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REVIEW

Narrative Review of the Evolution of COVID-19 Vaccination Recommendations in Countries in Latin America, Africa and the Middle East, and Asia

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ABSTRACT

The rapid rollout of vaccines to combat the coronavirus disease 2019 (COVID-19) pandemic over the past 2 years has resulted in the use of various vaccine platforms and regional differences in COVID-19 vaccine implementation strategies. The aim of this narrative review was to summarize evolving COVID-19 vaccine recommendations in countries in Latin America, Asia, and Africa and the Middle East across various vaccine platforms, age groups, and specific subpopulations. Nuances in primary and booster vaccination schedules were evaluated, and the preliminary impact of such diverse vaccination strategies are discussed, including key vaccine effectiveness data in the era of Omicron-lineage variants. Primary vaccination rates for included Latin American countries were 71–94% for adults and between 41% and 98% for adolescents and children; rates for first booster in adults were 36–85%. Primary vaccination rates for adults in the included Asian countries ranged from 64% in the Philippines to 98% in Malaysia, with corresponding booster rates varying from 9% in India to 78% in Singapore; for adolescents and children, primary vaccination rates ranged from 29% in the Philippines to 93% in Malaysia. Across included African and Middle Eastern countries, primary vaccination rates in adults varied widely from 32% in South Africa to 99% in the United Arab Emirates; booster rates ran-

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ged from 5% in South Africa to 60% in Bahrain. Evidence from the regions studied indicates preference of using an mRNA vaccine as a booster on the basis of safety and effectiveness of observed real-world data, especially during circulation of Omicron lineages. Vaccination against COVID-19 remains of paramount importance to reduce the burden of disease; strategies to overcome vaccine inequity, fatigue, hesitancy, and misinformation and to ensure adequate access and supply are also important.

Keywords: COVID-19; Vaccination; Booster; Recommendations; Latin America, Asia, Africa; Middle East; Heterologous

Key Summary Points

A comprehensive review of COVID-19 vaccine recommendations from countries in Latin America, Asia, and Africa and the Middle East.

Vaccine distribution during the COVID-19 pandemic has been challenging due to production shortages, economic constraints, and supply-chain infrastructure limitations, which severely hindered low- and middle-income countries.

A variety of vaccination strategies were applied in different regions of the world.

High primary COVID-19 vaccination rates for adults across regions studied were observed.

Coverage for primary series in children, as well as for booster doses in adolescents and adults, were low across the countries studied at the time of writing.

INTRODUCTION

Coronavirus disease 2019 (COVID-19) continues to cause considerable morbidity and mortality worldwide [1, 2]. Although the number of deaths and hospitalizations due to recent severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection peaks have notably decreased relative to peaks earlier in the pandemic in 2020 and 2021, before vaccines were rolled out broadly, current weekly numbers of infections, hospitalizations, and deaths, as well as long-term effects of COVID-19, continue to threaten public health across the Americas, Southeast Asia, and Africa and the Middle East [3]. The continued emergence of new variants of concern have compounded challenges for mounting adequate public health responses. For instance, since January 2022, the highly transmissible SARS-CoV-2 Omicron variant has been predominant, and by mid-August 2022, BA.4 and BA.5, two sub-lineages of the Omicron clade (B1.1.529), became the predominant subvariants globally [4].

For the first time since the start of the pandemic, the supply of COVID-19 vaccines to low- and lower-middle-income countries seems no longer a binding constraint, although there are critical distribution and delivery bottlenecks in some countries [5]. In addition, in some countries, an insufficient number of trained and remunerated health and care workers has been highlighted as a common challenge to the delivery of COVID-19 tools [5]. Other regional issues within low- and lower-middle-income countries and regions have imposed challenges in the pandemic public health response, including varied and dynamic sociopolitical environments, geography, and existing disease priorities [6]. In Latin America and Asia, the COVID-19 pandemic has exposed the preexisting inequities [7, 8]. In the Middle East, the effects of COVID-19 have varied widely across the region: the ability to respond to the pandemic has been inadequate, with chronic conflicts and divisions weakening healthcare systems and leading to less effective regional cooperation [9].

The aim of this narrative review was to summarize the evolving COVID-19 vaccination recommendations in countries in Latin America, Asia, and Africa and the Middle East across vaccine platforms, age groups, and special subpopulations, such as the immunocompromised. Primary and booster vaccination, as well as

heterologous booster regimens, are discussed. We also examine the preliminary impact of such diverse vaccination strategies in these regions, including key vaccine effectiveness data in the era of Omicron variants.

METHODS

COVID-19 vaccination recommendations, the vaccines in use, and coverage in various age groups were gathered from multiple diverse sources, such as official country dashboards for COVID-19, vaccine technical committee websites and publications, and documentation from relevant health ministries of each region. Countries were selected on the basis of the availability and clarity of vaccine recommendations at the time of writing, and if confirmation was available from the government or other official sources that the strategy was in place. Countries were included from three regions: Latin America (Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Panama, Peru, and Uruguay), Asia (India, Indonesia, Malaysia, the Philippines, Singapore, and Thailand), and Africa and the Middle East (Bahrain, Kuwait, Lebanon, Morocco, Qatar, Saudi Arabia, South Africa, and the United Arab Emirates). In addition, we conducted a literature search on 6 August 2022 in PubMed for studies on vaccine effectiveness using "SARS-CoV-2 vaccine" and "effectiveness" as keywords alongside each country included in this review. This article is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors.

THE DIVERSITY OF COVID-19 VACCINE PROGRAMS

Worldwide, COVID-19 vaccine recommendations have evolved, with vaccine availability and the increased understanding of vaccine safety, real-world effectiveness, SARS-CoV-2 variant prevalence, collective population immunity, and waning protection over time since vaccination or infection. Tables 1, 2, 3, 4, 5, and 6 present COVID-19 vaccine recommendations for adults, adolescents, and children in the Latin American, Asian, and African and Middle Eastern countries included in this review, respectively, as of August 2022. Information on vaccine type and corresponding platform are summarized in Table 7 and Fig. 1. Information on the number of each type of vaccine administered in each region as of 14 September 2022 is summarized in Fig. 2.

COVID-19 Vaccine Programs in the General Adult Population

At the time of writing, use of multiple vaccine platforms in adults (defined as $\geq$ 18 years of age in most countries) is a frequent practice in all regions surveyed (Fig. 1). Across the included Latin American countries, mRNA, replication-deficient adenoviral vector, and inactivated virus vaccines are largely recommended for the primary series in adults (Table 1). In the included Asian countries, in addition to the above-mentioned platforms, protein subunit vaccines are available for adults in most countries, including India (Table 3). A similar trend is observed in Africa and the Middle East for the included countries except for Qatar, where only mRNA vaccines are recommended (Table 5).

In the countries included in this review, for the 2-dose primary series, mix-and-match regimens (i.e., heterologous prime-boost vaccine types [10]) were usually not recommended in Latin America (with the exception of Argentina and Chile) or Asia (with the exception of the Philippines, Thailand, and Indonesia). Mix-and-match regimens were generally allowed in Africa and the Middle East (Fig. 1).

For booster doses given after a 2-dose primary series, several of the countries studied in each region implemented a heterologous booster regimen. Although mRNA vaccines are the preferred vaccine platform recommended across all studied countries, an exclusive use of mRNA vaccine boosters was observed only in Lebanon, Qatar, and Saudi Arabia in the Middle East and Uruguay in Latin America, while other countries studied also used other vaccine platforms according to vaccine availability. Figure 3

Table 1 General COVID-19 vaccine recommendations in Latin America by country: adults

	Country								
	Argentina	**Brazil**	**Chile**	**Colombia**	**Ecuador**	**Mexico**	**Panama**	**Peru**	**Uruguay**
Age	≥ 18 y	≥ 18 y	≥ 16 y	≥ 18 y	≥ 16 y	≥ 15 y	≥ 16 y	≥ 16 y	≥ 18 y
Vaccines available[a]	RNA	RNA	RNA	RNA	RNA	RNA	RNA	RNA	RNA
	Non-replicating viral vector	Non-replicating viral vector	Non-replicating viral vector	Non-replicating viral vector	Non-replicating viral vector Inactivated virus	Non-replicating viral vector	Non-replicating viral vector	Non-replicating viral vector	Non-replicating viral vector Inactivated virus
	Inactivated virus	Inactivated virus	Inactivated virus	Inactivated virus		Inactivated virus		Inactivated virus	
Primary schedule									
Mix and match[b]	Yes	No	Yes	No	No	No	No	No	No
IS 3-dose primary	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IC dose 3 (IC 1st booster)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Interval between IC primary and 1st booster	4 mo	4 mo	4 mo	4–6 mo	5 mo	4–6 mo	3 mo	3 mo	4 mo
Vaccines used[c]	RNA	RNA	RNA	RNA	RNA	RNA	RNA	RNA	RNA
	Non-replicating viral vector	Non-replicating viral vector	Non-replicating viral vector	Non-replicating viral vector	Non-replicating viral vector	Non-replicating viral vector	Non-replicating viral vector	Non-replicating viral vector	
			Inactivated virus	Inactivated virus					
Dose 4 (IC 2nd booster; IS 1st booster[d])	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
By age	≥ 18 y	≥ 40 y	≥ 18 y	≥ 50 y	≥ 50 y	≥ 50 y	≥ 50 y	≥ 40 y	> 70 y

Table 1 continued

	Country								
	Argentina	**Brazil**	**Chile**	**Colombia**	**Ecuador**	**Mexico**	**Panama**	**Peru**	**Uruguay**
By population	> 12 y IS	HCPs; IS	IS	≥ 12 y IS	HCPs; ≥ 12 y IS; ≥ 18 y with non-replicating viral vector vaccine primary series[e]	IS	≥ 12 y IS	HCPs; IS; ≥ 18 y with comorbidities	HCPs; IS; > 50 y with comorbidities; > 18 y with comorbidities and inactivated virus vaccine[f] primary series
Interval between dose 3 and dose 4	4 mo	4 mo	20 wk	4 mo	5 mo	4–6 mo	4 mo	5 mo	4 mo
Vaccines used[g]	RNA Non-replicating viral vector	RNA Non-replicating viral vector	RNA	RNA	RNA Non-replicating viral vector Inactivated virus	Non-replicating viral vector	RNA	RNA	BNT162b2
Pregnant/lactating women	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

HCP healthcare provider, *IC* immunocompetent, *IS* immunosuppressed, *mo* month, *wk* week, *y* year

[a]Argentina: BNT162b2, mRNA-1273, ChAdOx1-S, SII Covishield, Sputnik V, Sputnik Light, Ad5-nCoV, Sinopharm (Beijing), CoronaVac; Brazil: BNT162b2, ChAdOx1-S, SII Covishield, Ad26.COV2.S, Sputnik V, CoronaVac, Sinopharm (Beijing); Chile: BNT162b2, mRNA-1273, ChAdOx1-S, Ad5-nCoV, Ad26.COV2.S, Sputnik V, CoronaVac; Colombia: BNT162b2, mRNA-1273, ChAdOx1-S, Ad26.COV2.S, CoronaVac, ZF-2001; Ecuador: BNT162b2, ChAdOx1-S, Sputnik V, Ad5-nCoV (18–60 y), CoronaVac; Mexico: BNT162b2, mRNA-1273, ChAdOx1-S, Ad5-nCoV, Sputnik V, Bharat Biotech Covaxin, Sinopharm, CoronaVac, CIGB-66; Panama: BNT162b2, ChAdOx1-S (> 30 y), Sputnik V, CoronaVac; Peru: BNT162b2, mRNA-1273 (≥ 6 y), ChAdOx1-S, Sinopharm (Beijing); Uruguay: BNT162b2, ChAdOx1-S, CoronaVac

[b]Argentina: BNT162b2 ↔ mRNA-1273, ChAdOx1-S ↔ Sputnik; Chile: BNT162b2 ↔ ChAdOx1-S

[c]Argentina: BNT162b2, mRNA-1273, ChAdOx1-S, Sputnik, Ad5-nCoV; Brazil: BNT162b2, ChAdOx1-S, Ad26.COV2.S; Chile: BNT162b2, ChAdOx1-S, CoronaVac; Colombia: BNT162b2, mRNA-1273, ChAdOx1-S, Ad26.COV2.S, CoronaVac; Ecuador: BNT162b2, ChAdOx1-S, Ad5-nCoV; Mexico: mRNA-1273, ChAdOx1-S, Sputnik V; Panama: BNT162b2, ChAdOx1-S (> 30 y); Peru: BNT162b2, mRNA-1273, ChAdOx1-S; Uruguay: BNT162b2

[d]Recommendations for further booster doses in IS individuals not shown

[e]Ad26.COV2.S

[f]CoronaVac

[g]Argentina: All available [no Sinopharm (Beijing)]; Brazil: BNT162b2, ChAdOx1-S, Ad26.COV2.S; Chile: BNT162b2, mRNA-1273; Colombia: BNT162b2, mRNA-1273; Ecuador: BNT162b2, ChAdOx1-S, Ad5-nCoV, CoronaVac (only in travelers previously vaccinated with CoronaVac); Mexico: ChAdOx1-S; Panama: BNT162b2; Peru: BNT162b2, mRNA-1273; Uruguay: BNT162b2

Table 2 General COVID-19 vaccine recommendations in Latin America by country: adolescents and children

		Country								
		Argentina	**Brazil**	**Chile**	**Colombia**	**Ecuador**	**Mexico**	**Panama**	**Peru**	**Uruguay**
Adolescents	Age	12–17 y	12–17 y	12–15 y	12–17 y	12–15 y	12–15 y (IS only)	12–15 y	12–15 y	12–17 y
	Vaccines[a]	RNA	RNA Inactivated virus	RNA Inactivated virus	RNA	RNA	RNA	RNA	RNA	RNA
	IS 3-dose primary	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes (only oncology patients)	Yes
	IC dose 3 (IC 1st booster)	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Only if comorbidities
	Interval between IC primary and 1st booster	4 mo	4 mo	4 mo	4 mo	5 mo	N/A	N/A	5 mo	4 mo
	Vaccines used[b]	RNA	RNA Inactivated virus (not in IS)	RNA Inactivated virus	RNA	RNA	N/A	N/A	RNA	RNA
	Dose 4 (IC 2nd booster, IS 1st booster[c])	Only IS	Yes	Only IS	Only IS	Only IS	No	Only IS	Only IS	Only IS
	Interval between dose 3 and dose 4	4 mo	4 mo	16 wk	4 mo	5 mo	N/A	4 mo	3 mo	4 mo
	Vaccines used[d]	RNA	RNA Inactivated virus	RNA	RNA	RNA	N/A	RNA	RNA	RNA

Table 2 continued

		Country								
		Argentina	**Brazil**	**Chile**	**Colombia**	**Ecuador**	**Mexico**	**Panama**	**Peru**	**Uruguay**
Children	Age	3–11 y	5–11 y	3–11 y	3–11 y	3–11 y	5–11 y	5–11 y	5–11 y	≥ 5 y
	Vaccines[e]	RNA Inactivated virus	RNA Inactivated virus	RNA Inactivated virus	Inactivated virus	Inactivated virus	RNA	RNA	RNA	RNA
	IS 3-dose primary	Yes	No	Yes	No	Yes (≥ 5 y)	No	No	No	Yes
	IC dose 3 (IC 1st booster)	Yes	No	Yes	No	No	No	No	No	No
	Interval between IC primary and 1st booster	4 mo	N/A	4 mo	N/A	N/A	N/A	N/A	N/A	N/A
	Vaccines used[f]	RNA	N/A	RNA Inactivated virus	N/A	N/A	N/A	N/A	N/A	N/A
	Dose 4 (IC 2nd booster, IS 1st booster[c])	No	No	Only IS	No	No	No	No	No	No
	Interval between dose 3 and dose 4	N/A	N/A	16 wk	N/A	N/A	N/A	N/A	N/A	N/A
	Vaccines used[g]	N/A	N/A	RNA	N/A	N/A	N/A	N/A	N/A	N/A

IC immunocompetent, *IS* immunosuppressed, *mo* month, *N/A* not applicable, *wk* week, *y* year

[a]Argentina: BNT162b2, mRNA-1273; Brazil: BNT162b2, CoronaVac; Chile: BNT162b2, ChAdOx1-S, Ad5-nCoV, CoronaVac; Colombia: BNT162b2, mRNA-1273; Ecuador: BNT162b2; Mexico: BNT162b2; Panama: BNT162b2; Peru: BNT162b2, mRNA-1273; Uruguay: BNT162b2

[b]Argentina: BNT162b2, mRNA-1273; Brazil: BNT162b2, CoronaVac (except for IS); Chile: BNT162b2, CoronaVac; Colombia: BNT162b2, mRNA-1273; Ecuador: BNT162b2; Peru: BNT162b2, mRNA-1273; Uruguay: BNT162b2

[c]Recommendations for further booster doses in IS individuals not shown

[d]Argentina: BNT162b2, mRNA-1273; Brazil: BNT162b2 (5–11 y), CoronaVac (6–17 y); Chile: BNT162b2; Colombia: BNT162b2, mRNA-1273; Ecuador: BNT162b2; Panama: BNT162b2; Peru: BNT162b2, mRNA-1273; Uruguay: BNT162b2

[e]Argentina: BNT162b2, Sinopharm (Beijing); Brazil: BNT162b2, CoronaVac; Chile: BNT162b2, CoronaVac; Colombia: CoronaVac; Ecuador: CoronaVac; Mexico: BNT162b2; Panama: BNT162b2; Peru: BNT162b2, mRNA-1273 (≥ 6 y); Uruguay: BNT162b2

[f]Argentina: BNT162b2, mRNA-1273; Chile: BNT162b2, CoronaVac

[g]Chile: BNT162b2

Table 3 General COVID-19 vaccine recommendations in Asia by country: adults

	Country					
	India	**Indonesia**	**Malaysia**	**The Philippines**	**Singapore**	**Thailand**
Age	≥ 18 y	≥ 18 y	≥ 18 y	≥ 18 y	≥ 18 y	≥ 18 y
Vaccines available[a]	RNA Non-replicating viral vector Inactivated virus Protein subunit DNA	RNA Non-replicating viral vector Inactivated virus Protein subunit	RNA Non-replicating viral vector Inactivated virus	RNA Non-replicating viral vector Inactivated virus Protein subunit	RNA Inactivated virus Protein subunit	RNA Non-replicating viral vector Inactivated virus
Primary schedule						
Mix and match[b]	No	Yes	No	Yes	No	Yes
IS 3-dose primary	Yes	Yes	Yes	Yes	Yes	Yes
IC dose 3 (IC 1st booster)	Yes	Yes	Yes	Yes	Yes	Yes
Interval between IC primary and 1st booster	6 mo	≥ 3 mo	≥ 3 mo (2 mo if Ad26.COV2.S received as primary)	≥ 3 mo	≥ 5 mo	≥ 3 mo
Vaccines used[c]	Non-replicating viral vector Inactivated virus Protein subunit DNA	RNA Non-replicating viral vector Inactivated virus	RNA Non-replicating viral vector Inactivated virus	RNA Non-replicating viral vector	RNA	RNA Non-replicating viral vector
Dose 4 (IC 2nd booster; IS 1st booster[d])	No	Yes	Yes	Yes	Yes	Yes
By age	N/A	Special population (HCW only)	> 60 y	≥ 60 y	≥ 80 y	≥ 18 y
By population	N/A	Special population (HCW only)	≥ 12 y high risk	≥ 18 y HCPs; ≥ 18 y IS	≥ 18 y IS, chronic disease, or aged care facility	All
Interval between dose 3 and dose 4	N/A	6 mo	4–6 mo	≥ 4 mo (3 mo IS)	≥ 5 mo	≥ 4 mo

Table 3 continued

	Country					
	India	**Indonesia**	**Malaysia**	**The Philippines**	**Singapore**	**Thailand**
Vaccines used[e]	N/A	RNA	RNA	RNA Non-replicating viral vector Inactivated virus	RNA	RNA Non-replicating viral vector
Pregnant/lactating women	Yes	Yes	Yes	Yes	Yes	Yes

HCW healthcare worker, *IC* immunocompetent, *IS* immunosuppressed, *mo* month, *N/A* not applicable, *wk* week, *y* year

[a]India: mRNA-1273, GEMCOVAC-19, Sputnik V, Sputnik Light, Ad26.COV2.S, ChAdOx1-S, SII Covishield, Bharat Biotech Covaxin, Biological E Limited Corbevax, SII Covovax, ZyCoV-D; Indonesia: BNT162b2, mRNA-1273, Ad26.COV2.S, ChAdOx1-S, Ad5-nCoV, Sputnik V, Sinopharm (Beijing), CoronaVac, Shenzhen Kangtai KCONVAC, SII Covovax, ZF-2001; Malaysia: BNT162b2, mRNA-1273, Ad26.COV2.S, ChAdOx1-S, Ad5-nCoV, CoronaVac, Sinopharm (Beijing), Bharat Biotech Covaxin; the Philippines: BNT162b2, mRNA-1273, Sputnik V, Sputnik Light, Ad26.COV2.S, ChAdOx1-S, Sinopharm (Beijing), Sinopharm (Wuhan), CoronaVac, Bharat Biotech Covaxin, SII Covovax; Thailand: BNT162b2, mRNA-1273, ChAdOx1-S, Ad26.COV2.S, CoronaVac, Sinopharm (Beijing), SII Covovax; Singapore: BNT162b2, mRNA-1273, CoronaVac, NVX-CoV2373

[b]Indonesia: CoronaVac ↔ BNT162b2 or mRNA-1273 or ChAdOx1-S, ChAdOx1-S ↔ BNT162b2 or mRNA-1273 or CoronaVac; the Philippines: Clinical trial, CoronaVac (1st dose) → BNT162b2 or mRNA-1273 or Sputnik V or Sputnik Light or Ad26.COV2.S or ChAdOx1-S or SII Covovax (2nd dose); Thailand: CoronaVac ↔ BNT162b2 or ChAdOx1-S, ChAdOx1-S ↔ BNT162b2 or CoronaVac

[c]India: SII Covishield, Bharat Biotech Covaxin, Biological E Limited Corbevax, SII Covovax, Gamaleya National Research Centre for Epidemiology and Microbiology Sputnik V; Indonesia: BNT162b2, mRNA-1273, ChAdOx1-S, CoronaVac; Malaysia: BNT162b2, ChAdOx1-S, Ad5-nCoV, CoronaVac; the Philippines: BNT162b2, mRNA-1273, Sputnik Light, Ad26.COV2.S, ChAdOx1-S; Singapore: BNT162b2, mRNA-1273; Thailand: BNT162b2, mRNA-1273, ChAdOx1-S

[d]Recommendations for further booster doses in IS individuals not shown

[e]Malaysia: BNT162b2; the Philippines: BNT162b2, mRNA-1273, CoronaVac, ChAdOx1-S, Sinopharm (Beijing, Wuhan, Hayat-Vax); Singapore: BNT162b2, mRNA-1273; Thailand: BNT162b2, ChAdOx1-S

Table 4 General COVID-19 vaccine recommendations in Asia by country: adolescents and children

		Country					
		India	**Indonesia**	**Malaysia**	**The Philippines**	**Singapore**	**Thailand**
Adolescents	Age	12–17 y	12–17 y	12–17 y	12–17 y	12–17 y	12–17 y
	Vaccines[a]	Inactivated virus Protein subunit	RNA Inactivated virus	RNA	RNA	RNA	RNA Inactivated virus
	IS 3-dose primary	No	Yes	Yes	Yes	Yes	Yes
	IC dose 3 (IC 1st booster)	No	No	No	Yes	Yes	Yes
	Interval between IC primary and 1st booster	N/A	N/A	N/A	≥ 28 d	5–9 mo	≥ 3 mo (1 mo if inactivated virus primary)
	Vaccines used[b]	N/A	N/A	N/A	RNA	RNA	RNA
	Dose 4 (IC 2nd booster, IS 1st booster)	No	No	No	No	No	No
	Interval between dose 3 and dose 4	N/A	N/A	N/A	N/A	N/A	N/A
	Vaccines used	N/A	N/A	N/A	N/A	N/A	N/A

Table 4 continued

		Country					
		India	**Indonesia**	**Malaysia**	**The Philippines**	**Singapore**	**Thailand**
Children	Age	No	6–11 y	5–11 y	6–11 y	5–11 y	5–11 y
	Vaccines[c]	N/A	Inactivated virus	RNA	RNA Inactivated virus	RNA	RNA Inactivated virus
	IS 3-dose primary	N/A	No	Yes	Yes	Yes	Yes
	IC dose 3 (IC 1st booster)	N/A	No	Yes	No	Yes	Yes
	Interval between IC primary and 1st booster	N/A	N/A	N/A	N/A	5 mo	≥ 3 mo
	Vaccines used[d]	N/A	N/A	N/A	N/A	RNA	RNA
	Dose 4 (IC 2nd booster, IS 1st booster)	N/A	No	No	No	No	No
	Interval between dose 3 and dose 4	N/A	N/A	N/A	N/A	N/A	N/A
	Vaccines used	N/A	N/A	N/A	N/A	N/A	N/A

d day, *IC* immunocompetent, *IS* immunosuppressed, *mo* month, *N/A* not applicable, *wk* week, *y* year

[a]India: Covaxin, Covovax, BECOV2A; Indonesia: BNT162b2, CoronaVac, Sinopharm (Beijing); Malaysia: BNT162b2; the Philippines: BNT162b2, mRNA-1273; Singapore: BNT162b2; Thailand: BNT162b2, CoronaVac, Sinopharm (Beijing)

[b]The Philippines: BNT162b2, mRNA-1273; Singapore: BNT162b2; Thailand: BNT162b2

[c]Indonesia: CoronaVac; Malaysia: BNT162b2; the Philippines: BNT162b2, mRNA-1273, CoronaVac; Singapore: BNT162b2; Thailand: BNT162b2, mRNA-1273, CoronaVac; Vietnam: BNT162b2, mRNA-1273 (≥ 6 y)

[d]Singapore: BNT162b2; Thailand: BNT162b2

Table 5 General COVID-19 vaccine recommendations in Africa and the Middle East by country: adults

	Country							
	Bahrain	**Kuwait**	**Lebanon**	**Morocco**	**Qatar**	**Saudi Arabia**	**South Africa**	**UAE**
Age	≥ 18 y	≥ 16 y	≥ 16 y	≥ 18 y	≥ 16 y	≥ 16 y	≥ 18 y	≥ 16 y
Vaccines available[a]	RNA Non-replicating viral vector Inactivated virus	RNA Non-replicating viral vector Inactivated virus	RNA Non-replicating viral vector Inactivated virus	RNA Non-replicating viral vector Inactivated virus	RNA	RNA Non-replicating viral vector	RNA Non-replicating viral vector Inactivated virus	RNA Non-replicating viral vector Inactivated virus Protein subunit
Primary schedule								
Mix and match[b]	Yes	Yes	No	Yes	Yes	Yes	Yes	No
IS 3-dose primary	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
IC dose 3 (IC 1st booster)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Interval between IC primary and 1st booster	3 mo	4 mo	≥ 5 mo	4 mo	6 mo	3 mo	2–3 mo	3–6 mo
Vaccines used[c]	RNA Non-replicating viral vector Inactivated virus	RNA Non-replicating viral vector	RNA	RNA Inactivated virus	RNA	RNA	RNA Non-replicating viral vector	RNA Non-replicating viral vector Inactivated virus

Table 5 continued

	Country							
	Bahrain	**Kuwait**	**Lebanon**	**Morocco**	**Qatar**	**Saudi Arabia**	**South Africa**	**UAE**
Dose 4 (IC 2nd booster; IS 1st booster[d])	Yes	Yes	Yes	No	Yes	Yes	Yes	No
By age	≥ 60 y	≥ 50 y	≥ 12 y	N/A	≥ 60 y	≥ 60 y	≥ 50 y	N/A
By population	Frontline HCPs; ≥ 18 y who received 3 doses inactivated virus vaccine[e]; ≥ 18 y may take optional booster every 9 mo	≥ 12 y IS	All	N/A	Individuals of all ages at increased risk due to chronic disease	≥ 16 y IS or comorbidity	Comorbidities	N/A
Interval between dose 3 and dose 4	3 mo (≥ 60 y, HCPs, or 3 doses inactivated virus vaccine[e]) 9 mo (other adults)	4 mo	IS, 4 mo General, ≥ 6 mo	N/A	4 mo	4 mo	≥ 4 mo	N/A
Vaccines used[f]	RNA Non-replicating viral vector Inactivated virus	N/A	RNA	N/A	RNA	RNA	RNA	N/A

Table 5 continued

	Country							
	Bahrain	**Kuwait**	**Lebanon**	**Morocco**	**Qatar**	**Saudi Arabia**	**South Africa**	**UAE**
Pregnant/ lactating women	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

HCP healthcare professional, *IC* immunocompetent, *IS* immunosuppressed, *mo* month, *N/A* not applicable, *UAE* United Arab Emirates, *y* year

[a]Bahrain: BNT162b2, Ad26.COV2.S, SII Covishield, Sputnik V, Sputnik Light, Bharat Biotech Covaxin, Sinopharm (Beijing), Valneva; Kuwait: BNT162b2, mRNA-1273, Ad26.COV2.S, ChAdOx1-S; Lebanon: BNT162b2, Sputnik V, SII Covishield, Sinopharm (Beijing); Morocco: BNT162b2, Sputnik V, Ad26.COV2.S, ChAdOx1-S, SII Covishield, Sinopharm (Beijing); Qatar: BNT162b2, mRNA-1273; Saudi Arabia: BNT162b2, mRNA-1273, Ad26.COV2.S, ChAdOx1-S; South Africa: BNT162b2, Ad26.COV2.S, SII Covishield, Sinopharm (Beijing), CoronaVac; UAE: BNT162b2, mRNA-1273, Sputnik V, Sputnik Light, ChAdOx1-S, Sinopharm (Beijing), Valneva, National Vaccine and Serum Institute Recombinant SARS-CoV-2 Vaccine (CHO cell)

[b]Kuwait: ChAdOx1-S ↔ BNT162b2; Morocco: BNT162b2 ↔ AstraZenca or Sinopharm (Beijing); Qatar: BNT162b2 ↔ mRNA-1273; Saudi Arabia: ChAdOx1-S ↔ BNT162b2; South Africa: BNT162b2 ↔ Ad26.COV2.S

[c]Bahrain: BNT162b2, Ad26.COV2.S, SII Covishield, Oxford/AstraZeneca [ChAdOx1-S (recombinant) vaccine], Janssen COVID-19 vaccine, Gamaleya National Research Centre for Epidemiology and Microbiology Sputnik V, Sputnik Light, Sinopharm (Beijing); Kuwait: BNT162b2, ChAdOx1-S; Lebanon: BNT162b2, mRNA-1273; Morocco: BNT162b2, Sinopharm (Beijing); Qatar: BNT162b2, mRNA-1273; Saudi Arabia: BNT162b2, mRNA-1273; South Africa: BNT162b2, Ad26.COV2.S; UAE: BNT162b2, Sinopharm (Beijing), Sputnik V

[d]Recommendations for further booster doses in IS individuals not shown

[e]Sinopharm (Beijing)

[f]Bahrain: BNT162b2; Lebanon: BNT162b2, mRNA-1273; Saudi Arabia: BNT162b2, mRNA-1273

Table 6 General COVID-19 vaccine recommendations in Africa and the Middle East by country: adolescents and children

		Country							
		Bahrain	**Kuwait**	**Lebanon**	**Morocco**	**Qatar**	**Saudi Arabia**	**South Africa**	**UAE**
Adolescents	Age	12–18 y	12–15 y	12–15 y	12–18 y	12–15 y	12–15 y	12–18 y	12–15 y
	Vaccines[a]	RNA Inactivated virus	RNA	RNA	RNA Inactivated virus	RNA	RNA	RNA	RNA Inactivated virus
	IS 3-dose primary			Yes				No	
	IC dose 3 (IC 1st booster)	Yes	No	Yes	No	Yes	No	Yes	No
	Interval between IC primary and 1st booster	6 mo	4 mo	≥ 4 mo	N/A	6 mo	N/A	3 mo	N/A
	Vaccines used[b]	RNA Inactivated virus	RNA	RNA	N/A	RNA	N/A	RNA	N/A
	Dose 4 (IC 2nd booster, IS 1st booster)	Yes	≥ 12 y (IS only)	Yes	No	Individuals ≥ 12 y at increased risk due to chronic disease	No	No	No
	Interval between dose 3 and dose 4	9 mo	4 mo	IS, 4 mo General, ≥ 6 mo	N/A	4 mo	N/A	N/A	N/A
	Vaccines used[c]	RNA Inactivated virus	N/A	RNA	N/A	RNA	N/A	N/A	N/A

Table 6 continued

		Country							
		Bahrain	**Kuwait**	**Lebanon**	**Morocco**	**Qatar**	**Saudi Arabia**	**South Africa**	**UAE**
Children	Age	≥ 3–11 y	5–11 y	5–11 y	No	5–11 y	5–11 y	No	≥ 3–11 y
	Vaccines[d]	RNA	RNA	RNA	N/A	RNA	RNA	N/A	RNA
		Inactivated virus							Inactivated virus
	IS 3-dose primary				N/A			N/A	
	IC dose 3 (IC 1st booster)	No			N/A	No		N/A	
	Interval between IC primary and 1st booster	N/A			N/A	N/A		N/A	
	Vaccines used	N/A			N/A	N/A		N/A	
	Dose 4 (IC 2nd booster, IS 1st booster)	No			N/A	No		N/A	
	Interval between dose 3 and dose 4	N/A			N/A	N/A		N/A	
	Vaccines used	N/A			N/A	N/A		N/A	

IC immunocompetent, *IS* immunosuppressed, *mo* month, *N/A* not applicable, *UAE* United Arab Emirates, *y* year

[a]Bahrain: BNT162b2, Sinopharm (Beijing); Kuwait: BNT162b2; Lebanon: BNT162b2; Morocco: BNT162b2, Sinopharm (Beijing); Qatar: BNT162b2, mRNA-1273; Saudi Arabia: BNT162b2; South Africa: BNT162b2; UAE: BNT162b2, Sinopharm (Beijing)

[b]Kuwait: BNT162b2; Lebanon: BNT162b2; Qatar: BNT162b2; South Africa: BNT162b2

[c]Bahrain: BNT162b2, Sinopharm (Beijing); Lebanon: BNT162b2; Qatar: BNT162b2

[d]Bahrain: BNT162b2 (≥ 5 y), Sinopharm (Beijing; ≥ 3 y); Kuwait: BNT162b2; Lebanon: BNT162b2; Qatar: BNT162b2; Saudi Arabia: BNT162b2; UAE: BNT162b2 (≥ 5 y), Sinopharm (Beijing; ≥ 3 y)

Table 7 List of approved vaccines in the countries included in the review[a]

Manufacturer	Vaccine type	Generic identifier	Commercial name
Pfizer/BioNTech	RNA	**BNT162b2**	Comirnaty
Moderna	RNA	**mRNA-1273**	Spikevax
Gennova Biopharmaceuticals/HDT Bio	RNA	–	**GEMCOVAC-19**
CanSino Biologics	Non-replicating viral vector	**Ad5-nCoV**	Convidecia
Gamaleya Research Institute	Non-replicating viral vector	Gam-COVID-Vac (rAd26, rAd5)	**Sputnik V**
Gamaleya Research Institute	Non-replicating viral vector	– (rAd26)	**Sputnik Light**
Janssen (Johnson & Johnson)	Non-replicating viral vector	**Ad26.COV2.S**	Ad26.COV2.S
Oxford/AstraZeneca	Non-replicating viral vector	**ChAdOx1-S**	Vaxzevria AZD1222
Serum Institute of India (SII)	Non-replicating viral vector	Oxford/AstraZeneca formulation	**Covishield**
Bharat Biotech	Inactivated virus	BBV152	**Covaxin**
Sinopharm (Beijing)	Inactivated virus	BBIBP-CorV	Covilo
Sinopharm (Wuhan)	Inactivated virus	Inactivated SARS-CoV-2 (Vero cells)	–
Sinovac	Inactivated virus	–	**CoronaVac**
Valneva	Inactivated virus	VLA2001	–
Anhui Zhifei Longcom	Protein subunit	**ZF-2001**	Zifivax
Biological E Limited	Protein subunit	**BECOV2A**	Corbevax
Center for Genetic Engineering and Biotechnology (CIGB)	Protein subunit	**CIGB-66**	Abdala
Novavax	Protein subunit	**NVX-CoV2373**	Nuvaxovid
Serum Institute of India (SII)	Protein subunit	Novavax formulation	**Covovax**
Zydus Lifesciences	DNA	**ZyCoV-D**	ZyCoV-D

[a]For each vaccine, bold font indicates the identifier used within the review

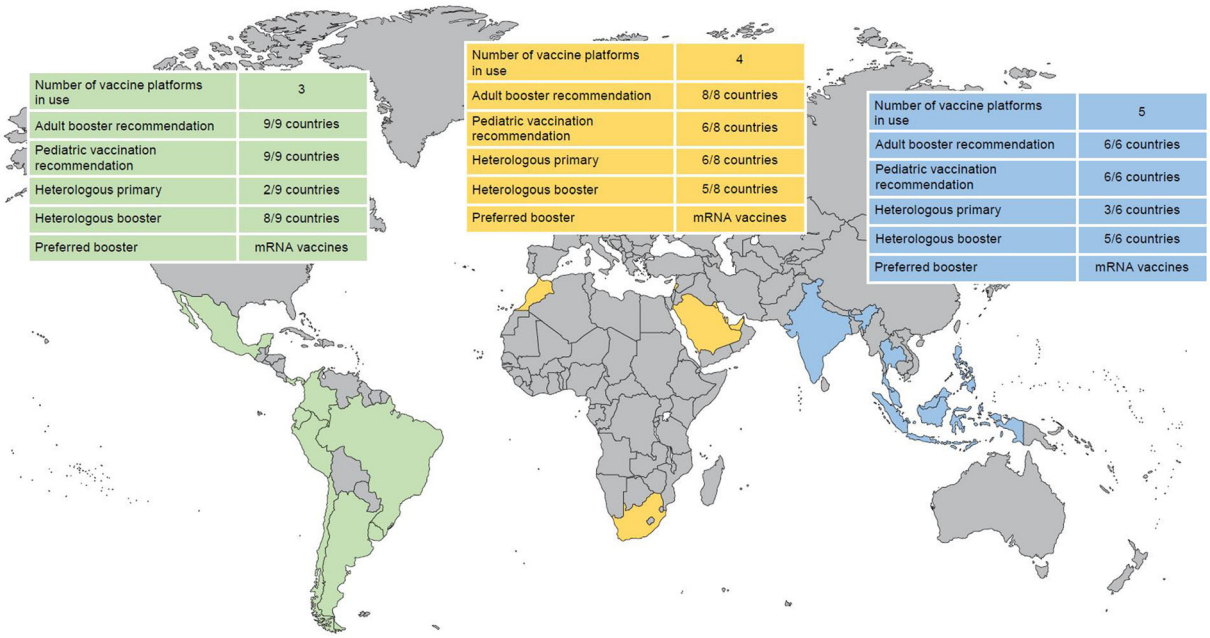

Fig. 1 COVID-19 vaccination recommendations. Data at the time of writing are presented by region for the countries included in the review

provides an overview of booster vaccination recommendations by region and country at the time of writing. In included Latin American countries (apart from Argentina and Chile, in which a second booster is recommended in those ≥ 18 years of age), a second booster was available for adults > 40 years old approximately 4 months after dose 3. In the included Asian countries, a second booster was recommended only in elderly adults (generally ≥ 60 years of age) and in those ≥ 18 years old with certain comorbid conditions (e.g., immunocompromised conditions) except in Malaysia where this age cutoff was ≥ 12 years. Across all studied countries in Africa and the Middle East, second booster doses were recommended only in Bahrain, Saudi Arabia, Lebanon, and South Africa (Fig. 3).

COVID-19 Vaccine Programs in Children and Adolescents

Both mRNA and inactivated virus vaccines were approved by regulatory bodies for pediatric age groups in the majority of the studied countries as of August 2022. In adolescents (defined in the majority of countries as those ≥ 12–17 years old), generally only mRNA vaccines were recommended in the included countries; inactivated vaccines were also authorized and recommended in Brazil, Chile, Indonesia, Thailand, Bahrain, Morocco, and the United Arab Emirates (Tables 2, 4, 6). In the included countries, a booster dose in adolescents was implemented only in the Philippines, Singapore, and Thailand in Asia, and only in Qatar, Bahrain, and South Africa in Africa and the Middle East. However, most countries in Latin America had already implemented a booster dose in this age group as of August 2022.

Regarding the pediatric population under 12 years of age, while mRNA vaccines are available for children from 6 months of age and inactivated virus vaccines were available for children from 3 years of age, the majority of studied countries in Asia and Africa and the Middle East recommended only mRNA vaccines in children (Tables 4, 6). In Latin America, mRNA and inactivated virus vaccines were recommended in Argentina, Brazil, Chile, and Peru, while only inactivated virus vaccines were recommended in Colombia and Ecuador

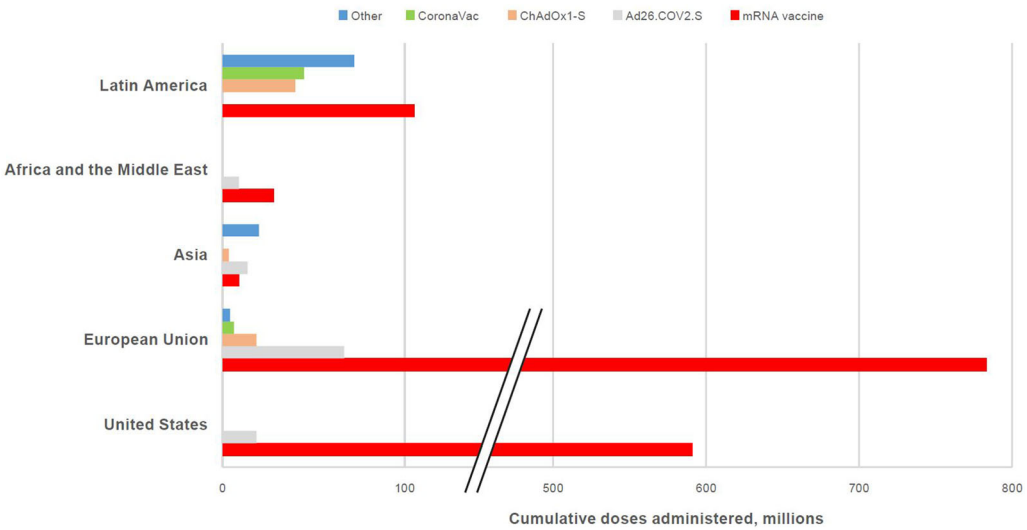

Fig. 2 Type of COVID-19 vaccines used and the number of doses (millions) administered to date in each region. Data show the cumulative number of doses administered according to vaccine manufacturer (current as of 14 September 2022 [11]). Data for Latin America include Chile, Peru, Ecuador, Argentina, and Uruguay; data for Africa and the Middle East include South Africa only; data for Asia include Nepal only. mRNA vaccines include BNT162b2 and mRNA-1273, and other vaccines include BBIBP-CorV, Ad5-nCoV, Gam-COVID-Vac, and NVX-CoV2373

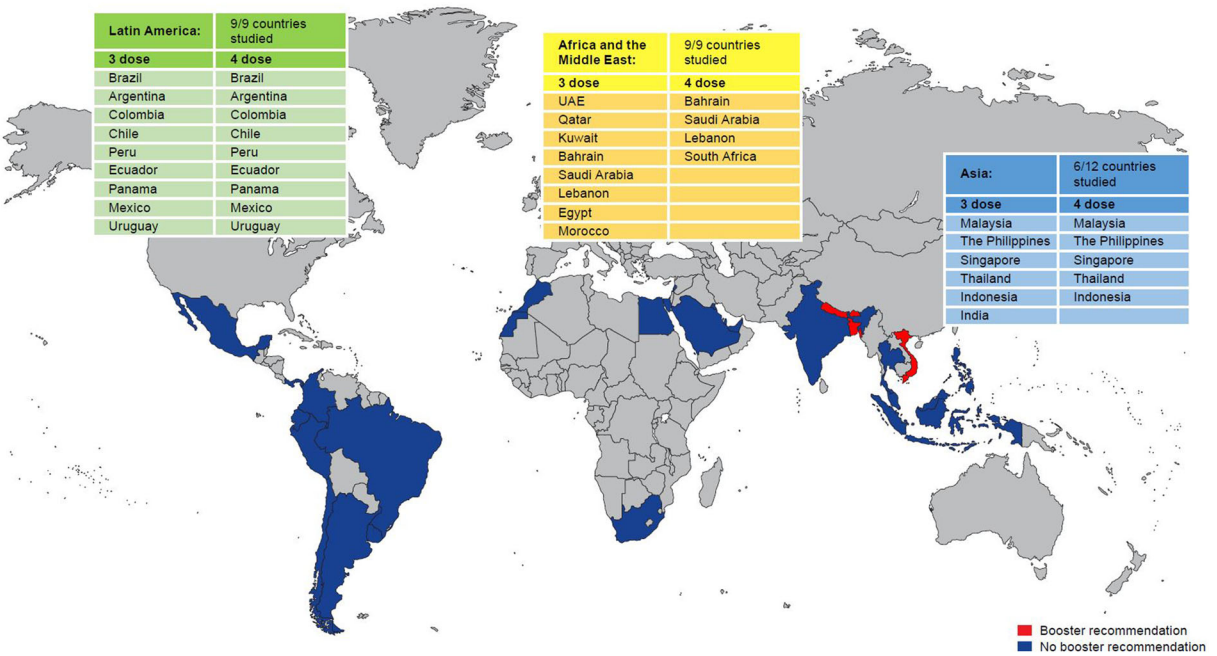

Fig. 3 Booster dose use: 3- and 4-dose recommendations by region. Data at the time of writing are presented by region for the countries included in the review. *UAE* United Arab Emirates

(Table 2). In most countries reviewed across all regions, a booster dose was not recommended for children ≥ 5–11 years of age at the time of writing.

VACCINATION COVERAGE

Vaccination against COVID-19 began in the USA on 14 December 2020. Of the countries included in this review, Argentina, Bahrain, Chile, Singapore, and Mexico started vaccinations at the end of December 2020, while other countries started vaccinating in January or February 2021 [11]. At the time of this writing, vaccination rates from 2-dose primary series and booster vaccinations varied widely across countries and regions studied (Table 8).

LESSONS LEARNED FROM PRIMARY AND BOOSTER IMPLEMENTATION

Real-world evidence has been crucial during the COVID-19 pandemic to inform critical vaccination decisions [12]. Real-world vaccine effectiveness data have been published for many of the countries examined in this review. These data are critical as they not only support findings from clinical trials but also enable evidence-based decisions in the implementation of vaccination programs.

Real-World Effectiveness from the Primary Vaccination Series

Real-world data from primary vaccination series in Latin America, Asia, and Africa and the Middle East generally showed high short-term effectiveness across vaccine platforms. However, after emergence of SARS-CoV-2 variants, showing increased immune evasion and higher transmissibility, evidence of significant waning of vaccine effectiveness, particularly against infection and mild disease, was observed, but with more sustained protection against severe outcomes of disease [13]. In Brazil, from February–July 2021, the Brazilian National Immunization Program reported vaccine effectiveness against death ≥ 14 days after primary vaccine series for each of the vaccines in use. Completion of primary vaccination was associated with 98% effectiveness (among 20–30-year-olds) for replication-deficient adenoviral vector vaccine ChAdOx1-S, 90% (among 40–59-year-olds) for mRNA vaccine BNT162b2, and 83% for inactivated virus vaccine CoronaVac [14]. When effectiveness was estimated according to age group, this study found a sharp declining trend after two doses of CoronaVac in the elderly, particularly among those older than 80 years, where protection against death was as low as 45% compared with 71% among the age group of 60–79 years or 83% for the age group of 40–59 years. In a mass vaccination campaign in Chile, vaccine effectiveness of CoronaVac against hospitalization, intensive care unit (ICU) admission, and death was > 80% and vaccine effectiveness of BNT162b2 against hospitalization and ICU admission was approximately 95% [15, 16]. In Argentina, the risk of all-cause death after a 2-dose primary vaccination series was reduced by 97%, with no significant differences between replication-deficient adenoviral vector vaccine Sputnik V and ChAdOx1-S [17]. In Colombia, BNT162b2, ChAdOx1 nCoV-19, Ad26.COV2.S (replication-deficient adenoviral vector vaccine), and CoronaVac vaccines were all effective in preventing COVID-19–associated hospitalization and deaths in fully vaccinated adults ≥ 60 years old, with BNT162b2 and ChAdOx1-S showing the highest effectiveness against hospitalization (83–91%) and death (88–98%) [18]. In Uruguay, vaccination with BNT162b2 reduced deaths by 94% in individuals ≥ 80 years old, while CoronaVac reduced deaths by 95% in 18–49-year-olds [19].

Real-world data from Asia also confirm short-term effectiveness of primary vaccination series. In India, the effectiveness of ChAdOx1-S against infection in fully vaccinated individuals was 89% [20]. Another study among healthcare workers predominantly vaccinated with ChAdOx1-S (> 97%), vaccines were 57% effective against moderate-to-severe disease [21]. In Malaysia, BNT162b2, ChAdOx1-S, and CoronaVac were all highly effective at preventing ICU admission (72–96%) or death (82–95%) in ≥ 18-year-olds [22]. Another Malaysian study

Table 8 Vaccination coverage in the countries included in the review

Region Country	Percentage of population vaccinated[a]					
	Adult/all ages[b] primary[c]	Adult/all ages booster	Adolescent[d] primary[c]	Adolescent booster	Children[e] Primary[c]	Children booster
Latin America						
Argentina	89.8	–	78.1	–	60	–
Brazil	78.8	48.7	80.9	5.3	51.4	–
Chile	93.8	85.2	97.6	66.8	79.1	27.7
Colombia	70.7	35.6	–	–	44.5	–
Ecuador	87.5	36.8	79.9	17.7	70.2/18.0[f]	–
Panama	78.6	51.6	–	–	–	–
Peru	89.6	68.7	71.7	17.7	76.3	–
Uruguay	93.4	65.6	80.2	25.8	41	–
Asia						
India	68	9	–	–	–	–
Indonesia	81.3	25	82.3	–	65.3	–
Malaysia	98.1	68.6	93.4	–	42.9	Not initiated
The Philippines	64	20.8	82.7	2.2	29.1	Not initiated
Singapore	96	78	–	–	75	Not initiated
Thailand	77	45	–	–	–	–
Africa and the Middle East						
Bahrain	74	60	–	–	–	–
Kuwait	79	31	–	–	–	–
Lebanon	34	8.5	–	–	–	–
Morocco	64	17	–	–	–	–
Qatar	92	57	–	–	–	–
Saudi Arabia	73	31	–	–	–	–

Table 8 continued

Region Country	Percentage of population vaccinated[a]							
	Adult/all ages[b] primary[c]	Adult/all ages booster	Adolescent[d] primary[c]	Adolescent booster	Children[e] Primary[c]	Children booster		
South Africa	32	5.4	–	–	–	–		
UAE	99	54	–	–	–	–		

Cells without values indicate that data were not available at the time of data collection. Countries with no available data at the time of collection are not included in the table. Values are reported with decimal places if included in the original source

[a]Vaccination rates at May/June/July 2022 (Latin American countries), July/August 2022 (Asian countries), and June 2022 (Middle Eastern and African countries)

[b]Adults ≥ 18 y, except for Ecuador (18–24 y), Peru, Chile, Kuwait, Lebanon, Qatar, Saudi Arabia, and UAE (≥ 16 y), Panama (≥ 5 y), Indonesia (≥ 6 y), the Philippines (≥ 5 y), Singapore (≥ 5 y), and Thailand (≥ 5 y)

[c]Receipt of 2 doses was considered a primary series

[d]12–17 y, except for Chile, Ecuador, and Peru (12–15 y)

[e]5–11 y, except for Argentina, Chile, and Colombia (3–11 y), Brazil and Indonesia (6–11 y)

[f]5–11 y/3–4 y

reported that age-standardized mortality rates per 100,000 population were 43 times higher in unvaccinated individuals than in those fully vaccinated with BNT162b2, and 13 times higher than in those who received inactivated virus vaccines [23]. In adolescents in Malaysia, BNT162b2 was 66% effective in preventing SARS-COV-2 infections [24].

In Bahrain, four COVID-19 vaccines (Sinopharm, Sputnik V, ChAdOx1-S, and BNT162b2) were rolled out; all were protective against infection, hospitalization, and ICU admission versus unvaccinated individuals, but recipients of the Sinopharm vaccine were at higher risk compared with the other vaccines [25]. In Saudi Arabia, COVID-19 case numbers and COVID-19–associated deaths were significantly reduced after introducing BNT162b2 and ChAdOx1-S vaccines [26]. Other studies in Saudi Arabia reported reduced risk of hospitalization or death for those vaccinated with BNT162b2 or ChAdOx1-S vaccines versus unvaccinated individuals [27, 28]. In Qatar, vaccination with both mRNA vaccines were highly protective against COVID-19–related hospitalization or death [29].

Effectiveness of Booster Vaccinations

Given evidence of waning vaccine efficacy after the 2-dose primary series [30–32], it is important to study the effectiveness of subsequent booster doses. A Brazilian study including more than 14 million individuals, in the context of Gamma and Delta being the dominant viral variants, found that vaccine effectiveness 6 months after the two-dose primary regimen of CoronaVac against both SARS-CoV-2 infection and COVID-19–related severe outcomes waned for all age groups, particularly in the elderly. A BNT162b2 booster 6 months after the second dose of CoronaVac improved vaccine effectiveness against infection to 92.7% (95% CI 91.0–94.0) and vaccine effectiveness against severe outcomes to 97.3% (95% CI 96.1–98.1) 14–30 days after the booster [33]. In Chile, a study of homologous and heterologous booster strategies found effectiveness against hospitalization was 86% for three doses of CoronaVac and 96% with a CoronaVac primary series and a

BNT162b2 booster [34]. In Argentina in October 2021, a press release reported that a single dose of Sputnik Light vaccine was an effective booster for other vaccine platforms [35].

Booster doses of mRNA vaccines BNT162b2 or mRNA-1273 were effective in Singaporean adults, with 73% protection against confirmed infection and 95% protection against severe infection compared with individuals who had no booster [36]. Heterologous boosting with mRNA-1273 after a BNT162b2 primary series conferred greater protection than three BNT162b2 doses (82% versus 73%) [36]. Among South African healthcare workers, a homologous booster of Ad26.COV.2 was up to 85% effective against hospitalization [37].

Vaccine Effectiveness against the Omicron Variant

In November 2021, the SARS-CoV-2 variant B.1.1.529 (Omicron) was designated a variant of concern by the World Health Organization [38] and rapidly became predominant globally [4]. Omicron is more transmissible than earlier variants of concern and with greater antibody escape [39]; thus, it is important to examine vaccine effectiveness data in the Omicron era. The SARS-CoV-2 Omicron variant (B.1.1.529 or BA.1) has since been replaced by successive emerging lineages BA.2, followed by BA.4 and BA.5. Since the emergence of the Omicron variant and its subvariants, vaccine effectiveness data confirm that protection against disease from current vaccines is lower than for previous variants [38–41]. Importantly, vaccination remains associated with higher levels of protection against the severe outcomes due to Omicron [41]. With Omicron BA.5 now predominant [4], it is likely that contemporary data of effectiveness against this subvariant will be available shortly. A recent Brazilian study examined vaccine effectiveness during a period of Omicron predominance against symptomatic COVID-19 and severe COVID-19 (hospital admission or deaths) for a CoronaVac primary series and homologous (CoronaVac) and heterologous (BNT162b2) booster doses [42]. Vaccine effectiveness 8–59 days after a homologous booster with inactivated vaccine was 9% against symptomatic COVID-19 and 74% against severe COVID-19; a BNT162b2 mRNA booster gave additional protection, with vaccine effectiveness of 57% and 86% against symptomatic and severe COVID-19, respectively [42]. In Chile, effectiveness of CoronaVac in a 2-dose primary series in children found modest protection against symptomatic infection with the Omicron variant (38%), but higher protection against severe disease (approximately 65%) [43].

In Singapore, two primary doses of BNT162b2 in adolescents was 25% and 75% effective against Omicron-associated infection and hospitalization, respectively, while a booster dose achieved effectiveness of 56% against infection and 94% against hospitalization compared with unvaccinated individuals [44]. Similarly, a study in children 5–11 years old in Singapore during the Omicron wave reported effectiveness of BNT162b2 of 37% against reported infection and 83% against hospitalization [45].

In South African healthcare workers, vaccine effectiveness of BNT162b2 was 71–88% against Omicron-associated hospitalization from 13 days to 4 months after the second dose; two doses of Ad26.COV2.S were similarly effective [40]. In another South African study, BNT162b2 effectiveness against hospitalization was estimated to be 70% during the Omicron period versus 93% in the period when Delta was predominant [46]. Another South African study found that a third dose of BNT162b2 was 66% and 69% effective against Omicron BA.1/BA.2- and BA.4/BA.5-associated hospitalization, respectively, between 1 and 2 months after the third dose, although effectiveness waned 3 to 4 months after the third dose to 50% and 47%, respectively [47]. In Qatar, two doses of mRNA-1273 or BNT162b2 had comparable, moderate, and short-lived protection against symptomatic Omicron infection (43–48% in the first 3 months after dose 2) but were highly protective against Omicron-associated severe disease or death (70–80% at any time after dose 2) [48]. In the same study, a booster dose of BNT162b2 was > 90% effective against severe, critical, or fatal COVID-19 [48]. In Qatar, BNT162b2 booster effectiveness against symptomatic Omicron infection was 49% and 77% against

COVID-19–related hospitalization and death due to Omicron infection versus the primary series [49]. The same study reported booster effectiveness of mRNA-1273 against symptomatic Omicron infection versus the primary series of 47%, but the effectiveness of mRNA-1273 against COVID-19–related hospitalization and death could not be calculated [49]. Another study from Qatar investigated the effectiveness of vaccination with BNT162b2 or mRNA-1273, immunity from previous infection with a variant other than Omicron, and hybrid immunity (previous infection plus vaccination) against symptomatic Omicron infection [50]. The effectiveness of three BNT162b2 doses was 52%, while the effectiveness of previous infection plus two or three doses of BNT162b2 was 55% and 77%, respectively [50]. All types of immunity had strong protection (> 70%) against severe COVID-19 or COVID-19–related hospitalization or death [50].

IMPLICATIONS FOR FUTURE VACCINATION POLICIES

Vaccination remains the key strategy to protect against COVID-19, help curb the pandemic, and maintain protection from new SARS-CoV-2 variants [51]. It is estimated that nearly 20 million lives were saved through vaccination during the first year of COVID-19 vaccine rollouts [52].

At the early stages of the pandemic, limited access, production shortages, economic constraints, and even political and public health neglect could have contributed to the variety of vaccination strategies deployed in the studied regions [53–55]. Compared with the USA or most European Union countries, which established their vaccination strategy only on the basis of mRNA and viral vector vaccines from four main brands [11], many of the countries studied in this review used three or more different vaccine platforms in their mass vaccination programs, chosen from more than ten brands. This diversity brings substantial complexity to vaccine implementation, considering the differences in cold chain, handling, and storage particularities and the potential impact on cost, healthcare provider training, vaccination uptake, and even in vaccine confidence [56]. Despite all challenges, vaccination coverage in adults for the primary schedule was generally high among the countries studied.

Although the supply of COVID-19 vaccines to low- and lower-middle-income countries now appears less constrained compared with earlier in the pandemic [57], booster uptake seems a challenge in most of the countries studied. Efforts to prioritize booster vaccinations in adults and high-risk groups [58], together with limited local capability to maintain mass-vaccination infrastructure [56], could potentially explain the suboptimal implementation of COVID-19 vaccines for younger age groups, particularly those younger than 12 years. Robust evidence coming from the regions studied could provide additional support for earlier policy preference of using an mRNA vaccine as a booster because of the safety profile and higher effectiveness against severe outcomes, especially during the Omicron circulation period [40, 42, 46, 47, 49, 50, 59, 60].

While North American countries and some European countries are already planning a programmatic use of COVID-19 vaccines, which includes bivalent booster (formulations containing the spike protein sequences from both the ancestral Wuhan strain and an Omicron variant) implementation in the autumn of 2022 [61, 62], a sustainable approach in the pandemic-to-endemic period is still not clear in most of the studied countries. Despite a substantial decrease in the number of severe COVID-19 cases and associated deaths, uncertainties remain regarding the trajectory of SARS-CoV-2 and the clinical impact of future variants [63]. Vaccination against COVID-19, including among children and adolescents, is likely the primary strategy to end the pandemic [64–66]. Countries and regions need strategies in place to overcome vaccine inequity, fatigue, hesitancy, and misinformation [63], as well as ensuring access and supply.

A limitation of this review is that not all countries from each region are included due to the data available at the time of writing. Additionally, the rapidly evolving nature of the COVID-19 pandemic means that vaccination data and vaccine recommendations will have

changed since the time of this writing. A strength of this article, however, is that this is the first review to gather comprehensive vaccine recommendations from countries in Latin America, Asia, and Africa and the Middle East, regions that are mostly represented by low- and lower middle-income countries. There is still an important gap in COVID-19 vaccine implementation in some countries; future vaccination strategies should consider the lessons learned in these regions.

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Data Availability. Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

REFERENCES

1. World Health Organization. WHO Director-General's opening remarks at the COVID-19 media briefing– 12 July 2022. Available at: https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-covid-19-media-briefing–12-july-2022. Accessed 20 Jul 2022.
2. Center for Systems Science and Engineering at Johns Hopkins University. COVID-19 Dashboard. Available at: https://coronavirus.jhu.edu/map.html. Accessed 15 Jul 2022.
3. World Health Organization. Weekly epidemiological update on COVID-19—3 August 2022. Available at: https://www.who.int/publications/m/item/weekly-epidemiological-update-on-covid-19—3-august-2022. Accessed 15 Aug 2022.
4. GISAID. Genomic epidemiology of SARS-CoV-2 with subsampling focused globally over the past 6 months. Available at: https://gisaid.org/phylodynamics/global/nextstrain/. Accessed 15 Aug 2022.
5. World Health Organization. Accelerating COVID-19 Vaccine Deployment. Available at: https://www.

who.int/publications/m/item/accelerating-covid-19-vaccine-deployment. Accessed 15 Aug 2022.

6. Tang JW, Caniza MA, Dinn M, et al. An exploration of the political, social, economic and cultural factors affecting how different global regions initially reacted to the COVID-19 pandemic. Interface Focus. 2022;12:20210079.

7. Ruano AL, Rodríguez D, Rossi PG, Maceira D. Understanding inequities in health and health systems in Latin America and the Caribbean: a thematic series. Int J Equity Health. 2021;20:94.

8. Jurzyk EM, Nair MM, Pouokam N, et al. IMF Working Paper: COVID-19 and inequality in Asia: breaking the vicious cycle. Available at: https://www.imf.org/en/Publications/WP/Issues/2020/10/16/COVID-19-and-Inequality-in-Asia-Breaking-the-Vicious-Cycle-49807. Accessed 15 Aug 2022.

9. Fawcett L. The Middle East and COVID-19: time for collective action. Global Health. 2021;17:133.

10. Palanica A, Jeon J. Initial mix-and-match COVID-19 vaccination perceptions, concerns, and side effects across Canadians. Vaccines (Basel). 2022;10:93.

11. Our World in Data. Coronavirus (COVID-19) Vaccinations. Available at: https://ourworldindata.org/covid-vaccinations?country=OWID_WRL#how-many-doses-have-been-donated-by-each-country. Accessed 19 Oct 2022.

12. Dron L, Kalatharan V, Gupta A, et al. Data capture and sharing in the COVID-19 pandemic: a cause for concern. Lancet Digit Health. 2022;4:e748–56.

13. Tartof SY, Slezak JM, Fischer H, et al. Effectiveness of mRNA BNT162b2 COVID-19 vaccine up to 6 months in a large integrated health system in the USA: a retrospective cohort study. Lancet. 2021;398:1407–16.

14. Villela DAM, de Noronha TG, Bastos LS, et al. Effectiveness of mass vaccination in Brazil against severe COVID-19 cases. medRxiv. 2021:2021.09.10.21263084.

15. Jara A, Undurraga EA, Gonzalez C, et al. Effectiveness of an inactivated SARS-CoV-2 vaccine in Chile. N Engl J Med. 2021;385:875–84.

16. Araos R, Jara A. Covid-19 vaccine effectiveness assessment in Chile. vCovid – Ministry of Health, Chile. Available at: https://cdn.who.int/media/docs/default-source/blue-print/chile_rafael-araos_who-vr-call_25oct2021.pdf?sfvrsn=7a7ca72a_7. Accessed 13 Jul 2022.

17. Macchia A, Ferrante D, Angeleri P, et al. Evaluation of a COVID-19 vaccine campaign and SARS-CoV-2 infection and mortality among adults aged 60 years and older in a middle-income country. JAMA Netw Open. 2021;4: e2130800.

18. Arregoces-Castillo L, Fernandez-Nino J, Rojas-Botero M, et al. Effectiveness of COVID-19 vaccines in older adults in Colombia: a retrospective, population-based study of the ESPERANZA cohort. Lancet Healthy Longev. 2022;3:e242–52.

19. The Brazilian Report. Uruguay says CoronaVac is 66-percent effective in preventing COVID-19. Available at: https://brazilian.report/liveblog/2021/06/09/uruguay-coronavac-effective/. Accessed 13 Jul 2022.

20. Bobdey S, Kaushik SK, Sahu R, et al. Effectiveness of ChAdOx1 nCOV-19 vaccine: experience of a tertiary care institute. Med J Armed Forces India. 2021;77:S271–7.

21. Kaur U, Bala S, Ojha B, et al. Occurrence of COVID-19 in priority groups receiving ChAdOx1 nCoV-19 coronavirus vaccine (recombinant): a preliminary analysis from north India. J Med Virol. 2022;94:407–12.

22. Suah JL, Tok PSK, Ong SM, et al. PICK-ing Malaysia's epidemic apart: effectiveness of a diverse COVID-19 vaccine portfolio. Vaccines (Basel). 2021;9:1381.

23. Abdul Taib NA, Baha Raja D, Teo AKJ, et al. Characterisation of COVID-19 deaths by vaccination types and status in Malaysia between February and September 2021. Lancet Reg Health West Pac. 2022;18: 100354.

24. Husin M, Tok PSK, Suah JL, et al. Real-world effectiveness of BNT162b2 vaccine against SARS-CoV-2 infection among adolescents (12–17-year-olds) in Malaysia. Int J Infect Dis. 2022;121:55–7.

25. AlQahtani M, Bhattacharyya S, Alawadi A, et al. Morbidity and mortality from COVID-19 post-vaccination breakthrough infections in association with vaccines and the emergence of variants in Bahrain. Available at: https://icap.columbia.edu/tools_resources/morbidity-and-mortality-from-covid-19-post-vaccination-breakthrough-infections-in-association-with-vaccines-and-the-emergence-of-variants-in-bahrain/. Accessed 13 Jul 2022.

26. Meo SA, Fahad Al-Jassir F, Al-Qahtani S, et al. Effect of Pfizer/BioNTech and Oxford/AstraZeneca vaccines against COVID-19 morbidity and mortality in real-world settings at countrywide vaccination campaign in Saudi Arabia. Eur Rev Med Pharmacol Sci. 2021;25:7185–91.

27. Alsaffar WA, Alwesaibi AA, Alhaddad MJ, et al. The effectiveness of COVID-19 vaccines in improving

the outcomes of hospitalized COVID-19 patients. Cureus. 2022;14: e21485.

28. AlKhafaji DM, Al Argan RJ, AlBahrani S, et al. The impact of vaccination against SARS-CoV-2 virus on the outcome of COVID-19 disease. Infect Drug Resist. 2022;15:3477–89.

29. Abu-Raddad LJ, Chemaitelly H, Bertollini R. Effectiveness of mRNA-1273 and BNT162b2 vaccines in Qatar. N Engl J Med. 2022;386:799–800.

30. Abu-Raddad LJ, Chemaitelly H, Bertollini R. Waning mRNA-1273 vaccine effectiveness against SARS-CoV-2 infection in Qatar. N Engl J Med. 2022;386: 1091–3.

31. Chemaitelly H, Tang P, Hasan MR, et al. Waning of BNT162b2 vaccine protection against SARS-CoV-2 infection in Qatar. N Engl J Med. 2021;385: e83.

32. Suah JL, Husin M, Tok PSK, et al. Waning COVID-19 vaccine effectiveness for BNT162b2 and CoronaVac in Malaysia: an observational study. Int J Infect Dis. 2022;119:69–76.

33. Cerqueira-Silva T, Katikireddi SV, de Araujo OV, et al. Vaccine effectiveness of heterologous CoronaVac plus BNT162b2 in Brazil. Nat Med. 2022;28: 838–43.

34. Jara A, Undurraga EA, Zubizarreta JR, et al. Effectiveness of homologous and heterologous booster doses for an inactivated SARS-CoV-2 vaccine: a large-scale prospective cohort study. Lancet Glob Health. 2022;10:e798–806.

35. Sputnik V Press Release. Interim results of a pioneering combination study in Argentina with more than 1,000 participants confirm the one-shot Sputnik Light vaccine (the first component of the Sputnik V vaccine) is an effective universal booster for vaccines produced by AstraZeneca, Sinopharm, Moderna and Cansino inducing strong immune response and showing high safety profile. Combination of AstraZeneca and Sputnik Light vaccines showed high immunogenicity results. Available at: https://sputnikvaccine.com/newsroom/pressreleases/interim-results-of-a-pioneering-combination-study-in-argentina-with-more-than-1-000-participants/. Accessed 16 Aug 2022.

36. Tan S, Pung R, Wang L-F, et al. Protection of homologous and heterologous vaccine boosters against COVID-19 in Singapore. SSRN Electronic Journal. 2021.

37. Gray GE, Collie S, Garrett N, et al. Vaccine effectiveness against hospital admission in South African health care workers who received a homologous booster of Ad26.COV2 during an Omicron COVID19 wave: preliminary results of the Sisonke 2 study. medRxiv. 2021:2021.12.28.21268436.

38. World Health Organization. Update on Omicron. Available at: https://www.who.int/news/item/28-11-2021-update-on-omicron. Accessed 16 Aug 2022.

39. Centers for Disease Control and Prevention. Omicron variant: what you need to know. Available at: https://www.cdc.gov/coronavirus/2019-ncov/variants/omicron-variant.html#:~:text=The%20Omicron%20variant%20spreads%20more,spread%20the%20virus%20to%20others. Accessed 16 Aug 2022.

40. Gray G, Collie S, Goga A, et al. Effectiveness of Ad26.COV2.S and BNT162b2 vaccines against Omicron variant in South Africa. N Engl J Med. 2022;386:2243–5.

41. Le TTB, Vasanthakumaran T, Thi Hien HN, et al. SARS-CoV-2 Omicron and its current known unknowns: a narrative review. Rev Med Virol. 2022;33:e2398.

42. Ranzani OT, Hitchings MDT, de Melo RL, et al. Effectiveness of an inactivated COVID-19 vaccine with homologous and heterologous boosters against Omicron in Brazil. Nat Commun. 2022;13: 5536.

43. Jara A, Undurraga EA, Zubizarreta JR, et al. Effectiveness of CoronaVac in children 3–5 years of age during the SARS-CoV-2 Omicron outbreak in Chile. Nat Med. 2022;28:1377–80.

44. Chiew CJ, M P, Wei WE, et al. Vaccine effectiveness against COVID-19 infection among 12 to 18 year olds in Singapore. SSRN Electronic Journal. 2022.

45. Tan SHX, Cook AR, Heng D, et al. Effectiveness of BNT162b2 vaccine against Omicron in children 5–11 years of age. N Engl J Med. 2022;387:525–32.

46. Collie S, Champion J, Moultrie H, Bekker LG, Gray G. Effectiveness of BNT162b2 vaccine against Omicron variant in South Africa. N Engl J Med. 2022;386:494–6.

47. Collie S, Nayager J, Bamford L, et al. Effectiveness and durability of the BNT162b2 vaccine against Omicron sublineages in South Africa. N Engl J Med. 2022;387:1332–3.

48. 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;13:3082.

49. Abu-Raddad LJ, Chemaitelly H, Ayoub HH, et al. Effect of mRNA vaccine boosters against SARS-CoV-

2 Omicron infection in Qatar. N Engl J Med. 2022;386:1804–16.

50. Altarawneh HN, Chemaitelly H, Ayoub HH, et al. Effects of previous infection and vaccination on symptomatic Omicron infections. N Engl J Med. 2022;387:21–34.

51. World Health Organization. COVID-19 advice for the public: getting vaccinated. Available at: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/covid-19-vaccines/advice. Accessed 16 Aug 2022.

52. World Health Organization. WHO releases global COVID-19 vaccination strategy update to reach unprotected. Available at: https://www.who.int/news/item/22-07-2022-who-releases-global-covid-19-vaccination-strategy-update-to-reach-unprotected. Accessed 16 Aug 2022.

53. Kim D, Keskinocak P, Pekgun P, Yildirim I. The balancing role of distribution speed against varying efficacy levels of COVID-19 vaccines under variants. Sci Rep. 2022;12:7493.

54. Ayenigbara IO, Adegboro JS, Ayenigbara GO, Adeleke OR, Olofintuyi OO. The challenges to a successful COVID-19 vaccination programme in Africa. Germs. 2021;11:427–40.

55. Lancet Commission on C-V, Therapeutics Task Force M. Urgent needs of low-income and middle-income countries for COVID-19 vaccines and therapeutics. Lancet. 2021;397:562–4.

56. Wouters OJ, Shadlen KC, Salcher-Konrad M, et al. Challenges in ensuring global access to COVID-19 vaccines: production, affordability, allocation, and deployment. Lancet. 2021;397:1023–34.

57. Pilkington V, Keestra SM, Hill A. Global COVID-19 vaccine inequity: failures in the first year of distribution and potential solutions for the future. Front Public Health. 2022;10: 821117.

58. World Health Organization. WHO SAGE roadmap for prioritizing uses of COVID-19 vaccines. Available at: https://www.who.int/publications/i/item/WHO-2019-nCoV-Vaccines-SAGE-Prioritization-2022.1. Accessed 24 Oct 2022.

59. Cerqueira-Silva T, Andrews JR, Boaventura VS, et al. Effectiveness of CoronaVac, ChAdOx1 nCoV-19, BNT162b2, and Ad26.COV2.S among individuals with previous SARS-CoV-2 infection in Brazil: a test-negative, case-control study. Lancet Infect Dis. 2022;22:791–801.

60. Murillo-Zamora E, Trujillo X, Huerta M, et al. First-generation BNT162b2 and AZD1222 vaccines protect from COVID-19 pneumonia during the Omicron variant emergence. Public Health. 2022;207:105–7.

61. Centers for Disease Control and Prevention. UPDATED: CDC fall vaccination operational planning guide. Available at: https://www.cdc.gov/vaccines/covid-19/downloads/cdc-fall-vaccination-operational-planning-guide.pdf. Accessed 24 Oct 2022.

62. European Commission. European Health Union: Statement by Commissioner Stella Kyriakides on the authorisation of the first COVID-19 variant-adapted booster vaccines. Available at: https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_22_5272. Accessed 24 Oct 2022.

63. World Health Organization. Statement on the thirteenth meeting of the International Health Regulations (2005) Emergency Committee regarding the coronavirus disease (COVID-19) pandemic. Available at: https://www.paho.org/en/news/19-10-2022-statement-thirteenth-meeting-international-health-regulations-2005-emergency. Accessed 24 Oct 2022.

64. Iacobucci G. Covid-19: vaccinating children will help end pandemic, says minister. BMJ. 2021;374:n2254.

65. American Medical Association. COVID-19 update: Stephen Parodi, MD, on shifting from pandemic to endemic. Available at: https://www.ama-assn.org/delivering-care/public-health/stephen-parodi-md-shifting-pandemic-endemic. Accessed 24 Oct 2022.

66. American Medical Association. Vaccination is our best chance to end the pandemic. Available at: https://www.ama-assn.org/about/leadership/vaccination-our-best-chance-end-pandemic. Accessed 24 Oct 2022.

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