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 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’.\(^5\) 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
strategies used to increase 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
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.
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

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

| Theme                                           | Strategies                                                                                                                                 |
|-------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Increasing accessibility                         | ► Increase in the number of laboratories                                                                                                 |
|                                                 | ► Health technology assessments                                                                                                            |
|                                                 | ► Setting up mobile testing units                                                                                                           |
|                                                 | ► Population-wide screening/mass testing                                                                                                    |
|                                                 | ► Gradual expansion of categories to test                                                                                                    |
|                                                 | ► Testing only symptomatic and high-priority groups                                                                                           |
|                                                 | ► Drive-through testing/walk-in testing                                                                                                     |
|                                                 | ► Community-wide testing using CHWs                                                                                                          |
|                                                 | ► Sample collection and referral of samples                                                                                                  |
|                                                 | ► Targeted/hot spot with mass testing                                                                                                       |
|                                                 | ► Free COVID-19 testing                                                                                                                    |
| Expanding and diversifying diagnostic platforms  | ► Testing strategy to incorporate the use of RDTs                                                                                           |
|                                                 | ► Development of molecular tests                                                                                                             |
|                                                 | ► Development and subsequent use of RDTs                                                                                                     |
|                                                 | ► Repurposing manufacturing capacity                                                                                                         |
|                                                 | ► Massive testing with RDTs                                                                                                                   |
|                                                 | ► Initiatives to support the production of diagnostics                                                                                       |
| Streamlining regulatory and legislative landscape| ► Licensing private providers/laboratories in testing                                                                                         |
|                                                 | ► Allowing research and academic institutions                                                                                              |
|                                                 | ► Legislation to allow for the development of tests                                                                                          |
| Leveraging existing systems                     | ► Leveraging existing platforms for testing diseases                                                                                         |
|                                                 | ► Leveraging infrastructure of other disease programmes                                                                                      |
|                                                 | ► Leveraging previous systems to develop tests                                                                                               |
|                                                 | ► Use of veterinary laboratories                                                                                                             |
| Human resource enhancement                      | ► Training of laboratory workers                                                                                                            |
|                                                 | ► Hiring of more personnel                                                                                                                   |
| Creative use of technology and innovation       | ► Pooled testing                                                                                                                           |
|                                                 | ► Information technology to do surveillance and contact tracing                                                                            |
|                                                 | ► Drone technology to ship samples                                                                                                            |
| Leveraging regional and continental networks    | 1. Africa CDC, PAHO in training and provision of supplies                                                                                   |

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.21

In a bid to save resources, countries adopted the symptomatic 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
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 countries22 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 testing21 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

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.
delivery of vital products like diagnostics. 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, in the low- and middle-income countries, they were engaged in testing. In most of the high-income countries, the private laboratories were engaged in testing quite late. Countries called on academic institutions to support the testing efforts. This was noted across all countries that is, low-, middle- and high-income countries. 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.

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. All they needed were supplies and the collaborations and donations helped with this. With most of the low- and middle-income countries accounting for the highest burden of TB, 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.

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. 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, and the use of this as a strategy was possibly to meet the shortfalls 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. 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. 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.

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. 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). 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.

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 underrepresentation 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 technologuy | 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 Budathoki, 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 | 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, Marshall Islands, Micronesia, Nauru, Palua,Samoia, Solomon Islands no in-country testing so export COVID testing was done |
| Authors                          | Paper Title                                                                 | Journal                        | Article Type       | Publication Date | Affiliations                                                                 |
|---------------------------------|------------------------------------------------------------------------------|--------------------------------|--------------------|------------------|------------------------------------------------------------------------------|
| 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 African from 2 in Feb to 43 by March |
| Amy S Patteerson 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 by Africa CDC, WAHO and WHO to increase number og lab 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) Throuf PACT, established warehousing and distribution hubs across Africa, coordinated the pooled procurement of diagnostics material, and training CHWs to support contact tracing |

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| Author(s)                                      | Title                                                                 | Journal/Type                        | Date | Country       | HIC | Notes                                                                                                                                                                                                 |
|-----------------------------------------------|-----------------------------------------------------------------------|-------------------------------------|------|---------------|-----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 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 regulation 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 testing. 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) 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 |
| Author(s)                                      | Title                                                                 | Journal                          | Commentary       | Date   | Country      | Category (LMIC/HIC/LIC) |
|------------------------------------------------|----------------------------------------------------------------------|----------------------------------|------------------|--------|--------------|-------------------------|
| 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 |
| Sangchun Choi, Chul Han, Jisook Lee, Sang-II 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 Mbula Je, Steven Munharo, Symon F. Naya, 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 |
| Jean B. Nachega, 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) Implementation of multiprofessional health system of nurses, drs, pharmacists, medical students & CHCWs in sensitisation, screening, and testing referral |
|                                                 |                                                                    |                                  |                  |        | Rwanda       | LIC 1) Sample collection and referral for testing |

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| Author(s) | Title | Subtitle | Methodology/Commentary | Country | Level | Description |
|-----------|-------|----------|------------------------|---------|-------|-------------|
| Nancy Odendaal | Shared Approaches, Innovations, and Challenges to Minimize Morbidity and Mortality | Constructing an “infrastructure of care” – understanding the institutional remnants and socio-technical practices that constitute South Africa’s Covid-19 response | Urban geography viewpoint | Jul-20 | SA | UMIC |
| H. Sibiri, S.M. Zankawah, D. Prah | Coronavirus disease 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) community wide testing using CHWs in areas identified thru a social vulnerability index |
| Jimoh Amzat, Kafayat Aminu, Victor I. Kolo, Maryann C. Danjibo | Coronavirus outbreak in Nigeria: Burden and socio-medical response during the first 100 days | internationa 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 |

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| Country          | Research Topic                                                                 | Journal/Action          | Date  | Region | Type  | Funding/Details                                                                                                                                 |
|------------------|---------------------------------------------------------------------------------|-------------------------|-------|--------|-------|------------------------------------------------------------------------------------------------------------------------------------------------|
| Mongolia         | Early policy actions and emergency response to the COVID-19 pandemic in Mongolia: experiences and challenges | The Lancet Global Health | 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 |
| Ethiopia         | Establishment of COVID-19 testing laboratory in resource-limited settings: challenges and prospects reported from Ethiopia | GLOBAL HEALTH ACTION    | Oct-20 | Ethiopia | LIC   | 1) Led by the EPHI, the malaria and NTD research lab used platforms originally used for other diseases (e.g., influenza & schistosomiasis) to set up the 1st testing lab 2) Training of lab personnel by the in-country virology experts |
| Nepal            | Early Epidemiological Features of COVID-19 in Nepal and Public Health Response  | Frontiers in medicine   | Aug-20 | Nepal   | LMIC  | 1) increased number of testing labs from 1 to 20 in a short period 2) included veterinary labs                                                                 |
| Bangladesh       | COVID-19 and Bangladesh: Challenges and How to Address Them                      | Frontiers in medicine   | Apr-20 | Bangladesh | LMIC  | 1) locally developed rapid diagnostic 2) expansion of labs from one to 17 including academic institution                                                                 |
| Authors | Topic | Journal | Date | Country | Region | Key Points |
|---------|-------|---------|------|---------|--------|------------|
| 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 of 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 | Ethiopia | LIC | 1) support and guidance from EPHI to academic institutions to set up testing in the academic institution. Support included 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 |
| Authors | Title | Journal | Type | Location | Year | Stage | Details |
|---------|-------|---------|------|----------|------|-------|---------|
| 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 | India | Dec-20 | 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 | Korea | Mar-20 | HIC | 1) introduction of drive through screening and testing centres |
| Tafadzwa Dzinamarira, Mathias Dzobo, Itai Chitungo | COVID-19: A perspective on Africa's capacity and response | Journal of Medical Virology | Review | Nigeria | Jun-20 | LMIC | 1) Leveraged the existing health infrastructure programs used for previous poliovirus |
| 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 | Yemen | Jun-20 | 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-Mustapha Al, 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 | Nigeria | Aug-21 | LMIC | 1) increased labs from the initial 6 to 124 in 4 months 2) leveraged the existing platforms used for endemic and sporadic outbreaks 3) deployed xpert platform previously 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 | Australia | Aug-20 | HIC | 1) identification of hotspots and mass testing including door to door testing |

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| Authors | Title | Methodology | Setting | Country | Income Group |
|---------|-------|-------------|---------|---------|--------------|
| 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 |
| 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 |
| 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; Peru, LMIC |
| 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 |
| 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; Malawi, LIC |
| Study Authors                        | Study Title                                                                 | Country       | LMIC/UMIC/LIC | Key Findings                                                                                       |
|-------------------------------------|-----------------------------------------------------------------------------|---------------|---------------|-----------------------------------------------------------------------------------------------|
| 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 |
| Zimbawbe                            |                                                                            | 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 | 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? | 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 | Ethiopia      | LIC           | 1) Identification and assessment of public and private labs with support from EPHI, WHO etc 2) On-site bench training, on-site 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 |
| Author(s)                                             | Title                                                                 | Journal                        | Date   | Location          | Details                                                                                                                                                                                                                                                                                                                                 |
|-------------------------------------------------------|-----------------------------------------------------------------------|--------------------------------|--------|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Matthew M Kavanagh, Ngozi A Erondu, Oyewale Tomori, Victor J Dzau, et al. | Access to life-saving medical resources for African countries:        | Lancet Viewpoint                | 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 | 4) Drone delivery service started to transport samples,                                                                                     |
| Pascale Ondoa, Yenew 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 refer labs in Africa, 2) Africa CDC Pathogen genomic intelligence institute part of joint continental covid-19 strategy to boost sequencing capacity of 16 AU member states, 3) Nigeria activated covid-19 testing at 26 sites using HIV molecular testing and TB expert instruments, 4) Ethiopia reconfigured existing platforms, 5) Ethiopia involved academic and animal health labs 6) PACT formed to increase testing and organising AU states as an eligible 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 | Philippines | LMIC | 1) Reconfiguring TB testing facilities to meet testing demands                                                                                                                                     |
| Authors | Title | Journal | Type | Date | Country | Income group |
|---------|-------|---------|------|------|---------|--------------|
| 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 |
| 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 |
| 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 |
| 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) introduction of legislation to alter the regulatory framework governing lab developed tests, 2) active scouting and import of resources outside usual territories, 3) repurposing manufacturing capacity

1) operationalised drive through coronavirus testing centers

1) implementation of covid-19 drive through point of screening and testing

1) deployed drone technology to help with sample transport
| Authors | Title | Journal | Perspective | Date | Country | Income Group | Key Points |
|---------|-------|---------|--------------|------|---------|--------------|------------|
| 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 | Several (China, USA, Vietnam, Europe) | Jun-21 | 1) commissioning of private biotech firms and academic institutions to undertake genomic analysis that lead to identification of the genome hence allowing rapid development of PCR tests 2) Germany and Korea among first countries to develop tests once genome was shared by China 3) Vietnam developed its own kits |
| Patricia García, Alex Alarco n, Angela Bayer, Paulo Buss, et al. | COVID-19 Response in Latin America | American journal of tropical medicine and hygiene | 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 | 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 | Bhutan | LMIC | 1) expanded RT-PCR testing from main centre to more geographically spread centres 2) increased human resource available (reappropriation of human resource) including engagement of students 3) free covid testing for its citizens 4) initiated population testing of all persons older than 10 years |
| Authors | Country | Response to COVID-19 | Journal | Issue | Country | Classification | Summary |
|---------|---------|----------------------|---------|-------|---------|----------------|---------|
| Mathew Alexander, Lynn Unrath, Andrij 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 test 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. Ogwell 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 previou diseases eg polio 3) Pasteur institute Dakar Senegal evaluated 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

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| Source                                      | Key Points                                                                                                                                                                                                 | Date     | Country | Region |
|---------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------|--------|
| OECD/European Union 2020                    | 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 | Jun-20   | Several |        |
| Janice Thompson and Sinead McMurray         | 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 | May-20   | UK      | HIC    |
| Elizabeth Rough                             | 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 | Oct-20   | UK      | HIC    |
| Department of Health and Social Care        | 1) New testing labs set up 2) Included universities and research institutes 3) Support to new innovators of tests                                                                                                                                               | Apr-20   | UK      | HIC    |
| Country/Author | Title | Source | Date | Region | Level | Interventions |
|---------------|-------|--------|------|--------|-------|---------------|
| 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 C-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 4) Mass testing 7) Offering PCR tests offered free of charge |
| Country                | HIC   | Details                                                                                                                                                                                                 |
|-----------------------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 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 Malheiro 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 3) leveraged HIV/AIDS viral load testing labs 4) 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 Sevral 1) ordered and provided test kits to member states 2) conducted trainings 3) leveraged the regions national influenza centre 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) |
|------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|
| 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     |
| Health technology assessments                                          | India                                                                                                                                                                                                    | Accessibility     |
| Licensing private providers/labs in testing                            | South Africa, India, Nigeria, Ghana, Ethiopia, China, Chile, USA, UK, North Korea, Singapore, Brazil                                                                                                        | Regulatory & Legislation |
| Allowing research and academic institutions                             | South Africa, Nigeria, France, Uruguay, Malawi, Ethiopia, Ghana, Chile, UK, USA, South Korea, Singapore, Brazil                                                                                           | Regulatory & Legislation |
| Setting up mobile testing units                                        | India, Nigeria, South Africa, Pakistan, Lithuania                                                                                                                                                        | Accessibility     |
| Leveraging existing platforms for testing diseases                     | India, Malawi, South Africa, Mongolia, Ethiopia, Nigeria, Ghana, Philippines, Uganda, Brazil                                                                                                               | Integration       |
| Leveraging infrastructure of other disease programs                   | Bangladesh, South Africa, Mongolia, Nigeria, Sierra Leone, Ethiopia, Uganda                                                                                                                                 | Integration       |
| Development of molecular tests                                         | Uruguay, Vietnam, Singapore, China, South Korea, Germany, USA                                                                                                                                              | Diagnostics       |
| Development and subsequent use of RDTs                                | India, Ghana, Bangladesh, Chile, Vietnam, UK, South Korea, China                                                                                                                                         | Diagnostics       |
| Repurposing manufacturing capacity                                    | USA                                                                                                                                                                                                       | Diagnostics       |
| Training of lab people                                                | Vietnam, Bangladesh, Nigeria, Pakistan, Ethiopia                                                                                                                                                          | Personnel         |
| Increased HR base                                                     | Bangladesh, DRC, Bhutan, South Africa                                                                                                                                                                     | Personnel         |
| Legislation to allow for development of tests                         | USA, South Korea, China, Brazil                                                                                                                                                                            | Regulatory & Legislation |
| Population wide screening/mass testing                                | South Africa                                                                                                                                                                                              | Accessibility     |
| Expanding categories of people to test                                 | Belgium, India, Nigeria, Pakistan, Ghana, Zambia, Bhutan, Iceland, UK, USA                                                                                                                               | Accessibility     |
| Testing only symptomatic and high priority groups                      | Vietnam, Nigeria, Malawi, France, UK, Brazil                                                                                                                                                              | Accessibility     |
| Pooled testing                                                        | Ghana, Chile                                                                                                                                                                                              | Technology & Innovation |
| Drive through testing/walk in testing                                 | South Korea, Israel, USA                                                                                                                                                                                   | Accessibility     |
| Community wide testing using CHWs                                     | South Africa, Mongolia                                                                                                                                                                                   | Accessibility     |
| Sample collection and referral of samples                              | India, DRC, Rwanda                                                                                                                                                                                        | Accessibility     |
| Use of veterinary labs                                                 | France, Nepal                                                                                                                                                                                              | Integration       |
| Massive testing with RDTs                                             | Slovakia, Peru                                                                                                                                                                                             | Diagnostics       |
| 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 |