

BMJ Open A systematic review of strategies adopted to scale up COVID-19 testing in low-, middle- and high-income countries

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ABSTRACT

Objective We undertook a systematic review of strategies adopted to scale up COVID-19 testing in countries across income levels to identify successful approaches and facilitate learning.

Methods Scholarly articles in English from PubMed, Google scholar and Google search engine describing strategies used to increase COVID-19 testing in countries were reviewed. Deductive analysis to allocate relevant text from the reviewed publications/reports to the a priori themes was done.

Main results The review covered 32 countries, including 11 high-income, 2 upper-middle-income, 13 lower-middle-income and 6 low-income countries. Most low- and middle-income countries (LMICs) increased the number of laboratories available for testing and deployed sample collection and shipment to the available laboratories. The high-income countries (HICs) that is, South Korea, Germany, Singapore and USA developed molecular diagnostics with accompanying regulatory and legislative framework adjustments to ensure the rapid development and use of the tests. HICs like South Korea leveraged existing manufacturing systems to develop tests, while the LMICs leveraged existing national disease control programmes (HIV, tuberculosis, malaria) to increase testing. Continent-wide, African Centres for Disease Control and Prevention-led collaborations increased testing across most African countries through building capacity by providing testing kits and training.

Conclusion Strategies taken appear to reflect the existing systems or economies of scale that a particular country could leverage. LMICs, for example, drew on the infectious disease control programmes already in place to harness expertise and laboratory capacity for COVID-19 testing. There however might have been strategies adopted by other countries but were never published and thus did not appear anywhere in the searched databases.

INTRODUCTION

At the end of 2019, a disease that presented with pneumonia in the Chinese city of Wuhan emerged.¹ The disease (caused by the SARS-CoV-2 virus) was later named COVID-19 and subsequently declared a global pandemic by

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ There have been challenges in testing in both developed and developing countries.
- ⇒ The strength of this systematic review is that it covers many countries across different income categories and provides strategies that worked for countries that other countries could leverage to increase testing now and for future pandemics.
- ⇒ The findings point to the diverse nature of the laboratory response across both developed and developing nations, mainly driven by the nature of existing capabilities and expertise.
- ⇒ The major limitation of this systematic review is an inability to link the testing strategies to testing rates in each country.

the WHO on 11 March 2020. Almost 2 years into the pandemic, both big and small economies have been hugely affected, and countries will likely continue to suffer for many years after the pandemic's peak. As of 16 December 2021, a total of 273 019 599 cases and 5 338 972 deaths from COVID-19 have been reported.² In North America, the USA has notified most cases per 100 000 population while the UK, India, Brazil and South Africa top the list in Europe, Asia, South America and Africa, respectively.²

Initially, scientists knew little about the disease and the virus, but there have been significant scientific advancements regarding prevention, diagnosis, treatment and prevention. The world moved from having no or few diagnostic tools to a plethora of diagnostic tools. Furthermore, there has been an unprecedented rapid development and deployment of vaccines, which could be game-changing to ending the pandemic. However, control efforts have been complicated by the emergence of variants, threatening vaccine efficacy.³



Beyond the non-pharmacological interventions deployed by countries to combat the pandemic, testing has been deployed to control the spread of COVID-19 by identifying, isolating and treating those infected. Indeed, a few months into the pandemic, WHO called on countries to 'test, test and test'.^{4 5} This was premised on the belief that early testing and contact tracing could interrupt transmission.

Amidst the calls for increased testing, WHO developed an emergency use listing procedure to expedite in vitro diagnostics to support testing,⁶ to ensure the availability of diagnostics needed for the public health emergency. WHO also made several recommendations to guide countries on testing. Initial guidance on approaches to testing was based on the number of cases reported per country (sporadic cases, clusters of cases and community transmission). WHO suggested the need for prioritised testing strategies within countries due to the variation in levels of community transmission.⁷ With the emergence of new tools like antigen detection rapid diagnostic tests (RDTs), the recommendations have been updated. WHO maintained nucleic acid amplification tests (NAAT) as the reference standard and recommended antigen RDTs as a complementary strategy.⁸

Despite the advice that testing should underpin the disease control efforts, there have been shortfalls across different countries. There is a noticeable lack of harmonised testing strategies across the globe due to several challenges, including the prepandemic laboratory capacity, barriers to access of tests due to increased demand and challenges with supply.⁹ To overcome some of the challenges, countries adopted different strategies to increase the number of tests per capita.

Developing countries (low- and lower-middle-income countries, see Results section for definitions) were deemed more likely to bear the heaviest burden of the pandemic, mainly due to fragile healthcare systems, political instability, economic vulnerability, limited fiscal space, equipment shortages, among others.^{10 11} This, however, does not seem to have been the case. For example, the number of cases in most African countries remains reasonably low, with low mortality rates reported.^{11 12} While there are many possible reasons why cases have stayed lower than anticipated, it is possible that there is inadequate testing in most of these countries. Indeed, low test per capita rates have been noted in Africa.¹³ Some reports have pointed to undercounting of deaths due to COVID-19.¹⁴

Challenges with testing have also been observed in developed countries,^{15 16} indicating that finances alone are not enough to achieve the desired testing capabilities. While the more affluent countries have outcompeted the rest on the COVID-19 diagnostics market,¹⁷ many developing countries have used what they have at their disposal to scale-up testing.

Future pandemics are always a possibility, and lessons must be learnt from the current pandemic to enable robust and expedited responses. There is an opportunity for countries at all income levels to learn lessons

from each other. Based on this background, we undertook a systematic review of strategies adopted to scale up COVID-19 testing in countries of all income levels to identify successful approaches and facilitate shared learning.

METHODS

The overall aim of the systematic review was to examine strategies adopted to scale up COVID-19 testing in low-, middle- and high-income-countries and identify drivers underlying the selection of strategy in a given setting.

Inclusion/exclusion criteria

We included original scholarly articles published in English between December 2019 and September 2021 describing strategies used to increase COVID-19 testing in different countries. Articles included original studies, situational and practice reports, case reports, features, commentaries, viewpoints, reviews and perspectives. Any scholarly articles that proposed strategies to scale up testing, but with no mention of whether these strategies had been implemented were excluded. The main outcome for the studies was COVID-19 testing strategy and given the diversity in the testing strategies, studies were grouped under themes to support the analysis.

Search strategy

The search was performed using resources and methods that ensure methodological transparency and reproducibility of the findings, leveraging the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols (PRISMA-P) guidelines.¹⁸ The search strategy was guided by the patient/population, intervention, comparison and outcomes (PICO) approach. For this case, the population was the individuals in the countries, intervention was the COVID-19 testing, while the outcome was COVID-19 testing strategy countries. The study did not have a comparative reference. We asked: *What strategies were adopted to scale up COVID-19 testing in Low- Middle and High-Income countries?* To obtain more relevant articles, we reviewed the bibliography section of the reviewed articles.

We used the following terms/statements to search the studies for consideration in the systematic review: COVID-19 diagnostics in Asia, South America, Latin America, Europe, North America; COVID-19 diagnostics in high-income countries; COVID-19 diagnostics in middle-income countries; COVID-19 diagnostics in low-income countries; COVID-19 testing in high-income countries; COVID-19 diagnostics in Asia, South America, Latin America, Europe, North America; increasing COVID-19 testing in Asia, South America, Latin America, Europe, North America and COVID-19 laboratory testing strategies. The publications returned by the search strategies are summarised in online supplemental table 1, while the publications included and the corresponding testing strategies are summarised in online supplemental table 2.

Data access and management

The investigation team of three researchers accessed the internet sources (PubMed, Google scholar, and google

search engine), identified and retrieved all the articles. All the retrieved articles were carefully analysed to identify and remove duplicates and irrelevant articles. Researchers through consensus agreed on the final list to consider. The team used the Mendeley referencing manager to store, organise and manage all the articles.

Database/sources searched

The researchers independently searched for scholarly articles (original studies, situational and practice reports, case reports, features, commentaries, viewpoints, reviews and perspectives) in PubMed, Google scholar and Google search engine (all last searched on 17 September 2021). Titles and abstracts were independently screened by researchers based on the inclusion criteria.

Study selection criteria and process

All qualitative or quantitative scholarly articles describing strategies adopted were included in the general screen. Further refinement considered only studies that offered information on the strategy used to increase COVID-19 testing in low-, middle- and high-income countries were considered further for inclusion.

The selection was carried out by the three researchers working independently. They then convened and reviewed the individual lists and harmonised to agree on one list of studies to be included. The three researchers have post-graduate qualifications in health-related disciplines.

Data extraction

Both abstracts and full texts were read to identify strategies countries used to increase COVID-19 testing. The outcome was COVID-19 testing strategy and in reviewing the selected articles, researchers sought information on the different approaches that countries used to increase and expand COVID-19 testing. This was achieved through the use of a predeveloped codebook that captured the outcome (online supplemental table 3). The codebook guided the identification of strategies and included themes and narratives of what the researchers were to consider as strategies for increasing testing. Where the researchers found any strategy not captured by the codebook, they noted this. The other variable sought in the reviewed articles was the COVID-19 testing methods used. The findings were later harmonised and summarised in a table that included authors, source of publication, date of publication, country, income category and strategy or strategies used.

Data analysis

Analysis entailed appraising and synthesising texts from the scholarly articles, which were then organised into major themes and content analysis, guided by the predeveloped codebook. We used deductive analysis to allocate relevant text from the reviewed publications and reports to the a priori themes. In the process of allocating text, there were emergent new themes. New and a priori themes included accessibility, diagnostics, regulatory and

legislation, integration, personnel, technology and innovation and collaboration.

Patient and public involvement

Patients and the public were not involved in any way.

Ethics statement

No human participants were included.

RESULTS

Study selection and characteristics

A total of 174 scholarly articles (134 publications and 40 reports) were identified by the search strategy, of which 59 peer-reviewed publications and 12 reports met the inclusion criteria and were reviewed in detail. The flow diagram (figure 1) summarises the steps to identify the publications and reports included in the review. Online supplemental table 4 represents the details of all papers and reports included and the findings.

Geoeconomic coverage of included publications/reports

The selected publications and reports covered six continents (Asia, Africa, North America, Europe, South America, Oceania). There are 32 countries, and of these 11 are high-income-countries, 2 are upper-middle-income, 13 are lower-middle-income and 6 are low-income-countries. Table 1 shows the countries' corresponding gross domestic product per capita (US\$).¹⁹

Testing strategies applied by different countries

Through content analysis, evidence was noted, demonstrating countries adopted diverse strategies to increase testing. These strategies are indicated in table 2 and summarised by income category in table 3 and by individual countries in online supplemental table 4. Notably, the strategies used were not exclusive, as some countries combined several strategies.

The results are presented in the following seven thematic areas.

1. Increasing accessibility

Accessibility encapsulates the strategies countries adopted to ensure that the testing services had a wider geographical reach closer to the people and that whoever needed a test would be able to get it. Under this theme, most countries increased the number of laboratories available for testing, while others increased sample collection points and referral to the available laboratories. The frequency of using these strategies was high in low- and middle-income countries and low in high-income countries. The increment was gradual, with more laboratories being recruited to meet the demand during the pandemic. High-income countries introduced drive-through testing to bring testing closer to the people. Sample collection and referral was mainly deployed by the low-income and the lower-middle-income countries, while community-wide testing using community health workers was done by the middle-income countries. The high- and

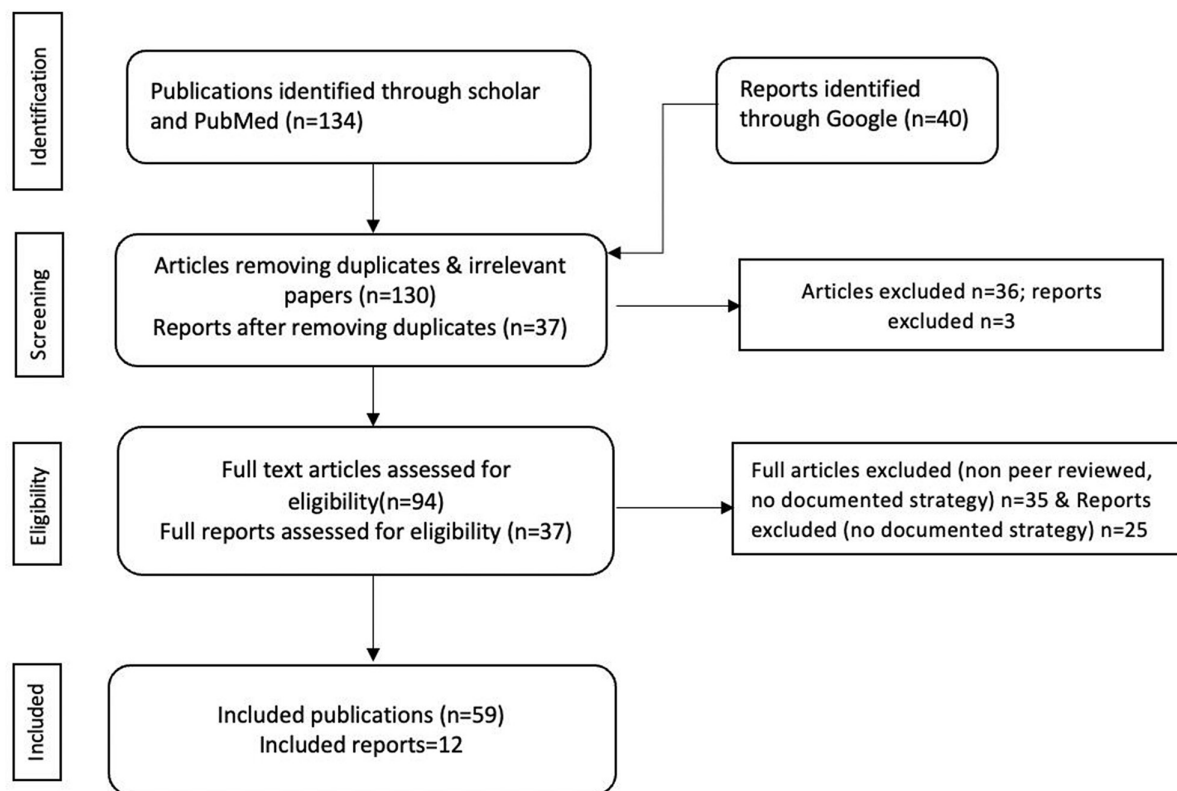


Figure 1 Flow diagram of included publications.

upper-middle-income countries increased testing rates by identifying the COVID-19 transmission hot spots in their countries and subsequently undertook mass testing. While the middle- and high-income countries could set up mobile testing units, this was not the case for the low-income countries.

2. Expanding and diversifying diagnostic platforms

Under this strategy, the diversity of diagnostics and testing modalities were considered. This included strategies that incorporated the use of RDTs, development of molecular tests, development and subsequent use of RDTs, repurposing manufacturing capacity to develop tests, community-wide testing with RDT and initiatives to support the production of diagnostics. Development of molecular diagnostics was undertaken in the high-income countries (South Korea, Germany, Singapore, USA) but not in the low- and middle-income countries except Vietnam, which reported producing a molecular diagnostic to increase testing. In a bid to increase testing, both high-income (South Korea, Chile, UK) and lower-middle-income countries (India, Bangladesh, Vietnam, Ghana) developed RDTs. Adopting RDTs increased the testing rates in these countries. Only one country (USA) reported repurposing manufacturing capacity to manufacture testing kits. Both high- and upper-middle-income countries carried out massive testing with RDTs.

3. Streamlining the regulatory and legislative landscape

Streamlining the regulatory and legislative landscape evolved in two ways: accelerating the manufacturing

process and increasing the number of laboratories available for testing. Governments of high-income countries adjusted the regulatory and legislative frameworks to ensure the rapid development and the use of the developed tests. For example, the USA and South Korea deployed emergency use authorisation and saved the manufacturers from bureaucratic and administrative inefficiencies associated with the approval process for the diagnostics. The governments also linked test manufacturers with the clinical bodies to help fast-track the validation process. As a result, tests were readily available for use in a short timeframe. In Singapore, public-private partnerships were instrumental in ensuring the massive production of tests.

Governments also made regulatory and legislative adjustments to ensure more laboratories became available for COVID-19 testing. The added laboratories included the private, research and academic laboratories. This was noted mainly in the upper-middle-, lower-middle- and low-income countries. For example, France, brought private providers later in the pandemic to avoid the possibility of having non-harmonised reporting.

Also, as part of the regulations and strategies to attract private test developers, the high-income countries (USA, South Korea) deployed initiatives to interest private developers in manufacturing. Such initiatives included easing the approval processes and assurance that the governments would buy the developed kits.

Table 1 Countries included in the systematic review and the corresponding GDP

Country	GDP (US\$)
High-income countries	
Canada	43241.6
France	38625.1
Belgium	44594.4
Uruguay	15438.4
Slovakia	19156.9
South Korea	31489.1
Australia	51812.2
Chile	13231.7
USA	63543.6
Singapore	59797.8
Israel	43610.5
Upper middle-income countries	
China	10434.8
South Africa	5090.7
Peru	6126.9
Lower middle-income countries	
India	1900.7
Nepal	1155.1
Nigeria	2097.1
Vietnam	2785.7
Bangladesh	1968.8
Ghana	2328.5
Pakistan	1193.7
Mongolia	4007.3
Zambia	1050.9
Zimbabwe	1128.2
Philippines	3298.8
Bhutan	3122.4
Low-income countries	
Malawi	625.3
Democratic Republic of the Congo	556.8
Rwanda	797.9
Ethiopia	936.3
Sierra Leone	484.5
Uganda	817.0

GDP, gross domestic product.

4. Leveraging existing systems

The countries leveraged existing systems in two ways. One, using the current systems and frameworks to scale up the development of diagnostics and second, using the existing systems to incorporate COVID-19 testing.

High-income countries like South Korea leveraged structures established during the previous epidemics like Middle East respiratory syndrome (MERS) to be able to develop tests in a short time. Low- and middle-income-countries integrated COVID-19 testing within the existing disease systems to increase testing. The countries

leveraged the testing systems available for other diseases like tuberculosis, HIV and influenza to embark on testing for COVID-19. In most of these countries, there were existing platforms for HIV viral load monitoring and Xpert MTB/RIF testing, which were leveraged to test for COVID-19. The integration also leveraged already set up systems to increase testing. For example, Nigeria leveraged the established polio systems to ensure the collection and transport of samples to the testing facilities.²⁰

5. Human resource enhancement

Countries undertook human resource initiatives. Such initiatives included recruiting more health workers and increasing their capacity through training. Recruitment of more personnel happened mainly in the upper-middle-income countries, followed by lower-middle-income countries and then in the low-income countries. The trend was slightly different when it came to increasing capacity through training. The training was conducted mainly in the lower-middle- and low-income countries.

6. Creative use of technology and innovation

Countries such as South Korea and Ghana leveraged the technology to increase COVID-19 testing. South Korea was the first country to roll out a contact tracing and surveillance application to help increase testing. Ghana reported using a contact tracing application to increase testing. Ghana also increased testing by using drones to transport samples from the field to the testing facilities established. Furthermore, Ghana innovatively used pooled testing to increase the number of samples tested with limited kits. Only India reported undertaking health technology assessment (HTA) on a locally developed COVID-19 diagnostic, whereby they assessed the impact of an RDT on health systems in dimensions of efficiency, equity and quality guided by the HTA framework.²¹

7. Leveraging regional and continental networks

While most of the interventions happened at the country level, some of the efforts resulted from continent-wide collaborations led by the continental bodies. By far, the most extensive continental-led testing response was on the African continent, where the African Centres for Disease Control and Prevention (Africa CDC) increased testing across most African countries by building capacity through the provision of testing kits and training. In addition, through the Africa Task Force for Corona Virus and the Partnership to Accelerate COVID-19 testing, the Africa CDC helped increase testing. The Pan African Health Organisation (PAHO) led the efforts in South America and North America by ordering and providing test kits, conducting training and leveraging the national influenza centres to increase the laboratory network.

DISCUSSION

This systematic review of strategies adopted to scale up COVID-19 testing has revealed strategies unique to some

**Table 2** Thematic analysis of the different strategies used by the countries

Theme	Strategies
Increasing accessibility	<ul style="list-style-type: none"> ▶ Increase in the number of laboratories^{9 21 26–28 34 38–40 44 47 53 54 58–64} ▶ Health technology assessments²¹ ▶ Setting up mobile testing units^{26 41 42 61 65} ▶ Population-wide screening/mass testing^{28 66 67} ▶ Gradual expansion of categories of people to test^{5 24 26} ▶ Testing only symptomatic and high-priority groups^{60 63–65} ▶ Drive-through testing/walk-in testing^{68–73} ▶ Community-wide testing using CHWs^{48 74–76} ▶ Sample collection and referral of samples⁴⁸ ▶ Targeted/hot spot with mass testing^{27 77} ▶ Free COVID-19 testing^{26 28 67}
Expanding and diversifying diagnostic platforms	<ul style="list-style-type: none"> ▶ Testing strategy to incorporate the use of RDTs^{10 21 27 34 78 79} ▶ Development of molecular tests^{22 30 58 67} ▶ Development and subsequent use of RDTs^{5 21 26 33 44 45 67} ▶ Repurposing manufacturing capacity³¹ ▶ Massive testing with RDTs⁸⁰ ▶ Initiatives to support the production of diagnostics^{32 81}
Streamlining regulatory and legislative landscape	<ul style="list-style-type: none"> ▶ Licensing private providers/laboratories in testing^{5 23 26 38–42 47 64} ▶ Allowing research and academic institutions^{5 10 40 45–47 59 64} ▶ Legislation to allow for the development of tests^{31 64 67}
Leveraging existing systems	<ul style="list-style-type: none"> ▶ Leveraging existing platforms for testing diseases^{39 40 47 49 53 59 64 82} ▶ Leveraging infrastructure of other disease programmes^{39 42 47 48 53 83 84} ▶ Leveraging previous systems to develop tests^{30 81} ▶ Use of veterinary laboratories^{40 62}
Human resource enhancement	<ul style="list-style-type: none"> ▶ Training of laboratory workers^{46 47 49 53 54 58 60 61} ▶ Hiring of more personnel^{28 48 53}
Creative use of technology and innovation	<ul style="list-style-type: none"> ▶ Pooled testing^{9 27 33} ▶ Information technology to do surveillance and contact tracing^{33 72} ▶ Drone technology to ship samples^{33 42 85}
Leveraging regional and continental networks	1. Africa CDC, PAHO in training and provision of supplies ^{11 47 60 86 87}

CDC, Centres for Disease Control and Prevention; CHWs, community health workers; PAHO, Pan African Health Organisation; RDTs, rapid diagnostic tests.

and common to all countries. We note that the choice of strategy was mainly driven by the previous outbreak management system to leverage the country's income and manufacturing capacity. The adopted strategies fall under seven thematic areas: increasing accessibility, expanding and diversifying diagnostic platforms, streamlining regulatory and legislative landscape, leveraging existing systems, human resource enhancement, creative use of technology and innovation, and leveraging regional and continental networks.

The COVID-19 pandemic caught many countries unawares, irrespective of their income status. For example, in the USA and the UK, initial testing responses are marked by the absence of a clear testing strategy, defective tests and sluggish inclusion of private laboratories.^{22 23} These obstacles were later overcome; private and academic institutions were included and the categories of people prioritised for testing was expanded.²³

Countries in a bid to avail tests to their people took on strategies to improve access. Most countries gradually increased the number of testing laboratories. This was largely done in the low- and middle-income countries and to a lesser extent in high-income countries. The high-income countries introduced drive-through/walk-in testing. The lower- and upper-middle-income countries

undertook community-wide testing using community healthcare workers, a strategy supported by the decentralised nature of the healthcare system in most low- and middle-income countries. Countries like Zambia, South Africa, used community health workers with good results.²⁴

In a bid to save resources, countries adopted the symptomatological approach to ration testing to only those exhibiting COVID-19 like symptoms. While this may have saved resources, it most likely missed many asymptomatic cases that are now thought to have driven the transmission of COVID-19. Both high-, middle- and low-income countries applied the approach, and gradually expanded the categories of individuals to test. High-income countries expanded testing faster than low- and middle-income countries though it is important to note that apart from contact tracing, test seeking is still largely driven by experience of symptoms. Despite healthcare workers being at the front line and the need to have them tested, the UK did not prioritise them until later in the pandemic.²⁵ Whereas large economies like South Korea and Singapore opened up testing to everyone and did mass testing; several African, Asian and European countries across all income categories limited testing to the symptomatic and the high priority groups, and only

Table 3 Strategies by income country

Strategy used	Countries using the strategy (%)			
	HIC	UMIC	LMIC	LIC
Increase in the number of laboratories	25.0	66.7	50.0	57.1
Health technology assessments	0.0	0.0	8.3	0.0
Testing strategy to incorporate the use of RDTs	0.0	33.3	16.7	0.0
Licensing private providers/laboratories in R&D and testing	37.5	66.7	25.0	14.3
Inclusion of research and academic institutions	31.3	66.7	16.7	28.6
Setting up mobile testing units	6.3	33.3	25.0	0.0
Leveraging existing testing platforms for other diseases	0.0	66.7	41.7	42.9
Development of molecular tests	31.3	0.0	8.3	0.0
Development of RDTs	25.0	0.0	33.3	0.0
Repurposing manufacturing capacity	6.3	0.0	0.0	0.0
Training of laboratory personnel	0.0	0.0	33.3	14.3
Increased human resource	0.0	33.3	16.7	14.3
Legislation to allow for the development of tests	18.8	33.3	0.0	0.0
Leveraging existing infrastructure and systems	6.3	33.3	16.7	42.9
Expanding categories of people to test	18.8	0.0	50.0	0.0
Prioritisation of who to test (symptomatic and high-priority groups)	12.5	33.3	16.7	14.3
Pooled testing	6.3	0.0	8.3	0.0
Drive-through testing/walk-in testing	18.8	0.0	0.0	0.0
Community-wide testing using CHWs	0.0	33.3	8.3	0.0
Sample collection and referral	0.0	0.0	8.3	28.6
Use of existing veterinary laboratories	6.3	33.3	0.0	0.0
Massive testing with RDTs	6.3	33.3	0.0	0.0
Identification of hot spots and mass testing	12.5	33.3	0.0	0.0
Initiatives to support the production of diagnostics	6.3	0.0	0.0	0.0
Free COVID-19 testing	6.3	0.0	8.3	0.0
IT to do surveillance and contact tracing	6.3	0.0	8.3	0.0
Drone technology to ship samples	0.0	0.0	8.3	0.0
Massive/large-scale testing	6.3	0.0	0.0	0.0

.CHWs, community health workers; HIC, high-income country; IT, information technology; LIC, low-income country; LMIC, lower middle-income country; R&D, research and development; RDTs, rapid diagnostic tests; UMIC, upper middle-income country.

expanded the categories later. This could largely have been due to the logistical challenges and the need to use the supplies available sparingly as it was hard for most of them to compete.^{24 26–29}

Countries sought to expand and diversify the diagnostic platforms available for COVID-19 testing largely through the development and/or the adoption of molecular and RDTs. For the high-income countries, this was achieved through the development of molecular tests and RDTs, while for other countries, it was mainly through RDTs. All the molecular (reverse transcription PCR (RT-PCR)) diagnostics were developed in the high-income countries^{22 23 30–32} and this to some extent protected them from shortages of RT-PCR testing supplies that other countries had to contend with. RT-PCR testing required highly specialised laboratories that were few in most low- and middle-income countries. Some of these countries adopted RDTs in their testing algorithms as an interim measure. These were either imported or made from

within. Some lower- and middle-income countries developed RDTs, and these helped increase testing^{21 33} and were gradually introduced in other low-income countries to boost testing.^{9 27 34}

Some countries enhanced their regulatory and legislative landscape to maximise the number of tests within the shortest timeframe. High-income countries led the introduction of legislation mainly to increase manufacturing capacity, adoption of new diagnostic tests and accreditation of non-traditional facilities for involvement in testing COVID-19. In the USA, legislation to modify the regulatory framework governing laboratory developed tests led to more tests being introduced later.³¹ However, this came several months into the pandemic. The federal government was blamed for the bureaucracy that prevented the provision of tests by academic and private laboratories and product developers.³⁵ In an emergency, an early response is the key, and lifting non-critical administrative barriers without compromising oversight can help expedite the



delivery of vital products like diagnostics.³⁶ As part of the regulation and licencing, countries included private, academic and research laboratories in the response.

There were differences in the engagement of private stakeholders between high-income countries and the low- and middle-income countries and the point at which they were engaged. While the high-income countries private sector was engaged in the early days of the pandemic as test developers,^{23 32 37} in the low- and middle-income countries, they were engaged in testing.^{38–43} In most of the high-income countries, the private laboratories were engaged in testing quite late.^{23 29} Countries called on academic institutions to support the testing efforts. This was noted across all countries that is, low-, middle- and high-income countries.^{44–46} The academic institutions in most countries have molecular platforms they use mainly for research purposes, and when leveraged could help supplement government level efforts to increase testing. Furthermore, most academic institutions in low- and middle-income countries have collaborative links with partners in the developed world. Such networks could have been leveraged to ensure the availability of kits for testing. Early in the pandemic, the UK engaged the academic institutions by asking them to avail their platforms for use in public facilities. This was later changed and instead the academic institutions were called on to do the testing.⁵

Countries also took advantage of available systems and previous experiences to mount responses to increase COVID-19 testing. While the high-income countries used prior experience to develop tests, the low- and middle-income countries leveraged the systems available to increase testing. The existing systems worked in favour of low- and middle-income countries as they could tap into these to effect testing. The PCR testing footprint within the disease programmes like tuberculosis (TB), HIV, influenza and schistosomiasis were used by most of the low- and middle-income countries.^{40 47–49} All they needed were supplies and the collaborations and donations helped with this.^{11 47 50} With most of the low- and middle-income countries accounting for the highest burden of TB,⁵¹ there have been progressive investments in diagnostics for TB and these have been leveraged for COVID-19 testing. Korea was able to rapidly develop testing kits by leveraging the test development strategy used for MERS.⁵²

Human resources underpin most of the testing needed by the countries, as having equipment alone is not enough. As a result, countries recruited and trained more personnel.^{11 48 49 53 54} Recruitment of extra personnel was mainly reported by the upper-middle-income countries followed by the lower-middle-income countries, while the training of personnel was reported mainly by the lower-middle-income countries followed by the low-income countries. Human resource challenges in low- and middle-income countries have previously been documented,⁵⁵ and the use of this as a strategy was possibly to meet the short falls in number available to run the COVID-19 tests. The recruitment and training of personnel were not

noted in any of the high-income countries, possibly an indicator that these countries are not facing challenges of limited human resources for health.

Some countries were creative and innovative in their approach. To save the limited logistics, Ghana adopted pooled testing.³³ Specimen pooling is a method of screening a large number of patients for an infection and typically involves combining multiple patient specimens into a single test tube than testing multiple samples in separate reaction tubes.⁵⁶ This approach enabled Ghana to increase the number of tests done to the extent that in Africa they posted the highest number of tests done only behind South Africa.³³

There were strategies at continental level, and these were overseen by the relevant bodies. By far, the greatest demonstration of continent-led efforts was in Africa where the African Centres for Disease Control and Prevention (Africa CDC) developed several response initiatives. Africa CDC demonstrated the need for harmonisation, solidarity and coordination at a continental level. They launched a joint continental strategy, the partnership to accelerate COVID-19 testing, purchased kits and equipped several African laboratories.^{11 50} African countries were outcompeted on the global supplies market and through the Africa CDC, pooled purchasing was implemented so that African countries competed as a block (as one large customer).⁴⁷ Similar efforts are noted in South America where the Pan American Health Organisation oversaw country-level coordination, planning and monitoring. It mobilised experts and furnished countries with laboratory supplies for detection of the virus.⁵⁷

The review has revealed that while the response was reactive, mostly trial and error in the early days of the COVID-19 pandemic, it yielded strategies that could be leveraged to support the implementation of evidence-based practices in the present and future epidemic-pandemic scenarios. We have noted how countries drew on the existing systems such as standard operating procedures used in responding to previous epidemics and/or refocusing manufacturing base to produce testing kits. The lesson that can be learnt from this is that preparedness is crucial to put systems in place that can be drawn on to effectively respond to disease outbreaks and epidemics. Testing was only part of the response that included clinical management of patients, contact tracing, quarantining, lockdowns to mention a few. This implies that preparedness should be holistic including health system strengthening (laboratory, clinical, referral system, disease surveillance, procurement and governance), socioeconomic empowerment of people and a flexible legislative and regulatory framework to enable rapid public health intervention in periods of health emergency.

The limitations of this review are that there might have been strategies adopted by other countries but were never published and thus did not appear anywhere in the searched databases. Further, the review only considered scholarly articles in English, and thus there might

be under-representation of strategies used in the non-English-speaking countries.

CONCLUSION

All countries regardless of their income level had unique challenges associated with the scale-up of COVID-19 testing, and the review has revealed evidence that countries used different strategies to increase testing. While the low- and middle-income countries struggled to increase the testing rates as reflected by the low testing rates, they were able to post optimal testing rates because of experience in dealing with disease outbreaks and leveraging of the existing disease control programmes. The high-income countries in Europe and North America, despite their economic advantage, also struggled having enough tests available in the short term to medium term of COVID-19 pandemic. This was not the case in Asia where the high-income economies leveraged the previous disease outbreak experience like SARS, MERS to have in place diagnostics in a short period of time and quickly put in place effective testing strategies. Country's epidemic handling experience, and manufacturing and financial landscape were critical in informing strategy to scale up testing. Learning lessons from the COVID-19 pandemic and strengthening health systems will equip the world to respond more effectively to any future pandemics.

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Supplementary Table 1: Publications from the search strategy

Search strategy	Number of publications
COVID-19 diagnostics in Asia	42
COVID-19 diagnostics South America	26
COVID-19 diagnostics Latin America	17
COVID-19 diagnostics Europe	29
COVID-19 diagnostics North America	30
COVID-19 diagnostics in middle-income countries	37
COVID-19 diagnostics in low-income countries	45
COVID-19 testing in high-income countries	34
Increasing COVID-19 testing in Asia	28
Increasing COVID-19 testing in South America	11
Increasing COVID-19 testing in Latin America	5
Increasing COVID-19 testing in Europe	16
Increasing COVID-19 testing in North America	17
COVID-19 laboratory testing strategies	56

A systematic review of COVID-19 diagnostics uptake pathways in Low- Middle Income and High-Income countries							
Author(s)	Title of the article	Journal name	Type of article	Month & Year Published	Country	Income category (LMIC or HIC)	How COVID-19 testing was increased
Kanchan Mukherjee	Integrating technology, innovation and policy: COVID-19 and HTA	Elsevier- Health policy and technology	research article	Feb-21	India	LMIC	1)Department of science and technology launched initiatives to support COVID-19 response. This lead to development of the FELUDA test for COVID-19 diagnosis. 2)Deployed HTA to assess the innovations 3)testing strategy that used RDP (antigen) and RT-PCR for negative RDT
Pravash Budhathoki, Dhan Bahadur Shrestha, Sitaram Khadka, Santoshi Giri	COVID-19 Status in Nepal and the Way Forward	Europasian Journal of Medical Sciences	review article	Jun-20	Nepal	LMIC	1)Introduction of RDTs in 3 districts 2)PCR testing expanded from national public health lab to 17 centres
Atieme Ogbolosingha	COVID-19 pandemic: Review of impediments to public health measures in SSA	American Journal of Preventive Medicine and Public Health · January 2020	review article	Jun-20	South Africa	UMIC	1) Private pathology labs in SA to supplement public facilities 2) Mobile testing units in SA
					Nigeria	LMIC	1) Mobile testing units
Zheng Li , Cynthia Jones, Girum S. Ejigu, Nisha George, et al	Countries with delayed COVID-19 introduction – characteristics, drivers, gaps and opportunities	Globalisation and Health	research article	2021	24 countries	Mixed	1)Lesotho, Sao Tome & Principle, Cook Islands, Kiribati, Marshal Islands, Micronesia, Nauru, Palua,Samoa, Solomon Islands no incountry testing so export COVID testing was done

Olivier Vandenberg, Delphine Martiny, Olivier Rochas, Alex van Belkum, Zisis Kozlakidis	Considerations for diagnostic COVID-19 tests	Nature reviews- Microbiology	review article	Oct-20	Several		1) Leveraging platforms used for SARS-CoV and MERS to develop tests 2) government intervention seg financial investments and policies instituted to support manufacturing capacity 3) USA introduced legislation to alter regulatory frameworks governing lab developed tests 3) continued operation of manufacturing businesses 4) repurposing of manufacturing capacity 5) Centralised system in UK, clinical lab network in Germany, 6) setting up networks of regional sequencing centres hosted in academic and or public health agencies,,
Shabir Ahmad Lone and Aijaz Ahmad	COVID-19 pandemic – an African perspective	Emerging Microbes & Infections	review article	May-20	Several	mixed	1) Continental efforts like AFCOR helped increase testing labs in Africa from 2 in Feb to 43 by March
Amy S Patterson and Emmanuel Balogun	African responses to COVID-19: The reckoning of agency	african: studies review	review article	Feb-21	Several		1) Donations of test kit from China 2) Continental efforts eg Africa CDC developed a COVID-19 Joint Continental Strategy which included training HCWs in lab dx, 3) PACT formed to strengthen testing capacity on the continent, it procured testing kits and distributed them to several countries, and also created distribution warehouses & distribution hubs 4) AFCOR created btn Africa CDC, WAHO and WHO to increase number of labs conducting testing 5) Partnered with Unitaid, Gates foundation, CHAI on devt of rapid diagnostics
Alfonso Medinilla, Bruce Byiers and Philomena Apiko	Africa regional responses to COVID-19	ecdpm making policies work	discussion paper	May-20	Several		1) central role played by Africa CDC in boosting testing capabilities and trainings (it improved testing capacity of labs across the continent, supplying essential equipment to 48 countries and also provided training 2) Through PACT, established warehousing and distribution hubs across Africa, coordinated the pooled procurement of diagnostics material, and training CHWs to support contact tracing

Zachary Desson, Emmi Weller, Peter McMeekin, Mehdi Ammi	An analysis of the policy responses to the COVID-19 pandemic in France, Belgium, and Canada	Health policy and technology	review article	Dec-20	Canada	HIC	1) Initially had one testing centre and gradually capacity was built in other provinces
					France	HIC	1) France massive testing of suspected cases by hospitals, labs, vet clinics and in both govt and private facilities, which led to non harmonised reporting and later special temporary legislation allowed a secure platform to allow consolidation of results,
					Belgium	HIC	
Luke Taylor	Uruguay is winning against covid-19. This is how	BMJ	feature	Sep-20	Uruguay	HIC	1)Uruguay ramped testing by developing a national testing kit to shield it from market shortages 2) created a network of testing labs in weeks; which included academic labs 3) decentralised testing
Elisabeth Mahase	Covid-19: mass testing in Slovakia may have helped cut infections	BMJ	news	Dec-20	Slovakia	HIC	population wide (mass testing) using an rapid antigen test administered by trained medical personnel instead of self testinf. Only those that tested and were negative were allowed to move
GRID COVID-19 Study Group	Combating the COVID-19 pandemic in a resource-constrained setting: insights from initial response in India	BMJ Global health	Practice article	Oct-20	India	LMIC	1) Increased testing and collection centres 2) expanded testing criteria, 3) engagement of private labs, and existing labs upgraded 4) free of costs testing 5) sample collection kiosks and mobile COVID testing vans 6)(ma6) made in india testing kits on market
Thuong Vu Nguyen, Quang Dai Tran, Lan Trong Phan, Long Ngoc Vu	In the interest of public safety: rapid response to the COVID-19 epidemic in Vietnam	BMJ Global health	Practice article	Jan-21	Vietnam	LMIC	1)collecting samples from people at risk 2) local production of RT-PCR diagnostic kit 3)developed and stocked diagnostic testing products (primers & probes) and antibody tests 4) staff training and assistance 5) increased lab capacity from 2 to 120 labs in 8 months

Senjuti Saha, Madhukar Pai	Can COVID-19 innovations and systems help low- and middle-income countries to re-imagine healthcare delivery?	Med	Commentary	Apr-21	Bangladesh	LMIC	1) Opened up multiple testing labs 2) multiple groups of people within any basic lab training asked to volunteer & support lab techs 3) govt & lab offered training on sample collection across the nation 4) local reagent & supply vendors solved supply chain puzzles to import supplies from different parts 5) expanded program of immunisation and local WHO office leveraged expertise & network of distributing vaccines to instead transport C-19 samples 6) local sequencing capacity and did sequencing for C-19
					India	LMIC	1) utilisation of existing technologies & resources and repurposing existing technologies
Sangchun Choi, Chul Han, Jisook Lee, Sang-Il Kim, In Byung Kim	Innovative screening tests for COVID-19 in South Korea	Clinical and Experimental Emergency Medicine	Commentary	Apr-20	South Korea	HIC	1) established drive through testing for C-19, 2) testing for C-19 at a walking-through site
Patrick Mbulaje, Steven Munharo, Symon F. Nayupe, Parth Patel	Challenges of COVID-19 testing in low-middle income countries (LMICs): the case of Malawi	Journal of laboratory and precision medicine	letter to the editor	Sep-20	Malawi	LIC	1) with support from UNICEF an existing RT-PCR machine at Lilingwe NRL was set up 2) complementary efforts by teaching and research institutions and Malawi-Liverpool Wellcome Trust 3) increased the number of testing facilities in the country 4)
Jean B. Nachege, Ashraf Grimwood, Hassan Mahomed, Geoffrey Fatti, et al	From Easing Lockdowns to Scaling Up Community-based Coronavirus Disease 2019 Screening, Testing, and Contact Tracing in Africa—	Clinical infectious disease	view point	Jan-21	South Africa	UMIC	1) deployed CHCWs for screening & referral for testing 2) leveraging UBV infrastructure for COVID-19, and other diseases like malaria, TB, HIV
					DRC	LIC	1) mplementation of multiprofessional health system of nurses, drs, pharmacists, medical students & CHCWS in senitisation, screening, and testing referral
					Rwanda	LIC	1) Sample collection and referral for testing

	Shared Approaches, Innovations, and Challenges to Minimize Morbidity and Mortality						
Nancy Odendaal	Constructing an “infrastructure of care” – understanding the institutional remnants and socio-technical practices that constitute South Africa’s Covid-19 response	Urban geography	view point	Jul-20	SA	UMIC	1) community wide testing using CHWs in areas identified thru a social vulnerability index
H. Sibiri, S.M. Zankawah, D. Prah	Coronavirus diseases 2019 (COVID-19) response: Highlights of Ghana’s scientific and technological innovativeness and breakthroughs	ethics medicine and public health	commentary	May-20	Ghana	LMIC	1) pooling technique 2) drone technology to transport samples 3) COVID-19 tracker up to identify who needs to be tested 4) development of RDTs
Jimoh Amzat, Kafayat Aminu, Victor I. Kolo, Maryann C. Danjibo	Coronavirus outbreak in Nigeria: Burden and socio-medical response during the first 100 days	international journal of infectious diseases		Sep-20	Nigeria	LMIC	1) prioritised those that need to be tested- returnees, symptomatic, contacts, those in high prevalence areas 2) training experts in RT-PCR by Africa CDC 3) Increased number of testing labs from 5 to 23 within 6 months - only public minus private were testing
A. Waris, U.K. Atta, M. Ali, A. Asmat, A. Baset	COVID-19 outbreak: current scenario of Pakistan	new microbes and new infections	mini review	May 202	Pakistan	LMIC	1) Increased number of testing labs 2) national institute of health opened up a mobile testing lab 3) NIH partnered with national disaster management authority to launch training

							program for paramedics and lab staff to overcome HR issues
Ryenchindorj Erkhembayar, Emma Dickinson, Darmaa Badarch, Indermohan Narula et al	Early policy actions and emergency response to the COVID-19 pandemic in Mongolia: experiences and challenges	The Lancet Global Health	health policy	Sep-20	Mongolia	LMIC	1)ordered for probes, primers and positive controls from Japan 2) used already available platforms 3) lab testing organised by national influenza centre virology lab 4) random community sampling and walk in testing
Adugna Abera, Habtamu Belaya, Aboma Zewudea, Bokretsion Gideya, et al	Establishment of COVID-19 testing laboratory in resource-limited settings: challenges and prospects reported from Ethiopia	GLOBAL HEALTH ACTION	narrative	Oct-20	Ethiopia	LIC	1)Led by the EPHI, the malaria and NTD research lab used platforms originally used for other diseases eg influenza & schistosomiasis to set up the 1st testing lab 2) Training of lab personnel by the in-country virology experts
Santosh Dhakal and Surendra Karki	Early Epidemiological Features of COVID-19 in Nepal and Public Health Response	frontiers in medicine	original research	Aug-20	Nepal	LMIC	1)increased number of testing labs from 1 to 20 in a short period 2) included veterinary labs
Saeed Anwar, Mohammad Nasrullah and Mohammad Jakir Hosen	COVID-19 and Bangladesh: Challenges and How to Address Them	frontiers in medicine	policy brief	Apr-20	Bangladesh	LMIC	1) locally developed rapid diagnostic 2) expansion of labs from one to 17 including academic institution

Ahsan Nawaz, Xing Su, Muhammad Qasim Barkat, Sana Asghar, et al.	Epidemic Spread and Its Management Through Governance and Leadership Response Influencing the Arising Challenges Around COVID-19 in Pakistan—A Lesson Learnt for Low Income Countries With Limited Resource	frontiers in medicine	narrative review	Dec-20	Pakistan	LMIC	1) increased labs precoid to 57 labs after covid 2) training program for staff to increase number ofo techs and experts in molecular biology
Nega Assefa, Jemal Yousuf Hassen, Desalegn Admassu, Mussie Brhane et al	Existing Facilities in Public Health Emergency Management	frontiers in medicine	case study	Jun-21	Ethiopa	LIC	1) support and gyidance from EPHI to academic institutions to set up testing in the academic institution. Support inlcuded training, protocols among others
Percy Herrera-Añazco, Angela Uyen-Cateriano, Edward Mezones-Holguin, Alvaro Taype-Rondan et al.	Some lessons that Peru did not learn before the second wave of COVID-19	international journal of health management	letter to the editor	2021	Peru	UMIC	1)deployed massive use of rapid serological tests as diagnostic and epidemiological tools
Jaroslav Frnda and Marek Durica	On Pilot Massive COVID-19 Testing by Antigen Tests in Europe. Case Study: Slovakia	infectious disease reports	research paper	Jan-21	Slovakia	HIC	Population/country wide rapid antigen testing

Azizah F. Siddiqui, Manuel Wiederkehr, Liudmila Rozanova and Antoine Flahault	Situation of India in the COVID-19 Pandemic: India's Initial Pandemic Experience	International journal of Environmental research and public health	case report	Dec-20	India	LMIC	1) gradual increase in number of testing labs from 1 to 11 to 885 by end of June 2) private labs included too
Ki Tae Kwon, Jae-Hoon Ko, Heejun Shin, Minki Sung and Jin Yong Kim	Drive-Through Screening Center for COVID-19: a Safe and Efficient Screening System against Massive Community Outbreak	infectious diseases, microbiology and parasitology	brief communication	Mar-20	Korea	HIC	1) introduction of drive through screening and testig centres
Tafadzwa Dzinamarira, Mathias Dzobo, Itai Chitungo	COVID-19: A perspective on Africa's capacity and response	journal of medical virology	review	Jun-20	Nigeria	LMIC	1) Leveraged the existing health infrastructure programs used for previous poliovirus
					Sierra Leone	LIC	1) In Sierra Leone they leveraged structures previoulsy deployed for ebola
Ghulam N Dhabaan, Walid A Al-Soneidor, Nezar N Al-Hebshi	Challenges to testing covid-19 in conflict zones: Yemen as an example	journal of global health	view point	Jun-20	Yemen	LIC	1) used 4 of the 6 central public health labs to test, but this was largely supported by WHO (who trained and also gave supplies)
Al-Musthapha AI, Tijani AA, Oyewo M, Ibrahim A, Elelu N, et al	Nigeria's race to zero COVID-19 cases: True disease burden or testing failure?	Journal of Global Health	view point	Aug-21	Nigeria	LMIC	1) increased labs from the initial 6 to 124 in 4 months 2) leveraged the exisiting platforms used for endemic and sporadic outbreaks 3) deployed xpert platform previoulsy used for HIV and TB 4) private and corporate labs included in testing
Alberto Boretti	The Increasing Number of Infected in Victoria,	integrative journal of medical sciences	case report	Aug-20	Australia	HIC	1) identification of hotspots and mass testing including door to door testing

	Australia since June 15, 2020, is the Result of Over-Testing and Over-Controlling without Safety						
Godfred Acheampong, Michael Owusu, Bernard Nkrumah, Priscilla Obeng-Boadi, et al.	Laboratory capacity in COVID-19 diagnosis and the need to enhance molecular testing in Ghana	global security: health, science and policy	research article	Mar-21	Ghana	LMIC	1)initially used 3 of the 4 public health labs that had capacity and also used 2 of the academic institutions that had capacity 2)gradual increase in number of labs including non clinical labs eg vet labs and academic labs 3) accredited private labs 4)leveraged the GeneXpert platforms 5) scientists among first to sequence the sars-cov-2
Karen E. Ferree, Adam S. Harris, Boniface Dulani, Kristen Kao, et al.	Stigma, Trust, and procedural integrity: Covid-19 testing in Malawi	world development	research article	Jan-21	Malawi	LIC	1) increased labs from 1 to 11 in around 2.5 months, 2)focus on suspected cases , immediate contacts and travelers into the country
María Alejandra Benítez, Carolina Velasco, Ana Rita Sequeira, Josefa Henríquez et al.	Responses to COVID-19 in five Latin American countries	Health policy and technology	narrative review	Aug-20	Chile	HIC	2) Adopted pooled testing in elderly homes 2) introduced low cost tests for COVID
					Peru	UMIC	1)they increased labs doing testing gradually
Peter J. Chipimo, Danielle T. Barradas, Nkomba Kayeyi, Paul M. Zulu, et al.	First 100 Persons with COVID-19 — Zambia, March 18–April 28, 2020	morbidity and mortality weekly report	report	Oct-20	Zambia	LMIC	1)expanded national testing strategy to include asymptomatic persons with possible COVID-19 exposures and no international travel
Tinashe K. Nyazika, Rabelani Kaela, Mathias Mugoni, Kudakwashe	Implementation of Antibody Rapid Diagnostic Testing versus Real-Time	American society for microbiology	perspective	Jul-20	Ghana	LMIC	1) Deployed sample pooling later in the pandemic
					Malawi	LIC	1) Increased testing coverage by increasing number of testing labs

Musomekwa, et al.	Reverse Transcription-PCR Sample Pooling in the Screening of COVID-19: a Case of Different Testing Strategies in Africa				South Africa	UMIC	1) Deployed targeted community symptom screening and testing for both symptomatic and asymptomatic individuals in some provinces
					Zimbabwe	LMIC	1) Introduced RDT as a screening test strategy to complement RT-PCR
Bruce J. Tromberg, Tara A. Schwetz, Eliseo J. Pérez-Stable, Richard J. Hodes, et al.	Rapid Scaling Up of Covid-19 Diagnostic Testing in the United States — The NIH RADx Initiative	New England journal of medicine	special report	Sep-20	USA	HIC	1) Initiatives like RADx to support the development, production scale-up, and deployment of accurate, rapid tests across the country
Oppah Kuguyo, Andre Pascal Kengne, and Collet Dandara	Singapore COVID-19 Pandemic Response as a Successful Model Framework for Low-Resource Health Care Settings in Africa?	Integrative biology	Narrative	2020	Singapore	HIC	1) Drew lessons from the sars-cov-1 outbreak in 2002 2) in country biotechnology companies produced several tests
Adisu Kebede, Betty Lanyero, Berhane Beyene, Mayur Lalji Mandalia, et al.	Expanding molecular diagnostic capacity for COVID-19 in Ethiopia: operational implications, challenges and lessons learnt	PanAfrican medical journal	Perspective	Jan-21	Ethiopia	LIC	1) identification and assessment of public and private labs with support from EPHI, WHO etc 2) on site bench training, onsite mentorship and drills for the lab personnel 3) calibration of existing PCR machines to be able to do covid testing using kits donated 4) progressive expansion of network by adding more labs 5) used the national influenza, arbovirus and VHF reference lab at EPHI to establish covid testing in the country 6) inclusion of research, academic and private labs in testing

Matthew M Kavanagh, Ngozi A Erundu, Oyewale Tomori, Victor J Dzau, et al.	Access to life-saving medical resources for African countries:	Lancet	View point		Several		1)Africa CDC established pooled purchasing platform
Paul Adepoju	Africa's struggle with inadequate COVID-19 testing	Lancet microbe	News	May-20	Ghana, Nigeria, South Africa	LMIC	4) Drone delivery service started to transport samples,
					Nigeria	LMIC	1)Involved already existing viral hemorrhagic fevers lab network & other labs with molecular diagnostic capacity to increase coverage 2) health start up LifeBank established covid-19 mobile testing centres
					South Africa	UMIC	2) Involved the private sector in testing
Pascale Ondo, Yewew Kebede, Marguerite Massinga Loembe, Jinal N Bhiman, et al.	COVID-19 testing in Africa: lessons learnt	Lancet microbe	Comment	Jul-20	Several		1)continental efforts coordinated by AFTCOR included teaming up with SA national institute for ID, Senegalese Institute Pasteur Daker & WAHO to train expert staff from refe labs in Africa.2)Africa CDC Pathogen genomic intelligence institute part of joint ocnitnental covid-19 startegy to boost sequecning capcity of 16 AU member states 3)Nigeria activated covid-19 testing at 26 sites using HIV molecular testing and TB xpert instruments 4)Ethiopia reconfigured exisiting paltforms 5)Ethiopia involved academic and animal health labs 6) PACT formed to increase testing and organising AU states as on elarge customer to be able to compete
Lincoln Leehang Lau, Natalee Hung and Kendall Wilson	COVID-19 response strategies: considering inequalities	International journal for equity in health	Commentary	Aug-20	Phillipines	LMIC	1)reconfiguring TB testing facilities to meet testing demands

	between and within countries						
Olivier Vandenberg, Delphine Martiny, Olivier Rochas, Alex van Belkum and Zisis Kozlakidis	Considerations for diagnostic COVID-19 tests	Nature reviews Microbiology	review	Mar-21	USA	HIC	1)introduction of legislation to alter the regulatory framework governin glab developed tests, 2) active scouting and import og resources outside usual territories, 3) repurpoing manufacturing capacity
Edward Kim	Drawing on Israel's Experience Organizing Volunteers to Operationalize Drive-Through Coronavirus Testing Centers	Disaster Medicine and Public Health Preparedness	field report	2020	Israel	HIC	1)operationalised drive through coronavirus testinf centres
Lauran K. Evans, Austin Shinagawa, Sarah Sutton, Lisa Calvo	COVID-19 Drive-Through Point of Screening and Testing (POST) System: A Safe, Efficient, and Adaptable Model for Nasopharyngeal Swab Collection	Disaster Medicine and Public Health Preparedness	original research	2020	USA	HIC	1)implementation of covid-19 drive through point of screening and testing
Anthony Kwabena Sarfo, Shankar Karuppannan	Application of Geospatial Technologies in the COVID-19 Fight of Ghana	Indian National Academy of Engineering	original research	Jul-20	Ghana	LMIC	1)deployed drone technology to help with sample transport

David Lee and Jaehong Lee	Testing on the move: South Korea's rapid response to the COVID-19 pandemic	Transportation Research Interdisciplinary Perspectives			South Korea	HIC	1)drive through testing 2)used IT to do surveillance and contact tracing . IT included mobile phone tracking, credit card transaction and video footage from surveillance cams
Dean T. Jamison, Kin Bing Wu	The East–West Divide in Response to COVID-19	Transportation Research Interdisciplinary Perspectives	perspective	Jun-21	Several (China, USA, Vietnam, Europe		1)commisioning of private biotech firms and academic isntitutions to undertake genomic analysis that lead to identificatiomn of the genome hence allowing rapid development of of PCR tests 2)Germany and Korea among first countries to develop tests once genome was shared by China 3)Vietnam developed itw own kits
PatriciaJ.Garcia, AlexAlarco n, AngelaBayer, PauloBuss, et al.	COVID-19 Response in Latin America	American journal of tropical medicine and hygiene	perspective piece	Sep-20	Chile	HIC	1) lab screening capacity expanded by including all the country's institutions with PCR equipment and supplying reagents to the lab network of universities and institutes
					Peru	UMIC	1) government purchased serologic tests which were validated and swiftly deployed to scale up testing
Ramanan Laxminarayan, Shahid Jameel, and Swarup Sarkar	India's Battle against COVID-19: Progress and Challenges	American journal of tropical medicine and hygiene	editorial	Aug-20	India	LMIC	1) India ramped up testing by rolling out rapid antigen testing 7 months into the pandemic
Thinley Dorji	The Gross National Happiness Framework and the Health System Response to the COVID-19 Pandemic in Bhutan	American journal of tropical medicine and hygiene	perspective piece	Dec-20	Bhutan	LMIC	1) expanded RT-PCR testing from main centre to more geoprphically spread centres 2) increased human resource available (reappropriation of human resource) including engagment of students 3)free covid testing for its citizens 4) initiated population testing of all persons older than 10 years

Mathew Alexander, Lynn Unruh, Andriy Koval and William Belanger	United States response to the COVID-19 pandemic, January–November 2020	Health Economics, Policy and Law	article	Jan-21	USA	HIC	1)authorisation of private and state and local health labs to develop tetst in February (1st commercial test approved in March -3 months after 1st case). 2) enlistment of private labs in testing.
Aditya Shah, Douglas Challener, Aaron J. Tande, Maryam Mahmood et al.	Drive-Through Testing: A Unique, Efficient Method of Collecting Large Volume of Specimens During the SARS-CoV-2 (COVID-19) Pandemic	Foundation for Medical Education and Research	brief report	Jul-20	USA	HIC	1)drive through testing at Mayo Clinic
Marguerite Massinga Loembé, Akhona Tshangela, Stephanie J. Salyer, Jay K. Varma, Ahmed E. Ogwel Ouma and John N. Nkengasong	COVID-19 in Africa: the spread and response	Nature medicine	comment	Jul-20	Several		1) Africa CDC efforts to increase no of labs 2) leveraged network of community health agents used for previosu diseases eg polio 3) Pasteur institute Dakar Senegal evalusated RDTs
Marc Mendelson, Shabir Madhi,	South Africa's coronavirus testing strategy is broken and not fit for purpose: It's time for a change	South African Medical Journal	Guest editorial	Jun-20	South Africa	UMIC	1) Initiated the community screening and testing (CST) program 2) Recruited field workers to support CST
Reports							

OECD/European Union 2020	How resilient have European health systems been to the COVID-19 crisis?	Health at a Glance: Europe 2020		Jun-20	Several		1) France limited testing to patients with serious conditions at start of pandemic 2) Iceland conducted large scale testing regime early in outbreak 3) Iceland later did voluntary self referral testing regardless of status 4) Lithuania set up mobile points for testing
Janice Thompson and Sinead McMurray	COVID-19: Testing for Sars-CoV-2 in the UK; and the Use of Testing and Contact Tracing in Selected Countries	Northern Ireland assembly		May-20	UK	HIC	1) Early on "containment phase" testing was for the symptomatics after travel and contacts 2) Later moved to delay phase and tested only those requiring admission to hospital 3) Later rolled out to symptomatic NHS staff and their households 4) academic institutions involved
Elizabeth Rough	Coronavirus: Testing for Covid-19	House of commons library	Briefing paper	Oct-20	UK	HIC	1) Decentralised approach of testing 2) Inclusion of both public and private providers 3) Inclusion of academic and research institutions 4) containment phase 5) delay phase 6) expanded eligibility to those above 65 with symptoms and later to anyone with 5 yrs and above with symptoms 7) developed point of care tests
Department of Health and Social Care	Coronavirus (COVID-19) Scaling up our testing programmes		Report	Apr-20	UK	HIC	1) new testing lanes set up 2) included universities and research institutes 3) support to new innovators of tests

Ministry of Finance Planning and Economic development	COVID-19 Interventions Report	MoFPED		Oct-20	Uganda	LIC	1) Operationalising testing labs at border points 2) Accreditation of UVRI by Africa CDC and WHO 3) Used Genexpert at border points
Infectious diseases society of America	COVID-19 Prioritization of Diagnostic Testing	Infectious diseases society of America		Mar-20	USA	HIC	1) Expanded testing to a wider group of symptomatic patients in March 2020
FDA	South Korea's Response to COVID-19	Center for Devices and Radiological Health			Korea	HIC	1) Korea leveraged structures from previous epidemics like mers, 2) govt designed EUA pathway for tests and 1st test on market in Jan 3) invited private providers and assured them of ready market 4) linked manufacturers with clinical bodies to conduct clinical studies reducing
Nigeria Centre for Disease Control	National strategy to scale up access to COVID-19 disease testing in Nigeria			2020	Nigeria		1) leveraged existing disease structures for Malaria, TB and HIV, 2) built capacity by increasing labs 3) developed a national strategy to scale up access to COVID-19 testing
Mathieu Ductatel and Francois Godement	Fighting COVID-19: East Asian Responses to the pandemic		Policy paper	Apr-20	North Korea	HIC	1) Started developing very quickly the NAA tests 2) Also started developing serological tests 3) Fast approval process for medical devices including tests 3) 4) mass testing 7) offering PCR tests offered free of charge

					China	HIC	1) started developing very quickly the NAA tests 2) Also started developing serological tests 3) Fast approval process for medical devices including tests
					Singapore	HIC	1) PP partnerships to develop/produce tests
Congressional Research service	COVID-19 testing: Key issues		In focus	Apr-20	USA	HIC	1) initially used public health labs but later included commercial and clinical labs in hospitals and universities, 2) FDA allowed labs and commercial manufacturers to use and market test kits prior to receiving EUA
Koichi Kameda, Mady Malheiros Barbeitas, Rosangela Caetano, Ilana Lowy et al.	Testing COVID-19 in Brazil: fragmented efforts and challenges to expand diagnostic capacity at the Brazilian Unified National Health system	Reports in Public health	brief communication	Feb-21	Brazil	UMIC	1) initially testing in hospital testing for symptomatics 2) Included public labs and labs from public universities 2) leveraged HIV/AIDS viral load testing labs 3) increased labs testing for covid 4) public private partnerships 5) private developed leveraged molecular system developed for blood screening to test covid 6) fast tracking market authorisation of COVID tests by EUA
Pan African Health Organisation	Pan American Health Organisation Response to COVID-19 in the Americas		report	May-20	Several		1) ordered and provided test kits to member states 2) conducted trainings 3) leveraged the regional influenza centred and severe acute respiratory infection lab network

Theme	Definition	When to use	When not to use
Accessibility	The interventions include approaches deployed to make the tests affordable and accessible to the population	Apply this code to mean strategies that brought testing closer to the people, covered more people, in addition to making testing affordable. Interventions that fall under this could include increasing number of testing facilities; categories of individuals tested among others.	Do not use this code if interventions are proposed, but have not been implemented
Diagnostics	This covers all the diagnostic assays available and approaches to ensuring they are in plenty	Apply this code to capture all strategies that resulted in new or more testing assays on the market. This could include use of both PCR and RDTs, repurposing manufacturing plants for manufacturing of diagnostics among others	Do not use this code if there is no evidence that this indeed happened.
Regulatory & Legislation	Regulatory and legislative frameworks that allowed several players onto the market to help boost availability of testing	Apply this code where there is indication that existing legislation and regulatory frameworks were made more accommodative and flexible to handle the immediate challenges around COVID-19 testing. Use if there is an indication that the red tape was reduced.	Do not use this code if the frameworks were more prohibitive than accommodative
Integration	Integration of COVID-19 testing in the existing health care systems without having to reinvent the wheel	Apply this code to descriptions on where countries used the already existing systems to increase testing. This could include systems available for the other diseases e.g., Malaria, TB, HIV among others.	Do not apply this code if there is no evidence that these systems were actually leveraged. Do not include if these were mere proposals, and did not happen.

Personnel	The number of personnel available to do COVID-19 testing as well as approaches that improve capacity of the personnel to do COVID-19 testing	Apply this code to strategies that involved increasing capacity and number of for the human resources.	Do not apply this code to criteria that does not relate to increasing number of personnel available for COVID-19 testing. Also do not include if there is no indication of such trainings
Technology & Innovation	Interventions that leverage technology and also use the available testing systems more efficiently.	Apply this code in instances where innovative ways to increase testing were adopted. This could include better use of technology and testing systems., as well as efficient testing approaches.	Do not apply this code if the routine or expected is what has been done
Collaboration	Countries develop partnerships both in country and out of the country to help with increased testing. These partnerships are aimed at supporting countries to expand testing.	Apply this code to instances where countries created partnerships to help with increased testing. These partnerships could be aimed at increasing testing equipment, reagents, trainings, guidelines among others	Do not use this code if partnerships or collaborations did not lead to influence testing

	Strategy	Countries	Thematic area (6)
1	Increase in no. of labs	Bangladesh, Malawi, Nepal, Pakistan, Yemen, Nigeria, Ghana, Malawi, Peru, Ethiopia, Chile, Bhutan, UK, Uganda, Nepal, Canada, Uruguay, Vietnam, Nigeria, Brazil	Accessibility
2	Health technology assessments	India	Accessibility
3	Testing strategy to incorporate use of RDTs	India, Zimbabwe, Peru	Diagnostics
4	Licensing private providers/labs in testing	South Africa, India, Nigeria, Ghana, Ethiopia, China, Chile, USA, UK, North Korea, Singapore, Brazil	Regulatory & Legislation
5	Allowing research and academic institutions	South Africa, Nigeria, France, Uruguay, Malawi, Ethiopia, Ghana, Chile, UK, USA, South Korea, Singapore, Brazil	Regulatory & Legislation
6	Setting up mobile testing units	India, Nigeria, South Africa, Pakistan, Lithuania	Accessibility
7	Leveraging existing platforms for testing diseases	India, Malawi, South Africa, Mongolia, Ethiopia, Nigeria, Ghana, Philippines, Uganda, Brazil	Integration
8	Leveraging infrastructure of other disease programs	Bangladesh, South Africa, Mongolia, Nigeria, Sierra Leone, Ethiopia, Uganda	Integration
9	Development of molecular tests	Uruguay, Vietnam, Singapore, China, South Korea, Germany, USA	Diagnostics
10	Development and subsequent use of RDTs	India, Ghana, Bangladesh, Chile, Vietnam, UK, South Korea, China	Diagnostics
11	Repurposing manufacturing capacity	USA	Diagnostics
12	Training of lab people	Vietnam, Bangladesh, Nigeria, Pakistan, Ethiopia	Personnel
13	Increased HR base	Bangladesh, DRC, Bhutan, South Africa	Personnel
14	Legislation to allow for development of tests	USA, South Korea, China, Brazil	Regulatory & Legislation
15	Population wide screening/mass testing	South Africa	Accessibility
16	Expanding categories of people to test	Belgium, India, Nigeria, Pakistan, Ghana, Zambia, Bhutan, Iceland, UK, USA	Accessibility
17	Testing only symptomatic and high priority groups	Vietnam, Nigeria, Malawi, France, UK, Brazil	Accessibility
18	Pooled testing	Ghana, Chile	Technology & Innovation
19	Drive through testing/walk in testing	South Korea, Israel, USA	Accessibility
20	Community wide testing using CHWs	South Africa, Mongolia	Accessibility
21	Sample collection and referral of samples	India, DRC, Rwanda	Accessibility
22	Use of veterinary labs	France, Nepal	Integration
23	Massive testing with RDTs	Slovakia, Peru	Diagnostics
24	Targeted/hot spot with mass testing	Slovakia, Australia, South Africa	Accessibility

25	Initiatives to support production of diagnostics	USA, South Korea, China	Diagnostics
26	Free COVID testing	India, Bhutan, South Korea	Accessibility
27	IT to do surveillance and contact tracing	Ghana, South Korea	Technology & Innovation
29	Drone technology to ship samples	Ghana	Technology & Innovation
20	Continental led efforts (Africa CDC)- pooled purchasing, capacity to country labs, training	Africa, South America, North America by Africa CDC and PAHO	Collaboration