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## Limited Protection of Inactivated SARS-CoV-2 Vaccine against Wild-Type Strain and Variants of Concern

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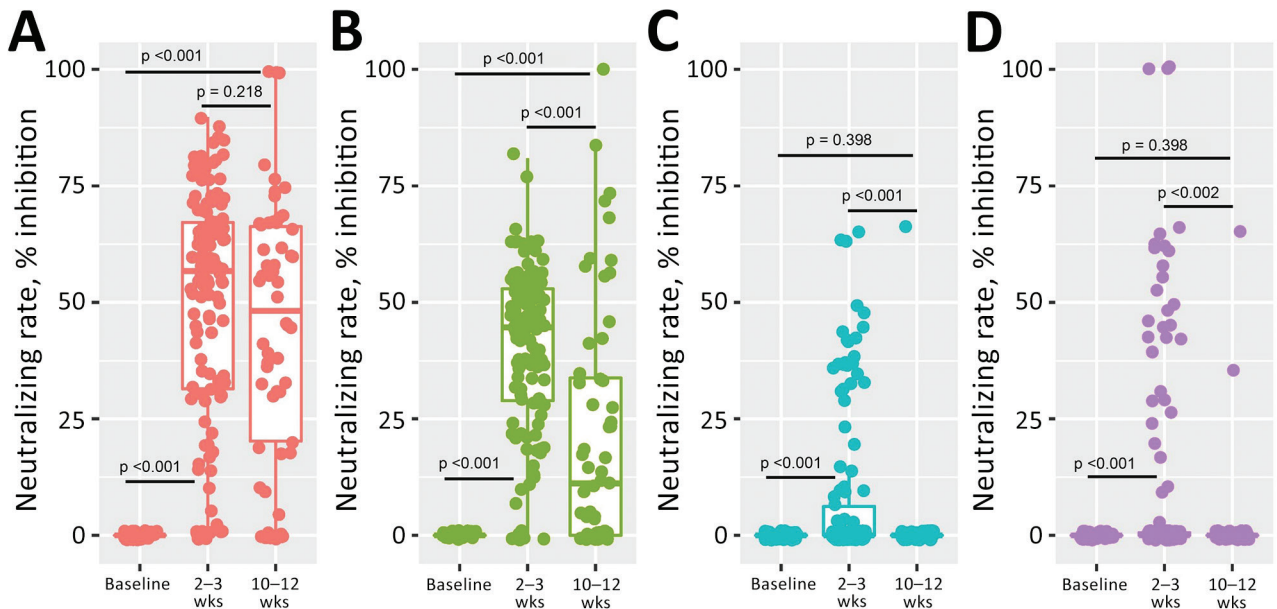
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In vitro determination of severe acute respiratory syndrome coronavirus 2 neutralizing antibodies induced in serum samples from recipients of the CoronaVac vaccine showed a short protection period against the original virus strain and limited protection against variants of concern. These data provide support for vaccine boosters, especially variants of concern circulate.

Circulation of novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) variants capable of evading vaccine-derived protection is challenging the efficacy of coronavirus disease (COVID-19) vaccines (1). The inactivated SARS-CoV-2 vaccine CoronaVac (Sinovac Biotech, <http://www.sinovac.com>), 1 of 2 COVID-19 vaccines licensed in Thailand, has been widely administered to health care workers. Clinical studies show CoronaVac efficacy against symptomatic COVID-19 ranging from 51% (Brazil) to 65.9% (Chile) and 100% against severe illness and illness requiring hospitalization (2,3). However, data on CoronaVac efficacy against variants of concern are very limited. Our study was approved by the Research Ethics Review Committee, Faculty of Medicine, Chulalongkorn University (Bangkok, Thailand) and recorded in the Thai Clinical Trial Registry (ICTR20210325003). Investigators adhered to U.S. Department of Defense AR 70–25 policies for protection of human subjects.

For this study, we enrolled 207 health care workers in Thailand who were fully vaccinated with 2 doses of CoronaVac (0.5 mL/dose, 2–4 wk between doses); all had received their first dose during February 22–March 12, 2021. Median age was 39 (interquartile range 30–51) years of age; 67 (49.6%) were men. Among study participants, 58 (28%) provided blood samples only at baseline (when the first dose was administered), 93 (44.0%) both at baseline and 2–3 weeks after the second dose, and 56 (27.0%) at baseline and at 2–3 weeks and 10–12 weeks after the second dose. Using an in vitro system (Appendix, <https://wwwnc.cdc.gov/EID/article/27/12/21-1772-App1.pdf>), we evaluated the ability of the serum of CoronaVac



**Figure.** Results of in vitro testing by surrogate virus neutralization test ELISA and microneutralization assay of CoronaVac-induced neutralizing Wild-type strain and Alpha-, Beta-, and Delta-variant SARS-CoV-2 antibodies (n = 207). Overall vaccine-induced neutralizing antibodies shown at baseline, 2–3 weeks, and 10–12 weeks after second dose. Differences in mean inhibition rate were compared based on blood collection times. p value <0.05 indicates statistical significance.

recipients to neutralize SARS-CoV-2. We measured circulating serum neutralizing antibodies to the original SARS-CoV-2 wild-type strain by using a cPass receptor binding domain antigen-based surrogate virus neutralization test (sVNT) ELISA (GeneScript, <https://www.genscript.com>) and using a microneutralization assay (MNA) for SARS-CoV-2 wild-type strain and Alpha, Beta, and Delta neutralizing antibodies. Seroconversion rates for CoronaVac-vaccinated participants, determined by sVNT ELISA using 30% inhibition as cutoff, were 85.2% (78.2% mean inhibition level) at 2–3 weeks and 35% (25.4% mean inhibition level) at 10–12 weeks. The MNA seropositivity cutoff was set at  $\geq 50\%$ .

At 2–3 weeks after the second dose, 61.1% (91/149) of participants were seropositive against the wild-type strain, 35.6% (53/149) against Alpha variant, 3.4% (5/149) against Beta, and 8.7% (13/149) against Delta (Figure). Mean neutralizing rate at 2–3 weeks was 49.3% (95% CI 44.9%–53.6%) against the wild-type

strain, 40.9% (95% CI 37.8%–43.9%) against Alpha variant, 9.0% (95% CI 6.1%–11.8%) against Beta, and 10.8% (95% CI 7.1%–14.5%) against Delta. At 10–12 weeks after the second dose, the proportion of seropositive participants fell to 50% (28/56) against Wild-type strain and was significantly reduced ( $p < 0.001$ ) to 17.9% (10/56) against Alpha variant, 1.8% (1/56) against Beta, and 1.8% (1/56) against Delta. Mean neutralizing rates at 10–12 weeks were 48.0% (95% CI 39.9%–56.1%) against the wild-type strain, 21.8% (95% CI 37.8%–43.9%) against Alpha variant, 1.2% (95% CI 3.5%–8.8%) against Beta, and 1.0% (95% CI 2.9%–7.5%) against Delta.

Comparing sVNT ELISA results between the 2 time points, Wild-type strain antibodies appear to have a half-life of 83.4 days (95% CI 76.6–90.3 days). However, when the MNA was used, neutralizing antibodies waned in a time- and variant-dependent manner. The half-life of neutralizing antibodies was as low as 47.2 days (95% CI 37.5–56.9 days) for the wild-type strain, 38.6 days (95%

**Table.** Results of in vitro testing by surrogate virus neutralization test ELISA and microneutralization assay of CoronaVac-induced neutralizing wild-type strain and Alpha, Beta, and Delta variants of severe acute respiratory syndrome coronavirus 2\*

Neutralization test detection method	Slope coefficient (95% CI)	Half-time coefficient, d (95% CI)
Surrogate virus neutralization test ELISA	–0.645 (–0.751 to –0.538)	83.42 (76.55–90.29)
Microneutralization assay		
Wild-type	0.008 (–0.141 to 0.159)	47.17 (37.48–56.86)
Alpha	–0.187 (–0.302 to –0.072)	38.57 (31.16–45.99)
Beta	–0.063 (–0.121 to –0.006)	6.88 (3.20–10.57)
Delta	–0.125 (–0.211 to –0.040)	12.27 (6.78–17.77)

\*CoronaVac vaccine by Sinovac Biotech (<http://www.sinovac.com>).

CI 31.2–45.9 days) for Alpha variant, 6.9 days (95% CI 3.2–10.6 days) for Beta, and 12.3 days (95% CI 6.8–17.8 days) for Delta (Table). These data indicate the possibility that SARS-CoV-2 variants are able to escape humoral induced by wild-type prototype inactivated vaccines, which is consistent with results of other recent studies (4,5). Our findings support administering vaccine boosters, especially where these variants circulate.

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## Breakthrough Infections of E484K-Harboring SARS-CoV-2 Delta Variant, Lombardy, Italy

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The Delta variant of concern of severe acute respiratory syndrome coronavirus 2 is dominant worldwide. We report a case cluster caused by Delta sublineage B.1.617.2 harboring the mutation E484K in Italy during July 11–July 29, 2021. This mutation appears to affect immune response and vaccine efficacy; monitoring its appearance is urgent.

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## Appendix

### Additional Methods

#### Cell Lines and Viruses

We obtained Vero E6 green monkey kidney epithelial cell line from American Type Culture Collection. Cells were grown in Invitrogen Eagle's minimum essential medium (EMEM; ThermoFisher, <https://www.thermofisher.com>) supplement with Invitrogen 5% heat-inactivated fetal bovine serum (HIFBS; ThermoFisher) 1% L-glutamine, 1% P&S, 40 µg/mL gentamicin and 0.25 µg/mL fungizone, at 35 ± 2°C, 5% CO<sub>2</sub> incubator. We used 1-day-old cells for measuring median tissue culture infectious dose 50 (TCID<sub>50</sub>) and microneutralization assay.

We obtained SARS-CoV-2 viruses, including the Wuhan lineage (Wuhan Hu-1 strain, isolate Hong Kong/VM20001061/2020, NR-52282), Alpha B.1.1.7 variant (hCoV-19/England/204820464/2020, NR-54000, contributed by Bassam Hallis) and Beta B.1.351 variant (hCoV-19/South Africa/KRISP-EC-K005321/2020, NR-54008, contributed by Alex Sigal and Tulio de Oliveira) through the National Institute of Allergy and Infectious Diseases Biodefense and Emerging Infections Research Resources Repository (<https://www.beiresources.org>). We isolated Delta B.1.617.2 variant (hCoV-19/Thailand/CU-A21287-NT/2021) from a clinical specimen collected at King Chulalongkorn Hospital. All isolates were quantitated in Vero E6 cells by TCID<sub>50</sub> using the Reed-Muench method based on 8 replicates per titration and propagated to generate sufficient titers (100 TCID<sub>50</sub>) for the microneutralization assay.

#### SARS-CoV-2 Isolation

We completed SARS-CoV-2 isolation in a Biosafety Level (BSL)-3 laboratory at Armed Forces Research Institute of Medical Sciences (<https://afrims.amedd.army.mil>). We sent the nasopharyngeal specimens with confirmed RT-PCR and genome sequencing for viral isolation.

Virus isolation was done in Vero E6. One day before inoculation, we seeded 1.5 mL of cell suspension at a concentration of  $3 \times 10^5$  cells/mL onto 5.5 cm<sup>2</sup> tissue culture tubes. We separately inoculated 150 µL of specimen into Vero E6 cells monolayer. After incubation for 1 hr at 37°C in 5% CO<sub>2</sub> incubator, we added 1.5 mL of EMEM supplement with 2% HIFBS, 1% L-glutamine, 1% P&S, 40 µg/mL gentamicin, and 0.25 µg/mL fungizone and continued culturing at 37°C in a 5% CO<sub>2</sub> incubator. We observed the cytopathic effect of virus-infected cells daily. We confirmed variant isolates by PCR and genome sequencing.

### **Microneutralization Assay**

We used a microneutralization assay to determine neutralizing antibodies against SARS-CoV-2 viruses, including the Wuhan strain and variants B.1.1.7 (Alpha), B.1.351 (Beta), and B.1.617.2 (Delta) (1). All procedures were performed in a BSL-3 laboratory following a standard neutralization assay using cytopathic effect (CPE)-based colorimetric read-out (2). Cell control (CC) and virus control (VC) wells were included. We heat-inactivated serum samples at 56°C for 30 min before making 1:10 dilutions in Invitrogen 2% HIFBS/EMEM media (ThermoFisher). We separately incubated an equal volume of diluted serum with 100 TCID<sub>50</sub> of SARS-CoV-2 virus at 37°C and inoculated 5% CO<sub>2</sub> incubation for 1 hr. 100 µL of serum-virus mixture into triplicate wells of Vero E6 cells in 96-well plates and incubated at 37°C and 5% CO<sub>2</sub> for 5 days before staining with Sigma 0.02% neutral red (<https://www.sigmaaldrich.com>) in Invitrogen 1X phosphate-buffered saline (PBS, ThermoFisher). We added lysis solution for 1 hr at room temperature (RT) before measuring optical density (OD) at 540 nm. All obtained OD values against different strains of SARS-CoV-2 have been normalized with the mean OD of baseline sera against a particular strain. We calculated percentages of virus infectivity in VC and samples based on OD of CC, infectivity (%) = (OD of CC – OD of sample) × 100. We calculated percentage of inhibition using inhibition (%) = 100 – [(100 × infectivity of sample)/infectivity of VC]. Percentage of inhibition ≥50% is considered a positive cutoff for seroconversion against SARS-COV-2.

### **Surrogate Neutralizing Antibody ELISA**

We performed a cPass surrogate neutralization antibody test (GenScript Biotech, <https://www.genscript.com>) as described elsewhere (3). We coated 96-well plates with hACE2 protein at 100 ng/well in 100 mmol carbonate-bicarbonate coating buffer (pH 9.6). We diluted serum samples at 1:10 and preincubated them with 6 ng of horseradish peroxidase-conjugated

SARS-CoV-2 spike receptor-binding domain for 1 hr at 37°C. We transferred the mixture into hACE2 coated plate and incubated for 1 hr at RT. After removing unbound horseradish peroxidase-conjugated SARS-CoV-2 spike receptor-binding domain and washing with PBS 0.05% tween-20 (PBST) solution 5×, we added TMB substrate and incubated for 30 minutes at RT. An equal volume of TMB stop solution was added to stop the reaction, and we acquired the absorbance reading at 450 nm and 570 nm by spectrophotometer. We calculated percentage of inhibition using the formula, inhibition (%) = (1 – sample OD value/negative control OD value) ×100.

### Statistical Analysis

We performed data analysis using R program version 4.0.2 (<https://cran.r-project.org/bin/windows/base/old/4.0.2>) and SPSS program Version 25 (<https://www.ibm.com/support/pages/downloading-ibm-spss-statistics-25>). We used a Mann-Whitney U test or Wilcoxon test to compare the mean % inhibition obtained against different SARS-CoV-2 variants and the differences between baseline and convalescent fully vaccinated serum samples. P value <0.05 was considered statistically significant. Pearson correlation coefficient was used to determine the strength of association between surrogate nitrotyrosine ELISA with each microneutralization datum against prototype and variants.

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