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Table 1: Rigor Adherence Table

Ethics
IRB: The CORSIP study received approvals from the University of British Columbia (H20-03620) and the University of Toronto Health Research Ethics Boards (40435).
Consent: The paramedics provided written consent upon enrolment through an internet-based portal.
Inclusion and Exclusion Criteria
Participants who had received any non-mRNA vaccines were excluded.
Attrition
not detected.
Sex as a biological variable
not detected.
Subject Demographics
Age: not detected.
Weight: not detected.
Randomization
not detected.
Blinding
not detected.
Power Analysis
not detected.
Replication
not required.

Table 2: Key Resources Table

Your Sentences	REAGENT or RESOURCE	SOURCE	IDENTIFIER
Antibodies			
SARS-CoV-2 infection was defined as: (1) a participant-reported positive SARS-CoV-2 nucleic acid amplification test (NAAT) or rapid antigen test (RAT) result; or (2) the presence of anti-nucleocapsid antibodies in the blood sample (Roche, IND, USA).	anti-nucleocapsid		
Serological testing We tested all blood samples with: (1) the V-PLEX SARS-CoV-2 Panel 28 ACE2 Kit (Meso Scale Discovery, MD, USA) to measure percent inhibition of angiotensin-converting enzyme 2 (ACE-2) binding to spike protein of Omicron (B.1.617.2) BA.4/BA.5 sub-lineages; and, (2) the Elecsys Anti-SARS-CoV-2 Nucleocapsid assay [Roche IND, USA] to identify the presence of anti-nucleocapsid protein antibodies, indicative of preceding SARS-CoV-2 infection.	ACE2		
	Anti-SARS-CoV-2		
	anti-nucleocapsid protein		
Software and Algorithms			
We used GraphPad Prism version 9.5.0 (GraphPad Software, San Diego, CA) and SAS version 9.4 for data analyses.	GraphPad Prism		Suggestion: (GraphPad Prism, RRID:SCR_002798)(link)
	GraphPad		Suggestion: (GraphPad Prism, RRID:SCR_002798)(link)

Other Entities Detected

Your Sentences	Recognized Entity
Statistical Tests	
We diagramed ACE-2 inhibition to BA.4/5 for the paired comparisons using scatter plots and used the Wilcoxon matched-pairs signed rank test to test the differences between the median ACE-2 inhibitions to BA.4/5 of the groups.	Wilcoxon matched-pairs signed rank test
In addition, we used the Bonferroni correction test to adjust p-values obtained from the Wilcoxon matched-pairs signed rank test in order to account for multiple comparisons of outcomes.	Bonferroni

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The MDAR framework establishes a minimum set of requirements in transparent reporting applicable to studies in the life sciences (see Statement of Task: doi:10.31222/osf.oio/9sm4x.). The MDAR checklist is a tool for authors, editors and others seeking to adopt the MDAR framework for transparent reporting in manuscripts and other outputs. Please refer to the MDAR Elaboration Document for additional context for the MDAR framework.

Materials

Antibodies	Yes (indicate where provided: page no/section/legend)	n/a
For commercial reagents, provide supplier name, catalogue number and RRID, if available	Yes, 4 antibodies detected, 0 RRID provided : anti-nucleocapsid : ACE2 : Anti-SARS-CoV-2 : anti-nucleocapsid protein Please add identifiers for all resources where possible	

Cell Materials	Yes (indicate where provided: page no/section/legend)	n/a
Cell lines: Provide species information, strain. Provide accession number in repository OR supplier name, catalog number, clone number, OR RRID	No cell lines detected Please add identifiers for all resources where possible	
Primary cultures: Provide species, strain, sex of origin, genetic modification status.	Not currently checked by SciScore	

Experimental Animals	Yes (indicate where provided: page no/section/legend)	n/a
Laboratory animals: Provide species, strain, sex, age, genetic modification status. Provide accession number in repository OR supplier name, catalog number, clone number, OR RRID	No organisms detected Please add identifiers for all resources where possible	
Animal observed in or captured from the field: Provide species, sex and age where possible	Not currently checked by SciScore	
Model organisms: Provide Accession number in repository (where relevant) OR RRID	See laboratory animals section for information.	

Plants and microbes	Yes (indicate where provided: page no/section/legend)	n/a
Plants: provide species and strain, unique accession number if available, and source (including location for collected wild specimens)	Not currently checked by SciScore	
Microbes: provide species and strain, unique accession number if available, and source	Not currently checked by SciScore	

Human research participants	Yes (indicate where provided: page no/section/legend)	n/a
Identify authority granting ethics approval (IRB or equivalent committee(s), provide reference number for approval.	The CORSIP study received approvals from the University of British Columbia (H20-03620) and the University of Toronto Health Research Ethics Boards (40435).	
Provide statement confirming informed consent obtained from study participants.	The paramedics provided written consent upon enrolment through an internet-based portal.	
Report on age and sex for all study participants.	**Age:**not detected. **Sex:**not detected.	

Design

Study protocol	Yes (indicate where provided: page no/section/legend)	n/a
For clinical trials, provide the trial registration number OR cite DOI in manuscript.	Not detected.	

Laboratory protocol	Yes (indicate where provided: page no/section/legend)	n/a
Provide DOI or other citation details if detailed step-by-step protocols are available.	Not detected.	

Experimental study design (statistics details)	Yes (indicate where provided: page no/section/legend)	n/a
State whether and how the following have been done, or if they were not carried out		
Sample size determination	not detected.	
Randomization	not detected.	
Blinding	not detected.	
inclusion/exclusion criteria	Participants who had received any non-mRNA vaccines were excluded.	

Sample definition and in-laboratory replication	Yes (indicate where provided: page no/section/legend)	n/a
State number of times the experiment was replicated in laboratory	Not detected.	
Define whether data describe technical or biological replicates	Not detected.	

Ethics	Yes (indicate where provided: page no/section/legend)	n/a
Studies involving human participants: State details of authority granting ethics approval (IRB or equivalent committee(s), provide reference number for approval.	The CORSIP study received approvals from the University of British Columbia (H20-03620) and the University of Toronto Health Research Ethics Boards (40435).	
Studies involving experimental animals: State details of authority granting ethics approval (IRB or equivalent committee(s), provide reference number for approval.	Not detected.	
Studies involving specimen and field samples: State if relevant permits obtained, provide details of authority approving study; if none were required, explain why.	Not detected.	

Dual Use Research of Concern (DURC)	Yes (indicate where provided: page no/section/legend)	n/a
If study is subject to dual use research of concern, state the authority granting approval and reference number for the regulatory approval	Not currently checked by SciScore	

Analysis

Attrition	Yes (indicate where provided: page no/section/legend)	n/a
State if sample or data point from the analysis is excluded, and whether the criteria for exclusion were determined and specified in advance.	not detected.	

Statistics	Yes (indicate where provided: page no/section/legend)	n/a
Describe statistical tests used and justify choice of tests.	We diagramed ACE-2 inhibition to BA.4/5 for the paired comparisons using scatter plots and used the Wilcoxon matched-pairs signed rank test to test the differences between the median ACE-2 inhibitions to BA.4/5 of the groups.	

Data availability	Yes (indicate where provided: page no/section/legend)	n/a
State whether newly created datasets are available, including protocols for access or restriction on access.	Not detected.	
If data are publicly available, provide accession number in repository or DOI or URL.	Not detected.	
If publicly available data are reused, provide accession number in repository or DOI or URL, where possible.	Not detected.	

Code availability	Yes (indicate where provided: page no/section/legend)	n/a
For all newly generated code and software essential for replicating the main findings of the study:		
State whether the code or software is available.	Not detected.	
If code is publicly available, provide accession number in repository, or DOI or URL.	Not detected.	

Analysis

Adherence to community standards	Yes (indicate where provided: page no/section/legend)	n/a
MDAR framework recommends adoption of discipline-specific guidelines, established and endorsed through community initiatives. Journals have their own policy about requiring specific guidelines and recommendations to complement MDAR.		
State if relevant guidelines (eg., ICMJE, MIBBI, ARRIVE) have been followed, and whether a checklist (eg., CONSORT, PRISMA, ARRIVE) is provided with the manuscript.	Not currently checked by SciScore	

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By Michael Asamoah-Boaheng

WORD COUNT	5040	TIME SUBMITTED	26-JAN-2024 10:22AM
		PAPER ID	106442592

Access Microbiology

Immunogenicity of bivalent versus monovalent mRNA booster vaccination among adult paramedics in Canada who had received three prior mRNA wild-type doses

--Manuscript Draft--

Immunogenicity of bivalent versus monovalent mRNA booster vaccination among adult paramedics in Canada who had received three prior mRNA wild-type doses

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Abstract

Introduction: Comparative immunogenicity from different mRNA booster vaccines (directed at wild-type [WT], BA.1, or BA.4/5 antigens) remains unclear.

Methods: We included blood samples from adult paramedics who received three mRNA WT-directed vaccines plus a fourth dose of: (1) WT monovalent; (2) Moderna BA.1-WT bivalent; or (3) Pfizer BA.4/5-WT bivalent vaccine. The primary outcome was angiotensin-converting enzyme 2 (ACE-2) inhibition to BA.4/5 antigen. We used optimal pair matching (using age, sex-at-birth, preceding SARS-CoV-2 infection, and fourth vaccine-to-blood collection interval) to create balanced groups to individually compare each vaccine type to each other vaccine (overall, within subgroups defined by SARS-CoV-2 infection, and after combining BA.1 and BA.4/5 cases). We compared outcomes with Wilcoxon matched pairs signed rank test.

Results: Overall, 158 paramedics (mean age 45 years) were included. ACE-2 inhibition was higher for BA.1 compared to WT (p=0.002); however, no difference was detected between BA.4/5 vs. WT, or BA.1 vs BA.4/5. Among cases with preceding SARS-CoV-2, there were no between-group differences. Among cases without preceding SARS-CoV-2, the only difference was BA.1 > WT (p=0.003). BA.1 and BA.4/5 cases combined had higher ACE2 inhibition than WT (p = 0.003).

Conclusion: Omicron-directed vaccines appear to improve Omicron-specific immunogenicity; however, this appears limited to SARS-CoV-2-naïve individuals.

Keywords: mRNA COVID-19 vaccines; Bivalent mRNA vaccines; SARS-CoV-2 Omicron infection; BA.4/5 Omicron subvariant; immunogenicity.

Word count (abstract): **200**

Word count (main): **1933**

Introduction

The emergence of SARS-CoV-2 variants, including the Omicron sublineages, has led to questions regarding optimal ongoing vaccination strategies. Recent studies have documented reduced vaccine effectiveness of two-dose mRNA vaccination (including original Wuhan Hu 1 platform mRNA-1273 and BNT162b2) against Omicron BA.1 infection, compared with earlier variants;[1] immunogenicity appears to improve after a third dose but subsequently wanes quickly thereafter[1–6]. While vaccination with three to four of the original mRNA vaccines remains highly effective against hospitalization for all variants, effectiveness 14-30 days post fourth dose against COVID-19 is only moderate for the BA.2, BA.2.12.1, and BA.4 strains, but low against BA.5, with benefit appearing to disappear after 90 days.[3]

To align vaccines with the current SARS-CoV-2 variants, vaccines directed at Omicron strains were developed[7,8]. The approved bivalent mRNA booster formulations contain both the Wuhan Hu-1 (wild-type) SARS-CoV-2 and Omicron (B.1.1.529) variant spike sequences. However, few studies have compared the effectiveness of bivalent booster doses against the wild-type mRNA monovalent vaccines. Further, the comparative immunogenicity conveyed from different mRNA booster vaccines (specifically wild-type vaccine vs. Moderna BA.1 vs. Pfizer BA4/5) among previously vaccinated individuals with or without preceding SARS-CoV-2 infection remains unclear.

For these reasons, we sought to compare the immunogenicity between those who received wild-type (WT), BA.1, or BA.4/5 booster vaccines among adult paramedics in Canada who had previously received three wild-type mRNA vaccines.

Methods

Study design and data source

We used blood sample test results and questionnaire data from adult paramedics participating in the COVID-19 Occupational Risk, Seroprevalence, and Immunity among Paramedics in Canada (CORSIP) study. CORSIP is an observational cohort study that recruited adult paramedics to investigate COVID-19 occupational risk and SARS-CoV-2 seroprevalence among paramedics in Canada. Recruitment of participants started on January 21, 2021 and ended on February 11, 2023. The CORSIP study received approvals from the University of British Columbia (H20-03620) and the University of Toronto Health Research Ethics Boards (40435). The paramedics provided written consent upon enrolment through an internet-based portal. The study included paramedics from five provinces in western and central Canada, including Alberta (AB), British Columbia (BC), Manitoba (MB), Ontario (ON), and Saskatchewan (SK). Participants provided questionnaire responses regarding demographic characteristics (age, sex at birth, race/ethnicity), SARS-CoV-2 infections and symptoms, vaccination history (including dates and

93 vaccination types), and medical history through an online portal, in addition to providing
94 longitudinal blood samples every six months for serological testing [9].

95

96 **Study population**

97 CORSIP participants were included in these analyses if they had received four mRNA vaccine
98 doses prior to providing a blood sample, with the first three doses being a wild-type (WT) based
99 mRNA vaccine, and the fourth dose being either: (1) a Moderna BA.1 bivalent vaccine, directed
100 at BA.1 and WT strains (hereafter referred to as "BA.1 vaccine"); (2) a Pfizer BA.4/5 bivalent
101 vaccine, directed at BA.4/5 and WT strains (hereafter referred to as "BA.4/5 vaccine"); or, (3) a
102 WT mRNA monovalent vaccine, directed only at the WT strain (hereafter referred to as "WT
103 vaccine"). Participants who had received any non-mRNA vaccines were excluded. The study
104 cohort included both those who had, and had not, previously been infected with SARS-CoV-2.
105 SARS-CoV-2 infection was defined as: (1) a participant-reported positive SARS-CoV-2 nucleic
106 acid amplification test (NAAT) or rapid antigen test (RAT) result; or (2) the presence of anti-
107 nucleocapsid antibodies in the blood sample (Roche, IND, USA).

108 Given that we aimed to investigate the impact of the fourth vaccine (after three WT-based
109 monovalent mRNA vaccines), we categorized cases based on the type of fourth vaccine: BA.1
110 vaccine, BA.4/5 vaccine, or WT vaccine. We chose samples (as described below) from eligible
111 participants to create matched groups for three separate comparisons to compare each vaccine
112 type to each other vaccine type.

Serological testing

We tested all blood samples with: (1) the V-PLEX SARS-CoV-2 Panel 28 ACE2 Kit (Meso Scale Discovery, MD, USA) to measure percent inhibition of angiotensin-converting enzyme 2 (ACE-2) binding to spike protein of Omicron (B.1.617.2) BA.4/BA.5 sub-lineages; and, (2) the Elecsys Anti-SARS-CoV-2 Nucleocapsid assay [Roche IND, USA] to identify the presence of anti-nucleocapsid protein antibodies, indicative of preceding SARS-CoV-2 infection. This Elecsys assay has previously been shown to have high sensitivity for detecting preceding SARS-CoV-2 infections[10].

Outcome variable

The primary outcome was ACE-2 percent (%) inhibition to the BA.4/5 Omicron antigen.

Statistical analysis

We described continuous variables with mean (and standard deviation [SD]) or median (with interquartile range [IQR]) and represented categorical variables with counts (with percentages). We used GraphPad Prism version 9.5.0 (GraphPad Software, San Diego, CA) and SAS version 9.4 for data analyses.

We performed a 1:1 matching to select the multiple pairs from the three vaccine types using the optimal pair matching method[11,12]. For the first main comparison, comparing BA.1 vaccine vs. WT vaccine, we used the optimal pair matching method to create two balanced groups for comparison, matching based on participant age, sex at birth, preceding SARS-CoV-2 infection,

and the number of days from fourth dose to blood collection. We repeated this process for the second main comparison of BA.1 vaccine vs. BA.4/5 vaccine, and again for the third main comparison of BA.4/5 vaccine vs. WT vaccine.

In addition, we performed several sensitivity analyses. First, we repeated the comparisons but only included samples from participants who had evidence of preceding SARS-CoV-2 infections. Second, we repeated the comparisons including only samples from participants who did not have preceding SARS-CoV-2 infections. Third, we combined all the BA.4/5 and BA.1 vaccine cases, and compared them to the WT vaccine cases (overall and within subgroups dichotomized by preceding SARS-CoV-2 infection).

We diagramed ACE-2 inhibition to BA.4/5 for the paired comparisons using scatter plots and used the Wilcoxon matched-pairs signed rank test to test the differences between the median ACE-2 inhibitions to BA.4/5 of the groups. Further, we used the Related-Samples Hodges Lehman test to estimate the confidence interval of the differences in medians. In addition, we used the Bonferroni correction test to adjust p-values obtained from the Wilcoxon matched-pairs signed rank test in order to account for multiple comparisons of outcomes.

Results

Overall, the study included a total of 158 paramedics, with a mean participant age of 45 years. Characteristics of participants included in the three different comparisons are shown in Table 1

and in supplementary Tables 1 and 2. Comparison group characteristics, and the interval between the fourth vaccine to blood collection, were similar.

Figure 1A shows the results of the main comparisons, including all samples (from both individuals with and without preceding SARS-CoV-2 infections). We observed a significantly higher percent inhibition to BA.4/5 among participants who received a fourth BA.1 vaccine, compared to those who received a fourth WT vaccine (median difference [Mdn]: 9.0, 95 % Confidence Interval (CI): 3.8, 14.4, p^* = 0.006; Figure 1A [left]). We did not detect a difference in the second main comparison, between the BA.4/5 vaccine vs. WT vaccine (Mdn: 7.1, 95% CI: -0.52, 13.7, p^* = 0.186; Figure 1A [middle]), nor in the third main comparison, between the BA.1 vaccine vs. BA.4/5 vaccine (Mdn=0.56, 95% CI: -3.0, 3.9, p^* = 0.999; Figure 1A [right]).

Figure 1B shows the results of the three comparisons when including only samples from individuals with preceding SARS-CoV-2 infections. We did not observe a difference in percent inhibitions for any comparison.

Figure 1C shows the results of the three comparisons when including only samples from individuals without preceding SARS-CoV-2 infections. We observed a significantly higher percent inhibition for the BA.1 vaccine, when compared to the WT vaccine, however, we did not detect a difference in the other two comparisons.

In the fourth analysis, samples from individuals that received either BA.1 or BA.4/5 vaccines had higher levels of ACE-2 percent inhibition to BA.4/5, compared to those who received the WT vaccine (Mdn = 7.8, 95% CI: 1.5, 16, p^* = 0.009; Supplementary Figure 1A). This was consistent

when comparing samples from individuals who had not previously had a SARS-CoV-2 infection (Mdn = 17.7, 95% CI: 7.9, 26; Supplementary Figure 1C), however, a difference was not seen when comparing samples from individuals who had previously had SARS-CoV-2 infections (Mdn = 2.8, 95% CI: -1.2, 8.1; Supplementary Figure 1B).

Discussion

The results of this work provide insights into the humoral immune response to the Omicron BA.4/5 subvariant among individuals vaccinated with different types of mRNA COVID-19 boosters. A unique aspect of this study is that it occurred in the Canadian context, where both the Moderna BA.1 and Pfizer BA.4/5 vaccines were introduced, allowing for a comparison of the humoral response elicited by both of these vaccines against a more recent variant. Among individuals who had already received three prior wild-type monovalent mRNA vaccines, we were able to compare those who received an additional wild-type vaccine, a BA.1 bivalent vaccine, or a BA.4/5 bivalent vaccine for their fourth dose, and examined resultant immunogenicity against a BA.4/5 antigen. Overall, bivalent fourth vaccines demonstrated superior immunogenicity compared to the fourth wild-type vaccine among SARS-CoV-2-naiive individuals. Interestingly, our results did not suggest that the BA.4/5-directed vaccine was superior to those targeting BA.1. This suggests that both bivalent boosters may be equally effective in boosting humoral immunity against the Omicron BA.4/5 subvariant, which is in

keeping with recent vaccine effectiveness data from Denmark comparing these two bivalent booster vaccines[13].

We found that neither bivalent vaccine demonstrated an advantage over WT vaccine boosting in those with evidence of prior SARS-CoV-2 infection; however, the majority of those in our cohort had evidence of infection during the Omicron era, which may help explain this finding. Although we could not detect a difference between the BA.4/5 vaccine and the WT vaccine, this may have been due to a smaller sample size compared to the BA.1 vs. WT comparison. This could also be attributable to the fact that the timing of the fourth monovalent dose to the blood draw was shorter than that of the fourth dose of BA.4/5 booster to the blood draw, thereby reducing the expected differences in immunogenicity between the two boosters. Further, the higher dose of the Moderna BA.1 booster (50 mcg) compared to the Pfizer BA.4/5 booster (30 mcg) could also help explain these findings. These results are also consistent with previous evidence demonstrating that the higher-dosed mRNA-1273 vaccine resulted in superior serological markers at six months compared to those who received the BNT162b2 vaccine[14].

Overall, our results suggest that the Omicron-specific bivalent booster may be more effective in boosting humoral immunity against the Omicron BA.4/5 subvariant, than using all four WT monovalent vaccines. However, the effect appears to be limited to those who have never been infected with SARS-CoV-2. These findings have important implications for ongoing COVID-19 vaccination strategies, especially in jurisdictions where the Omicron variant is prevalent. Further research is needed to confirm these results in other occupational groups and to

investigate the long-term effectiveness of different COVID-19 booster vaccines in inducing and maintaining humoral immunity.

Limitations

Our study might have been subjected to some limitations. This study may not be generalizable to the entire population across all age groups since we included a relatively homogenous group of middle-aged adult paramedics whose immunity may differ from other groups. Other limitations include lack of randomization, use of self-reported data, and small sample size, which might have influenced the findings of some comparisons between bivalent and WT boosters.

Conclusion

Our study suggests that the Omicron-specific bivalent boosters may induce a higher humoral immune response against the Omicron BA.4/5 subvariant compared to the mRNA monovalent boosters. However, this finding appears limited to those without preceding SARS-CoV-2 infections.

Conflict of Interest: None declared.

Ethical statement

The study was approved by the University of British Columbia (Reference number: H20-03620), and University of Toronto (Reference number: 40435) research ethics boards. Participants provided electronic consent upon enrolment.

Funding

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Author contribution

Conceptualization: M.A-B, D.M.G, I.K, J.Y, T.K, M.E.K, P.D, J.M.C, B.G. *Data curation*: M.A-B, B.G, D.M, G. *Formal analysis*: M.A-B, D.M.G, I.K, J.Y, T.K, M.E.K, P.D, J.M.C, B.G. *Funding acquisition*: M.A-B, D.M.G, I.K, J.Y, T.K, M.E.K, P.D, J.M.C, B.G. *Investigation*: M.A-B, D.M.G, I.K, J.Y, T.K, M.E.K, P.D, J.M.C, B.G. Methodology: M.A-B, B.G, D.M. G. *Project administration*: B.G, D.G, T.K, PD. *Resources*: B.G, D.G, T.K, PD. Software: M.A-B, D.M.G, I.K, J.Y, T.K, M.E.K, P.D, J.M.C, B.G. *Validation*: M.A-B, D.M.G, I.K, J.Y, T.K, M.E.K, P.D, J.M.C, B.G. *Visualization*: M.A-B, B.G, D.M. G. *Writing – original draft*: M.A-B, B.G, D.G. *Writing – review and editing*: all authors.

Data summary statement

The CORSIP data used for this study can be publicly assessed through the website of Canada COVID-19 Immunity Task Force (CITF) website via the link: https://portal.citf.mcgill.ca/.

Reference

1. Andrews N, Stowe J, Kirsebom F, et al. Covid-19 Vaccine Effectiveness against the Omicron (B.1.1.529) Variant. *N Engl J Med*. 2022;386(16):1532-1546. doi:10.1056/nejmoa2119451
2. Chemaitelly H, Ayoub HH, AlMukdad S, et al. Duration of mRNA vaccine protection against SARS-CoV-2 Omicron BA.1 and BA.2 subvariants in Qatar. *Nat Commun*. 2022;13(1):1-12. doi:10.1038/s41467-022-30895-3
3. Tseng HF, Ackerson BK, Bruxvoort KJ, et al. Effectiveness of mRNA-1273 vaccination against SARS-CoV-2 omicron subvariants BA.1, BA.2, BA.2.12.1, BA.4, and BA.5. *Nat Commun*. 2023;14(1):1-10. doi:10.1038/s41467-023-35815-7
4. Ferdinands JM, Rao S, Dixon BE, et al. Waning 2-Dose and 3-Dose Effectiveness of mRNA Vaccines Against COVID-19–Associated Emergency Department and Urgent Care Encounters and Hospitalizations Among Adults During Periods of Delta and Omicron Variant Predominance — VISION Network, 10 States, Aug. *MMWR Recomm Reports*. 2022;71(7):255-263. doi:10.15585/mmwr.mm7107e2
5. Link-gelles R, Levy ME, Gaglani M, Irving SA, Stockwell M, et.al. Effectiveness of 2, 3, and 4 COVID-19 mRNA Vaccine Doses Among Immunocompetent Adults During Periods when SARS-CoV-2 Omicron BA.1 and BA.2/BA.2.12.1 Sublineages Predominated — VISION Network, 10 States, December 2021–June 2022. *MMWR Morb Mortal Wkly Rep*. 2022;71(29):931-939.
6. Tartof SY, Slezak J, Puzniak L, et al. Durability of BNT162b2 vaccine against hospital and emergency department admissions due to the omicron and delta variants in a large health system in the USA: a test- negative case–control study. *Lancet*. 2022;10:689-699. doi:https://doi.org/10.1016/ S2213-2600(22)00101-1
7. Offit PA. Bivalent Covid-19 Vaccines— A Cautionary Tale. *N Engl J Med*. 2023;388(6):481-483. doi:10.1056/NEJMp2215780
8. pfizer. Pfizer and BioNTech Announce Omicron-Adapted COVID-19 Vaccine Candidates Demonstrate High Immune Response Against Omicron. Saturday, June 25. Published 2022. Accessed May 16, 2023. https://www.pfizer.com/news/press-release/press-release-detail/pfizer-and-biontech-announce-omicron-adapted-covid-19
9. CORSIP Canada. COVID-19 Occupational Risk, Seroprevalence and Immunity among Paramedics in Canada. Published 2023. Accessed April 20, 2023.

https://omc.ohri.ca/CORSIP/pages/About.aspx
10. Grunau B, Tom J, Asamoah-Boaheng M, et al. Sensitivity of the Elecsys Nucleocapsid Assay for the Detection of Preceding SARS-CoV-2 Infections. *Open Forum Infect Dis*. 2022;9(8):1-4. doi:10.1093/ofid/ofac349
11. SAS. The PSMATCH Procedure. *SAS 142 Users Guid*. 2016;14.2:7676-7768. https://support.sas.com/documentation/onlinedoc/stat/142/psmatch.pdf
12. Greifer N. Matching Methods. Published 2023. Accessed June 20, 2023. https://cran.r-project.org/web/packages/MatchIt/vignettes/matching-methods.html#optimal-pair-matching-method-optimal
13. Worm Andersson N, Thiesson EM, Baum U, et al. Comparative effectiveness of the bivalent BA.4-5 and BA.1 mRNA-booster vaccines in the Nordic countries. *medRxiv*. Published online 2023:1-25. doi:https://doi.org/10.1101/2023.01.19.23284764
14. Grunau B, Prusinkiewicz M, Asamoah-Boaheng M, et al. Correlation of SARS-CoV-2 Viral Neutralizing Antibody Titers with Anti-Spike Antibodies and ACE-2 Inhibition among Vaccinated Individuals. *Microbiol Spectr*. 2022;10(5):1-9. doi:10.1128/spectrum.01315-22

Table 1: Participant characteristics stratified by matched pairs of vaccine doses (including those with or without preceding COVID 19).

Variables	Comparison 1*		Comparison 2*		Comparison 3*	
	Moderna BA.1	WT	Moderna BA.1	Pfizer BA.4/5	Pfizer BA.4/5	WT
	n = 61	n = 61	n = 34	n = 34	n = 34	n =34
Matched variables						
Age in years, Mean (SD)	45 (11)	45 (10)	45 (11)	43 (10)	43 (10)	44 (11)
Sex (at birth)						
Female	22 (36)	23 (38)	13 (38)	15 (44)	15 (44)	16 (47)
Male	39 (64)	38 (62)	21 (62)	19 (56)	19 (56)	18 (53)
COVID-19 diagnosis, total [n (%)]	37 (61)	32 (53)	22 (65)	24 (71)	24 (71)	21 (62)
Pre-Omicron infections**	2 (5)	2 (6)	2 (9)	2 (8)	2 (8)	2 (10)
Omicron Infections**	35 (95)	30 (94)	20 (91)	22 (92)	22 (92)	19 (90)
V4-to-BC (days), Median (IQR)	81 (48, 119)	72 (41, 123)	60 (43,79)	54 (42, 75)	54 (42, 75)	47 (37, 85)
Other variables						
Race/Ethnicity, n (%)						
Racialized	6 (10)	5 (8)	4 (12)	5 (15)	5 (15)	32 (94)
White	55 (90)	56 (92)	30 (88)	29 (85)	29 (85)	2 (6)
Tobacco use, n (%)	3 (5)	4 (7)	2 (6)	1 (3)	1 (3)	3 (9)
Influenza vaccination, n (%)	54 (89)	54 (89)	30 (88)	30 (88)	30 (88)	31 (91)
Medical history, n (%)						
Hypertension	5 (8)	6 (10)	4 (12)	5 (15)	5 (15)	5 (15)
Diabetes	2 (3)	5 (8)	2 (6)	-	1 (2.9)	-
Asthma	10 (16)	5 (8)	4 (12)	1 (3)	1 (2.9)	2 (6)
Chronic Lung Disease	-	-	-	1 (3)	1 (2.9)	1 (3)
Cancer	2 (3)	1 (2)	1 (3)	4 (12)	4 (12)	1 (3)

WT: Wild-type; SD: Standard deviation, IQR: Interquartile range; V4-to-BC: Days from vaccine 4 to the blood collection date;
*No significant differences between vaccine groups, within comparison, were observed for characteristics.
** Pre-Omicron infection was defined as SARS-CoV-2 infections that occur before November 26, 2021; and Omicron infections were defined as infections that occurred after December 26, 2021.

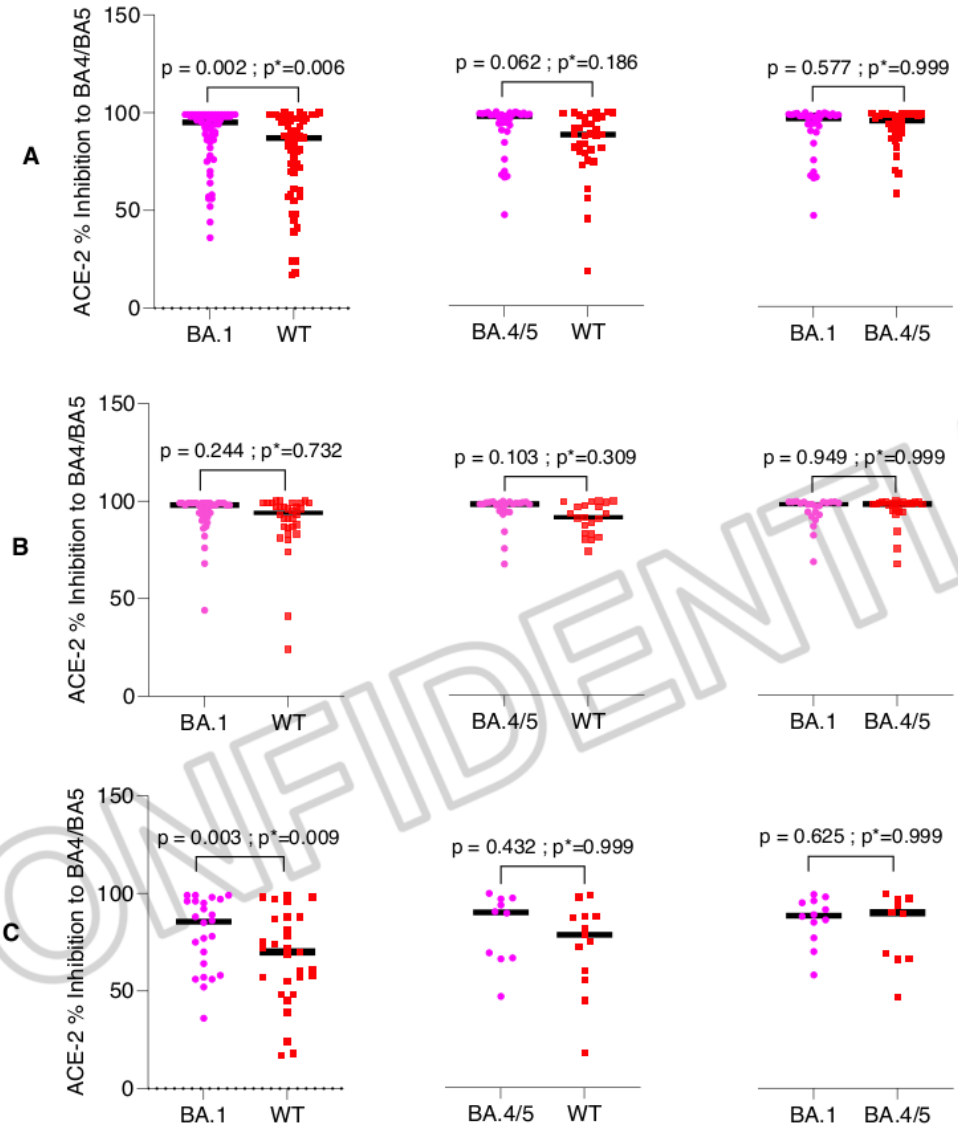


Figure 1: Comparing immunogenicity of bivalent vaccine doses with monovalent vaccine doses among all participants (**A**); among participants with previous SARS-CoV-2 infections (**B**); and among participants with no previous SARS-CoV-2 Infection (**C**).

The solid line denotes the median ACE-2 inhibitions. Outcomes were compared with the Wilcoxon matched pairs signed rank test, with the original p value (p) and Bonferroni corrected p-value (p*) as shown.

Supplementary Table 1: Participants characteristics among individuals without preceding COVID-19 diagnosis

Variables	Comparison 1*		Comparison 2*		Comparison 3*	
	Moderna BA. 1	WT	Moderna BA.1	Pfizer BA.4/5	Pfizer BA 4/5	WT
	n = 24	n = 29	n = 12	n = 10	n = 10	n =13
Matched variables						
Age, Mean (SD)	47 (11)	44 (9)	48 (10)	40 (8)	40 (8)	43 (10)
Sex (at birth)						
Female	9 (38)	9 (31)	5 (42)	4 (40)	4 (40)	6 (46)
Male	15 (62)	20 (69)	7 (58)	6 (60)	6 (60)	7 (54)
V4-to-BC (days)	77 (53, 118)	70 (41, 88)	67 (45, 78)	56 (51, 90)	56 (51, 90)	42 (36, 80)
Other variables						
Race/Ethnicity, n (%)						
Racialized	3 (12)	1 (3)	3 (25)	3 (30)	3 (30)	1 (8)
White	21 (88)	28 (97)	9 (75)	7 (70)	7 (70)	12 (92)
Tobacco use, n (%)	3 (13)	2 (7)	2 (17)	0 (0)	0 (0)	1 (8)
Influenza vaccination, n (%)	21 (88)	24 (83)	11 (92)	7 (70)	0 (0)	11 (85)
Medical history, n (%)						
Hypertension	1 (4.2)	1 (3)	0 (0)	0 (0)	0 (0)	0 (0)
Diabetes	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Asthma	6 (25)	4 (14)	2 (17)	0 (0)	0 (0)	1 (8)
Chronic Lung Disease	-	-	0 (0)	0 (0)	0 (0)	0 (0)
Cancer	1 (4)	1 (3)	0 (0)	2 (20)	2 (20)	1 (8)

WT: Wild type; SD: Standard deviation, IQR: Interquartile range; V4-to-BC: Days from vaccine 4 to the last blood collection date.

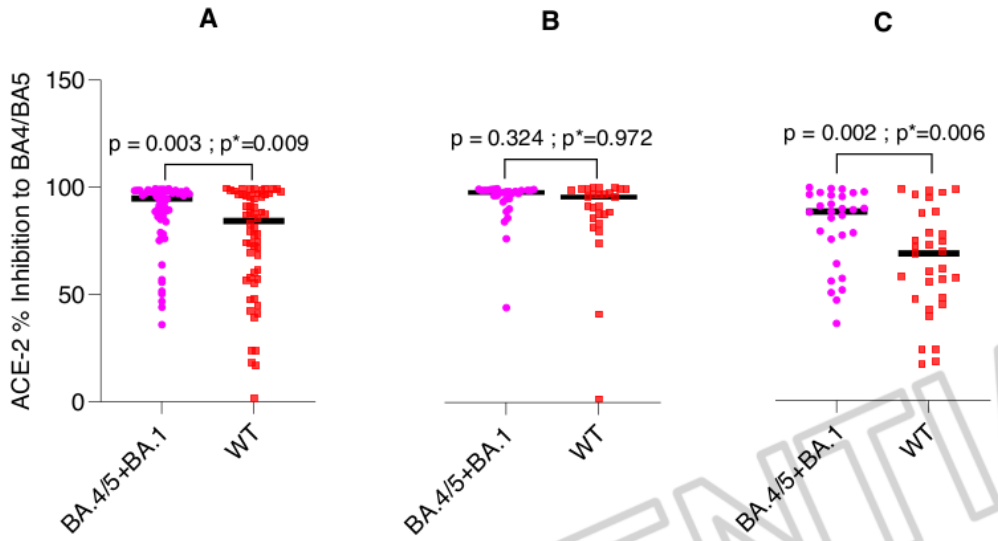
*No significant differences between vaccine groups, within comparison, was observed for characteristics.

Supplementary Table 2: Participants characteristics among individuals with preceding COVID-19 diagnosis

Variables	Comparison 1*		Comparison 2*		Comparison 3*	
	Moderna BA. 1	WT	Moderna BA.1	Pfizer BA.4/5	Pfizer BA 4/5	WT
	n = 37	n = 32	n = 22	n = 24	n = 24	n = 21
Matched variables						
Age, Mean (SD)	44 (10)	45 (11)	43 (11)	44 (11)	44 (11)	44 (12)
Sex (at birth)						
Female	13 (35)	14 (44)	8 (36)	11 (46)	11 (46)	10 (48)
Male	24 (65)	18 (56)	14 (64)	13 (54)	13 (54)	11 (52)
V4-to-BC (days)	83 (47, 120)	93 (41, 129)	53 (42, 82)	47 (41, 74)	43 (36, 51)	42 (36, 54)
Other variables						
Race/Ethnicity, n (%)						
Racialized	3 (8)	4 (12)	1 (4)	2 (8)	2 (8)	1 (5)
White	34 (92)	28 (88)	21 (96)	22 (92)	22 (92)	20 (95)
Tobacco use, n (%)	0 (0)	2 (6)	0 (0)	1 (4)	1 (4)	2 (10)
Influenza vaccination, n (%)	4 (11)	30 (94)	19 (86)	23 (96)	23 (96)	20 (95)
Medical history, n (%)						
Hypertension	4 (11)	5 (16)	4.0 (18)	5.0 (21)	5 (21)	4 (19)
Diabetes	2 (5)	0 (0.0)	2.0 (9)	0 (0)	0 (0)	0 (0)
Asthma	4 (11)	1 (3)	2 (9)	1 (4)	1 (4)	1 (5)
Chronic Lung Disease	0 (0)	0 (0)	0 (0)	1 (4)	1 (4)	1 (5)
Cancer	1 (3)	0 (0)	1 (5)	2 (8)	2 (8)	0 (0)

WT: Wild type; SD: Standard deviation, IQR: Interquartile range; V4-to-BC: Days from vaccine 4 to the last blood collection date

*No significant differences between vaccine groups, within comparison, was observed for characteristics.



Supplementary Figure 1: Comparing immunogenicity of the combined bivalent booster with the fourth dose monovalent vaccine booster.

A: The plot compares the fourth dose of combined bivalent booster (including BA.1 or BA.4/5) versus the fourth dose of monovalent booster among paramedics with or without preceding SARS-CoV-2 infections.

B: The plot compares the fourth dose of combined bivalent booster (including BA.1 or BA.4/5) versus the fourth dose of monovalent booster among paramedics with preceding SARS-CoV-2 infections.

C: The plot compares the fourth dose of combined bivalent boosters (including BA.1 or BA.4/5) versus the fourth dose of monovalent booster among paramedics without preceding SARS-CoV-2 infections.

The solid line denotes the median ACE-2 inhibitions. Outcomes were compared with the Wilcoxon matched pairs signed rank test, with the original p value (p) and Bonferroni corrected p-value (p*) as shown.

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