology. https://doi.org/10.1148/radiol.2021210436:210436
17. Ozutemiz C, Krystosek LA, Church AL et al (2021) Lymphadenopathy in COVID-19 vaccine recipients: diagnostic dilemma in oncologic patients. Radiology 300:E296–E300
18. Seely JM, Barry MH (2021) The Canadian Society of Breast Imaging/ Canadian Association of Radiologists' Recommendations for the Management of Axillary Adenopathy in Patients With Recent COVID-19 Vaccination. Can Assoc Radiol J. https://doi.org/10.1177/0846537121998949:846537121998949
19. Grimm L, Destounis S, Dogan B et al SBI recommendations for the management of axillary adenopathy in patients with recent COVID-19 vaccination. Society of Breast Imaging. Available via https://www.sbi-online.org/Portals/0/Position%20Statements/2021/SBI-recommendations-for-managing-axillary-adenopathy-post-COVID-vaccination.pdf. Accessed 21 June 2021
20. Mortazavi S (2021) Coronavirus Disease (COVID-19) Vaccination associated axillary adenopathy: imaging findings and follow-up recommendations in 23 women. AJR Am J Roentgenol. https://doi.org/10.2214/AJR.21.25651
21. Edmonds CE, Zuckerman SP, Conant EF (2021) Management of unilateral axillary lymphadenopathy detected on breast MRI in the era of coronavirus disease (COVID-19) vaccination. AJR Am J Roentgenol. https://doi.org/10.2214/AJR.21.25604
22. Lehman CD, D'Alessandro HA, Mendoza DP, Succi MD, Kambadakone A, Lamb LR (2021) Unilateral lymphadenopathy after COVID-19 vaccination: a practical management plan for radiologists across specialties. J Am Coll Radiol 18:843–852
23. Brown A, Shah S, Dluzewski S et al (2021) Unilateral axillary adenopathy following COVID-19 vaccination: a multimodality pictorial illustration and review of current guidelines. Clin Radiol. https://doi.org/10.1016/j.crad.2021.04.010
24. Mehta N, Sales RM, Babagbemi K et al (2021) Unilateral axillary adenopathy in the setting of COVID-19 vaccine. Clin Imaging 75:12–15
25. Cohen D, Krauthammer SH, Wolf I, Even-Sapir E (2021) Hypermetabolic lymphadenopathy following administration of BNT162b2 mRNA Covid-19 vaccine: incidence assessed by [(18)F]FDG PET-CT and relevance to study interpretation. Eur J Nucl Med Mol Imaging 48:1854–1863
26. Eifer M, Tau N, Alhoubani Y et al (2021) Covid-19 mRNA vaccination: age and immune status and its association with axillary lymph node PET/CT uptake. J Nucl Med. https://doi.org/10.2967/jnumed.121.262194
27. Schiaffino S, Pinker K, Magni V et al (2021) Axillary lymphadenopathy at the time of COVID-19 vaccination: ten recommendations from the European Society of Breast Imaging (EUSOBI). Insights Imaging 12:119
28. McCartan DP, Zabor EC, Morrow M, Van Zee KJ, El-Tamer MB (2017) Oncologic outcomes after treatment for MRI occult breast cancer (pT0N+). Ann Surg Oncol 24:3141–3147