

COVID-19 Pandemic Kindled Innovations Leading to Primary Care Management in India: A Review

Vasi A. E. Shaikh^{1*}, Ishrat V. Shaikh²

¹ School of Chemistry, Polymer Chemistry Research Laboratory, MIT World Peace University, Kothrud, Pune 411038, India

² Department of Zoology, Abeda Inamdar Senior College, Azam Campus, Camp, Pune 411001, India

Abstract: COVID-19, a new disease of the coronavirus family, has engulfed the entire world. While developed countries suffered the most; India, despite its high population density, has managed to keep the number of deaths relatively low. ‘Innovation challenges’ were given by the government, its intermediaries and corporate to crowd source the ideas and to empower the citizen innovators, on the onset of a pandemic. Government and the corporate supported them by testing, prototyping help, translating their relevant ideas into products and recognition. A large number of participants including individual citizens to students, startups, traders, and entrepreneurs responded to the challenge through their simple and frugal innovations when there was an acute shortage and urgent need of creative solutions in terms of personal protection equipment (PPE), medical equipment and accessories and other health and welfare tools to aid the personal hygiene as well as a safe environment for humans. Some innovations were impromptu attempts by citizen innovators. This communication summarizes notable instances of timely innovations at various levels in the society during the crisis. Various sources such as journal articles, news articles, commercial enterprises, as well as academic and research institutions have been reviewed for the collection of the information. The relevance of these practical innovations to COVID-19, which helped the society, underlines the people’s belief that innovation can indeed help the nation conquer the crisis and if empowered, a common man is capable of converting the crisis into opportunity. The active participation by various sectors of the society and the last person from the weaker section of society, including ‘women self-help groups’ have highlighted a good example of the ‘quadruple helix model of innovation’ which emphasizes on constant interactions between academia, industry, government and public. There is a need to sustain, support and encourage this inquisitive mindset to create the next wave of innovation to fight any such calamity and support socioeconomic development in the future.

Keywords: COVID-19; Coronavirus; Innovation; Society; India.

I. INTRODUCTION

Coronavirus (COVID-19) outbreak is the world’s most challenging crisis since the Second World War. The virus originated in bats and was transmitted to humans through yet unknown intermediary animals in Wuhan, Hubei province, China in December 2019 [1]. The symptoms are usually fever, cough, sore throat, breathlessness, fatigue, malaise among others. Though many people are asymptomatic [2]; elderly and those with comorbidities may face fatal respiratory complications. The global reach of the coronavirus, and the societal and economic shutdowns, has touched everyone and

everywhere. The economic hit is enormous, affecting every sector for a long time. The crisis, once expected to last for a month or two, is here to stay for an extended period. In the past two decades, there have been two instances wherein crossover of animal betacoronavirus to humans has resulted in severe disease, the first in 2002–2003 in China and another in 2012 in Saudi Arabia. Though it affected a few number of people, the mortality rate was relatively high at 11% and 34% respectively [3,4]. This pandemic is a test of our resolve, solidarity and trust in science.

After Wuhan was placed under lockdown, the Ministry of Health and Family Welfare of India issued a travel advisory [2,5]. The screening was done by demonstration of the virus in respiratory secretions. Those feeling sick within a month of return were advised to report to the hospitals in addition to maintaining self-isolation at home and tested for the virus [2,6].

India reported its first case of COVID-19 on January 30, 2020 [7]. Till the first week of March 2020, India had only 29 cases of COVID—19 [2], while at the same time about 96,000 cases and 3300 deaths were already reported worldwide [8]. Indian government imposed a nationwide lockdown on March 24, 2020. As of July 26, 2020, there were a total of 467,882 active cases, 885,576 cured and 320,63 deaths [9].

With 1.38 billion people, India is the 2nd most populous country in the world. India performed very well in its approach to COVID-19 in the initial period of the pandemic so as to successfully contain the community transmission in most regions [10]. Now, India is at number 3, just below the US, and Brazil if the number of active cases are considered and it stands at number 6 if the total number of deaths are considered as on July 26, 2020. The case fatality rate in India is in the range of 2 to 3% (below the world average of about 4.5%) while the same is in the range of 4 to 5% for US and 15 to 16% in UK [8].

WHO estimates that the development of anti-viral vaccines can take about 18 months [11]. With no specific vaccines or treatments available, the best way to prevent or slow down the transmission is getting protected from infection. The world’s infected population has crossed 16 million mark and over 650 thousand deaths have already occurred [8].

While the pandemic is engulfing the nation, there are a number of examples of common citizen who responded to it

through their simple innovations. Entrepreneurs took up the challenge by modifying their normal business models, to find the low-cost solutions. The quick response was due to the urgency of the humanitarian situation and a proactive approach to crowd sourcing ideas from the government. The COVID-19 crisis has compelled countrymen to think about innovation. It has kindled technology innovations by students, startups, corporations, entrepreneurs, and even citizen innovators, contributing to the primary care management in India. Women self help groups (SHGs) movement which began in India in the 1980s to provide social and financial support and organize poor communities in rural areas have risen to the extraordinary challenge of COVID-19 pandemic [12].

The pandemic COVID-19, has introduced an unprecedented challenge to healthcare systems around the globe. Apart from all the negative implications, a crisis of such a magnitude has offered a fertile ground for innovations.

This present paper mentions notable instances of fast, frugal and technology innovations at various levels in the society. It also talks about how government, (along with its intermediaries), corporate and universities played a catalytic role to encourage and support the innovators. All the countrymen from villages to cities, from small traders to startups and labs are inventing new ways, innovating in the fight against coronavirus. This compelling situation of innovation from every sector of the society may one day secure us from similar scenarios in the future if groomed favorably. The fact that the last person from the society has risen to the ground is encouraging. There is a need to nurture the present scenario in more structured and systematic way so as to encourage citizen innovators and to build an ecosystem; so that every citizen with creativity can contribute in the socioeconomic development through their innovations and a new research culture.

II. INNOVATIONS DURING THE PANDEMIC COVID-19

1) Contributions by citizen innovators:

Edmund S. Phelps, the 2006 Noble laureate in economics, says *“The recognition by a people that their prosperity depends on the breadth and depth of their innovative activity is of huge importance. Nations unaware of how their prosperity is generated may take steps that cost them much of their dynamism”* [13]. Frugal innovations, which originated mainly in India with its traditional values, are accepted in many western economies in the interest of society at large for creating low- and hi-tech affordable products. The economies should free themselves from corporatism and let innovations arising from frugality thrive in its rekindled dynamism for future prosperity [14].

30-year-old citizen, Mupparapu Raju, a BSc graduate, designed the foot-operated device for hand sanitization and washing; a timely solution in the COVID-19 environment. Rajendra Jadhav, a sexagenarian villager and a

self-taught engineer who has been making agricultural tools and machineries, has applied for a patent for his unique sanitizer sprayer [15,16]. He came up with an innovative tractor mounted sprayer within 25 days, capable of sanitizing large areas. Any tractor of power more than 15 horsepower (hp) can be used to operate this.

The National Innovation Foundation (NIF) with the assistance of the Department of Science and Technology (DST), India, through the ‘Challenge COVID-19 Competition’ identified several such innovative solutions by engaging citizens and provided incubation, mentoring and value addition support to the generator for further propagation of the ideas [15]. People also put in their efforts preparing disinfectant formulation and in ways to disinfect people. D. Venkatesh, who runs a water treatment company, has designed and developed a disinfectant tunnel made from a stainless steel structure fitted in a mild steel frame [17]. A Police team from Jammu and Kashmir has created a feet-operated hand-wash machine to install at police stations across the union territory [18]. Varaprasad Reddy, a nodal officer, installed India’s first organic disinfectant tunnel, made from polyethylene sheets, with the Indian *jugaad* in just two days using local materials and a work force [19].

2) Innovations by students, academicians and startups:

In present scenario many countries are focusing on young entrepreneurs to create an ecosystem for fostering their innovations. Government of India, has initiated a program called ‘Startup-India’, to encourage entrepreneurship. It focuses on simplification and hand-holding, funding support and incentives and industry-academia partnership and incubation [20] through large enterprises, various government agencies and public sector organizations. Universities are trying to impart the entrepreneurship competencies in the students before they leave the institution. In the present scenario of COVID-19, several startups have played a major by developing technology platforms.

Academicians from the Aligarh Muslim University (AMU) have developed low cost face shields by using the material that are readily available in the local market to meet the urgent need of doctors and health workers [21]. While the country was facing the shortage of protection equipments and ventilators, Indian Institute of Science (IIT), Roorkee, one of the premier educational institutes in India developed a low cost ventilator called ‘Prana-Vayu’; a face shield with 3D printed, reusable frame and herbal sanitizer as per the guidelines of WHO and the Centers for Disease Control and Prevention, US. IIT-Bombay came up with a portable ultraviolet sanitizer for currency notes, gadgets and other items. Aerobiosys innovations, an incubated startup of IIT-Hyderabad, has built a low-cost, portable emergency use ventilator called ‘Jeevan Lite’ which costs about one hundred thousand rupees and is enabled by Internet of Things (IoT) [22,23]. Innovators at REVA University have invented a low-cost and portable ventilator that delivers 500-600 ml of air per breath and 15-18 breaths per minute, as specified for COVID-

19 patients in addition to the masks to support the community [24]. IIT-Kanpur incubated startup Nocca Robotics has developed an ICU-grade ventilator customized for handling coronavirus patients with ultraviolet filter chambers to kill exhaled viruses, which costs less than one-tenth of a high-end imported ventilator [25]. A group of engineering students from various institutes came together and developed a low-cost ventilator '*Ruhdaar*' costing just Rs 10,000 using locally available material and advanced software [26,27]. The shortage of ventilators, led some startups to develop 3D printed plastic splitter to be used for multiple patients simultaneously during emergencies.

Another area of importance in present pandemic is hygiene in public spaces. The innovation by startup Aqoza technologies uses a water-based, highly efficient sanitizer than alcohol based. PerSapien, with a team of IIT and Stanford alumni has developed a device called '*Airlens Minus Corona*'. It makes use of the charged or ionized water droplets to make the virus ineffective [28].

Indian Council of Medical Research (ICMR) has given nod to IIT-Delhi's low-cost, probe-free testing kit, which will ramp up India's COVID-19 testing capacity. Mylab Discovery Solutions, a startup, got commercial approval for manufacturing of PCR testing kits in March 2020 [22,29]. This low cost kit has enabled and brought down the real time test from 7 hrs to 2.5 hrs. Another startup has developed a contact reducing device for conventional stethoscope to amplify and transmit the chest sounds on doctor's smart phone [26]. IIT-Guwahati has developed affordable and sterile Viral Transport Media (VTM) kits and RT-PCR kits, RNA isolation kits, mobile robot for medical waste disposal and for carrying drug/ food in isolation wards [30].

Indian Institute of Science (IISc) is addressing the issue through various projects such as diagnostic kits, assistive devices, vaccine development etc. [31]. It is also attempting to build an electro-mechanical ventilator model with components made in India [32]. Similarly several institutes are working on manufacturing of automatic mask making machines which will cost 40% less than their imported counterpart [33].

Use of artificial intelligence, robotics and IoT is predominant in most of the inventions. Startups partnered with government are making the use of drones to monitor social distancing rules through thermal imaging and deliver medicine [28]. Some startups are providing COVID-19 tests at home and online consultation with doctors through their platform. A startup called 'Dozee', has come up with the contact-free, smart health monitor for remote monitoring of vital health indicators, including respiratory rate and heart rate for vulnerable patients stuck at home [34]. Asimov Robotics, has developed and deployed robots in hospitals and public places to spread awareness, dispense sanitizer, disinfect and provide an audio-visual interface between doctors, patients

and relatives, carry food and medicines, which eases the pressure on medical staff [35].

It is not just scientists and leading institutions in the country who are aiding the fight against COVID-19 but also several school students who have come up with innovations. Sarthak Jain, a class 11 student has developed an automated touch less doorbell with ultrasonic sensors. Shivam Mukherjee, a class 9 student has invented a sanitization band to be worn around the wrist. It automatically disinfects the object via UV light and alcohol-based spray [36].

3) *Innovations by researcher groups:*

The National Chemical Laboratory (NCL), a lab under the Council for Scientific and Industrial Research (CSIR) has developed an indigenous oxygen enrichment unit helpful for COVID-19 patients. It makes use of an eco-friendly technology with polymeric membranes packed in a unit which selectively permeate oxygen over nitrogen [37]. A team of scientists from NCL has also come up with a nasopharyngeal swab at one fourth the cost of imported ones for collecting samples from the throat cavity of COVID-19 patients [38].

Researchers from Centre for Materials for Electronics Technology (CMET) has also developed a low-cost indigenous prototype of polymer swab which can be used for collection of samples for coronavirus testing making use of specialty polymer. Other inventions include anti-viral and anti-bacterial masks with metal/metal semiconductor nanoparticles like Ag@ZnO and Cu@ZnO as a cost effective alternative of N95 masks and a point of care plasmonic portable sensor with disposable semiconductor based chips to detect antibody with the presence of COVID-19 virus in blood [39].

To tackle the issue of safe disposal of infected secretions, scientists have developed a polymeric super absorbent material which absorbs infected body fluid efficiently, which allows safe disposal of medical waste from COVID-19 patients reducing the risk of secondary infection [40].

Scientists at Central Mechanical Engineering Research Institute (CMERI) have created a robotic device called 'hospital care assistive robotic device' (HCARD) which can be navigated, activated and controlled from the nursing booth to deliver food and medicine to the patients and audio-visual communication [41].

4) *The role of corporates and industries:*

There are innumerable examples of how firms, big and small, took up the challenge to beef up the health care infrastructure by diverting from their normal business models to find and deliver low-cost solutions. In India, the sugar industry is the second largest agro-based industry and it contributes significantly to the socioeconomic development of the nation. Indian sugar industry plays a leading role in global market being the world's largest producer, unseating Brazil [42]. During the pandemic, when the demand of sanitizers

increased suddenly, distilleries have pivoted to produce millions of bottles of hand sanitizer in order to maintain the demand and supply balance [43].

AgVa Healthcare (India) has shared the designs of its portable ventilator, which weighs ~3.5 kg, oxygenates room air and costs ~US\$ 2,000, with much of the software functionality provided by an app installed on the operator's smart phone [44,45]. The country's largest car-maker, Maruti, partnered with AgVa health care to produce these much needed ventilators and other protective equipments [22]. Ratan Tata, doyen of Indian industry, has pledged Rs 15 billion, thrown open Taj Mahal Hotel for free stay for COVID-19 health workers and also partnered with institutes of excellence under the DST and CSIR to come up with latest testing kits based on RT-LAMP technology for quick and effective results. Aditya Birla Group pledged Rs 5 billion and commenced production of triple layer surgical masks with the help of self-help groups and the support of the textiles ministry. A business house, the Mahindra group, planned to manufacture ICU ventilators and other healthcare equipment, and indigenously developed a prototype of the big valve mask, to help patients with breathing problems. Azim Premji of Wipro pledged Rs 11.25 billion to fight COVID-19. Another small-size industry has developed a one-of-its-kind, fully-automatic machine with locally procured parts that produces N-95 masks in bulk with the support of administration for various permissions during the lockdown period within 20 days [46].

The private sector is also contributing significantly through innovations in other areas. In addition to several contributions in health service areas (e-Psyclinic, Drona Maps, Infinite Analytics, Healthians, PCR Sample Pooling etc.), communication through cloud telephony queuing systems (StepOne) [22], one major contribution is Aarogya Setu mobile app, for limiting the spread of COVID-19, through Bluetooth based contact tracing, mapping of likely hotspots and dissemination of relevant information about COVID-19. The app has over 114 million users as of 26th May, which is more than any other contact tracing app in the world [47–49].

A biotechnology company, 'Bione', has launched a rapid antibody-based at-home screening test kit that is capable of giving results within 5-10 minutes by combining AI and predictive analysis tools. The kit which is approved by the ICMR makes use of the blood sample by pricking the finger [50]. In response to the growing seriousness of the COVID-19 pandemic Marico Innovation Foundation had launched 'Innovate2BeatCovid' – a healthcare challenge to innovate low-cost protective gears and equipments, in March 2020 and offered a total grant value of Rs. 25 million [51].

5) States and central government initiatives:

To accelerate the public-private efforts to fight against COVID-19, the Government of India has taken required steps to prevent the spread of the virus in the country and launched several campaigns on its portal 'innovate.mygov.in' to promote innovation [52]. There are hundreds of innovations

that have caught the attention of the central government under this campaign [33]. Startup India, a Ministry of Commerce and Industry (MoCI) body supporting Indian startups, launched the 'United Against COVID-19', innovation challenge calling companies and researchers, to submit their ideas. Those selected will have priority access to government procurement programs [53].

Defense research and development organization (DRDO), the premier research organization for the defense of the country, has developed a rapid and chemical free disinfection tower, based on ultraviolet (UV) radiation source for highly prone areas. This is particularly useful for high-tech gadgets and equipments, such as electronic equipments, computers and other sophisticated equipments in laboratories and offices, that cannot be disinfected with chemical methods. It has also developed many other products for combating COVID-19 which include automatic hand sanitizer dispensing unit, hand surface sanitizers, personnel vehicle area sanitization equipment, sample collection enclosures, hospital aids, mobile labs, PPE, robots and other miscellaneous items amongst others. DRDO has opened its testing facilities for indigenous developers and manufacturers of the country [54–56].

India's start-up community set-up platform 'ACT Grants', has mobilized Rs 1 billion to support ideas, scale-up of testing, disease management, healthcare support for workers & hospitals, management of critically ill patients and support for mental health to combat COVID-19. A number of projects that have been identified and supported are working on superior quality PPE kits; technique such as 3D printing to produce PPEs, face shields, aerosol boxes, goggles, etc., work flow chain, from tele-consulting to testing and uniquely designed differential pressure splitter for multiple patients [57].

Coronavirus risk-tracking app, named Corona Kavach, has been jointly developed and introduced by the government ministries. The app uses persons' locations to analyze whether they are in contact with the coronavirus patient [58]. A doctor in the Indian Navy has patented ICMR validated; low-cost PPE with high 'breathability' suitable for hot and humid conditions like in India in association with the 'national research development corporation' (NRDC), an enterprise under the Ministry of Science and Technology [59]. The Kerala state government has launched an app using a platform developed by QKopy. It sends COVID-19 updates via phone notifications and SMS in English and local language to older phones (people without smart phones) [28]. The Indian railways has converted train coaches into isolation units by making certain modifications for COVID-19 patients [60–62] and also developed PPE for the doctors of railway hospitals [63].

6) "Jugaad" - a fast and frugal innovation:

Solving complex situations using the most basic materials - the world calls it innovation, but India has coined a separate term for it - *Jugaad*. It is a time-tested Indian concept of a

frugal and flexible approach to innovation, which is again proving to be an important way out of the current crisis. Experts believe that it holds important lessons for the developed as well as emerging economies.

Municipal corporation authorities have come up with a *Jugaad* innovation where a wash basin in their premises has been modified in such a way that it can be operated by pushing a lever by foot without touching hand-wash bottle or water tap. A similar washbasin has also been developed by one of the wagon care centers of Indian railways. Doctors in Nagpur have innovated 'COVISAPE', a transportation chamber that ensures the safe transport of COVID-19 patients along with the safety of healthcare staff. This air tight box fits with oxygen and ventilators on medical stretchers and most importantly filters the air that comes out of the box [64]. Taking a cue from South Korea's model of testing, the Bombay Municipal Corporation (BMC) has started 'phone booth testing' for COVID-19 in its hospitals. It ensures that the healthcare workers are not infected [65].

Jugaad gave rise to some most innovative vehicles that allowed people to maintain social distancing while travelling. One such interesting example is an e-rickshaw (a small public transport vehicle for about 5-6 people) where the sitting area has been divided into four different chambers, thus splitting up all four passengers from each other and maintain social distancing. Partha Saha, a concerned father, has designed an electric motorcycle with one meter gap between the rider and pillion rider to accompany his daughter to school instead of having her use the bus and highlighted the importance of social distancing. This COVID-19 bike uses electric power train that provides a maximum ride of 80 km/charge. Several cab and rickshaw drivers have used a partition of transparent poly-carbonate or low cost polyethylene sheet to separate the space between the driver and other passengers [66]. With schools remaining closed for an extended duration came the reality of online teaching. Due to shortage of resources due to lockdown, a teacher made a tripod for her phone using a hanger and multiple cloth strings to hold it in position for live streaming of classes [67].

7) *Role of women self help groups:*

Women-led self-help groups (SHGs) have emerged as an effective frontline responder during the pandemic, reaching the last-mile. Approximately 67 million women are organized into 6 million SHGs in India. SHGs are voluntary groups of 10-20 women from their neighborhood, who pool their savings and gain access to credit. As of today, these collectives have saved \$1.4 billion, and leveraged another \$37 billion from commercial banks. Thus, it has grown into one of the world's largest institutional platforms for the poor [12].

SHGs have local as well as national reach. They are producing masks, sanitizers and personal protective equipments (PPEs), running community kitchens, delivering vegetables and essential goods through mobile apps and providing financial assistance to the most vulnerable during the pandemic [68].

Making use of information education and communication material developed by the state mission they are creating awareness about hand-washing, social distancing, sanitation and quarantine etc. [69].

A trained SHG under the 'district rural development cell' (DRDC) has started manufacturing hand sanitizers according to the guidelines of the WHO and under the guidance of chemists and educational & technological institutes to meet the demand of various quarantine centers, health workers and hospitals [70]. Another group of women came up with an idea to prepare sanitizer from the fermented flowers of Mahua, when spirit was not readily available in the market. Mahua (*Madhuca longifolia*), is an Indian tropical tree found largely in the central and north Indian plains and forests; flowers of which are usually fermented and distilled to make spirituous liquor also known as 'country beer' [71].

III. CONCLUSIONS

The on-going pandemic COVID-19 has certainly destabilized the populations, economies, and governments. Though the socio-economic impact of the pandemic is difficult to forecast, it has greatly affected the people from the lower socio-economic section in India. The International Monetary Fund (IMF) has lowered India's growth forecast to 4.5% for 2019-20 and stated that India's growth had contracted sharply [72] following a longer period of lockdown. Many scientists, innovators, and startups from across the world believe that only innovation can break the chain of the pandemic and the economic depression as well. Though developed countries have taken the lead, the stories of innovation in India, are encouraging. The only positive thing that the pandemic has done is it has got all of us together, including international joint ventures.

For the densely populated country like India, apart from social distancing without complete lockdown [73], shortage of PPE and medical devices for the protection of doctors and frontline health workers, ventilators, test kits and medical devices is the major on-going concern [74,75]. Not only India, but also the world is suffering with shortage of these gears. The government has ordered a huge quantity of PPEs, ventilators, N95 masks, oxygen cylinders, RT-PCR testing kits and several other protection equipments of which majority of the items will be procured from domestic manufacturers. Earlier, either there was no domestic manufacturing of these items in the country or their productions were insufficient to meet the demands. The urge to support government to fight the pandemic and timely intervention by various government intermediaries and bodies to bring together citizens, students, startups, universities, entrepreneurs and even corporate played a major role. The challenges given by them along with support in areas like startup funding, technical help, rapid testing facilities, prototyping and commercial production in collaboration with industries brought interdisciplinary teams together to develop innovative products. No wonder, Indian

manufacturers are now able to satisfy the humongous need of these equipments and devices.

These innovations and efforts in response to COVID-19 in India have highlighted a good example of ‘quadruple helix model’; an extension of ‘triple helix model of innovation’ [76]. While the ‘triple helix model’ of innovation refers to constant interactions between academia, industry and government, to foster economic and social development through innovation and entrepreneurship; the ‘quadruple helix model’ adds a fourth component to the framework of interactions between university, industry and government: the public, consisting of civil society and the media [77,78]. It focuses on “innovation in innovation” and promotes an innovation ecosystem, through various hybrid organizations, such as technology transfer offices, venture capital firms, incubators, accelerators, and science parks. Though universities and industry play a vital role in such innovations other enabling factors are also particularly very crucial.

Many innovators can do wonders if only government and industry take interest in them. They can seed early-stage researches that are useful for business and societies. Close monitoring of the progress by providing funding and mentoring by scientists or engineers to guide them and if something promising emerges, pouring more funds either directly or via a collaboration can help grow the innovation. India’s coronavirus tally has crossed that of many countries, there is still no respite from the pandemic. We urgently need to take advantage of such talent from every community, region and country, to do better in the interest of the society. Enormous untapped potential is out there, just waiting for an opportunity.

REFERENCES

- Li, Q, Guan, X, Wu, P, Wang, X, Zhou, L, Tong, Y, Ren, R, Leung, K S M, Lau, E H Y, Wong, J Y, Xing, X, Xiang, N, Wu, Y, Li, C, Chen, Q, Li, D, Liu, T, Zhao, J, Liu, M, Tu, W, Chen, C, Jin, L, Yang, R, Wang, Q, Zhou, S, Wang, R, Liu, H, Luo, Y, Liu, Y, Shao, G, Li, H, Tao, Z, Yang, Y, Deng, Z, Liu, B, Ma, Z, Zhang, Y, Shi, G, Lam, T T Y, Wu, J T, Gao, G F, Cowling, B J, Yang, B, Leung, G M and Feng, Z (2020). Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. *N. Engl. J. Med. Massachussets Medical Society.* **382** 1199–207. <http://www.nejm.org/doi/10.1056/NEJMoa2001316>
- Singhal, T (2020). A review of coronavirus disease-2019 (COVID-19). *Indian J. Pediatr.* Springer. **87** 281–6. <https://doi.org/10.1007/s12098-020-03263-6>
- World Health Organization (2020). *Middle East Respiratory Syndrome Coronavirus (MERS-CoV)*. World Health Organization. <http://www.who.int/emergencies/mers-cov/en/>
- Chan-Yeung, M and Xu, R-H (2003). SARS: *Epidemiology. Respirology.* **8** S9–S14
- Ministry of Health & FW (2020). Government of India: Consolidated Travel advisory in view of COVID-19. [https://www.mohfw.gov.in/pdf/Consolidated Travel advisory to travelers Updated 26-02-2020.pdf](https://www.mohfw.gov.in/pdf/Consolidated%20Travel%20advisory%20to%20travelers%20Updated%2026-02-2020.pdf)
- Jin, Y H, Cai, L, Cheng, Z S, Cheng, H, Deng, T, Fan, Y P, Fang, C, Huang, D, Huang, L Q, Huang, Q, Han, Y, Hu, B, Hu, F, Li, B H, Li, Y R, Liang, K, Lin, L K, Luo, L S, Ma, J, Ma, L L, Peng, Z Y, Pan, Y B, Pan, Z Y, Ren, X Q, Sun, H M, Wang, Y, Wang, Y Y, Weng, H, Wei, C J, Wu, D F, Xia, J, Xiong, Y, Xu, H B, Yao, X M, Ye, T S, Yuan, Y F, Zhang, X C, Zhang, Y W, Zhang, Y G, Zhang, H M, Zhao, Y, Zhao, M J, Zi, H, Zeng, X T, Wang, Y Y and Wang, X H (2020). A rapid advice guideline for the diagnosis and treatment of 2019 novel coronavirus (2019-nCoV) infected pneumonia (standard version). *Med. J. Chinese People’s Lib. Army.* **45** 1–20
- Reid, D (2020). India confirms its first coronavirus case. <https://www.cnbc.com/2020/01/30/india-confirms-first-case-of-the-coronavirus.html>
- Worldometer (2020). Coronavirus Cases. Worldometer. 1–22. <https://www.worldometers.info/coronavirus/>
- Mygov.in (2020). IndiaFightsCorona COVID-19 in India, Corona Virus Tracker. <https://www.mygov.in/covid-19/>
- Prajapat, M, Sarma, P, Shekhar, N, Avti, P, Sinha, S, Kaur, H, Kumar, S, Bhattacharyya, A, Kumar, H, Bansal, S and Medhi, B (2020). Drug targets for corona virus: A systematic review. *Indian J. Pharmacol. Wolters Kluwer Medknow Publications.* **52** 56–65. [/pmc/articles/PMC7074424/?report=abstract](https://doi.org/10.4103/0250-2688.244424)
- Jiang, F, Deng, L, Zhang, L, Cai, Y, Cheung, C W and Xia, Z (2020). Review of the clinical characteristics of coronavirus disease 2019 (COVID-19). *J. Gen. Intern. Med. Springer.* **35** 1545–9. <https://pubmed.ncbi.nlm.nih.gov/32133578/>
- Misha, S and Shreya, C (2016). Revitalizing the self-help group movement in India. <https://www.cgap.org/blog/revitalizing-self-help-group-movement-india>
- Phelps, E (2013). *Mass Flourishing: How Grassroots Innovation Created Jobs, Challenge, and Change* - Edmund S. Phelps - Google Books. Princeton University Press. https://books.google.co.in/books?id=wjVFLgndBkC&lr=&source=gbs_navlinks_s
- Rao, B (2014). Edmund Phelps. *Mass flourishing: How grassroots innovation created jobs, challenge, and change*. Princeton, NJ: Princeton University Press, 2013. ISBN 978-0-691-15898-3. *Enterp. Soc. Cambridge University Press.* **15** 407–9. [/core/journals/enterprise-and-society/article/edmund-phelps-mass-flourishing-how-grassroots-innovation-created-jobs-challenge-and-change-princeton-nj-princeton-university-press-2013-isbn-9780691158983-2995-hardcover/8647150E337177F33E963811B205C3CD](https://doi.org/10.1017/S1522058113000097)
- Department of Science & Technology (2020). S&T based innovative solutions by common people participating in NIFs Challenge COVID-19 Competition (C3) ready to make a difference. <https://dst.gov.in/st-based-innovative-solutions-common-people-participating-nifs-challenge-covid-19-competition-c3>
- The Hindu Business Line (2020). We have to fight Covid on our own, says Rajendra Jadhav of Mann ki Baat fame. <https://www.thehindubusinessline.com/news/we-have-fight-covid-19-with-all-possible-tools-rajendra-jadhav/article31721075.ece>
- The News Minute (2020). A tunnel that disinfects as you walk along it, now at Tiruppur farmers’ market. <https://www.thenewsminute.com/article/tunnel-disinfects-you-walk-along-it-now-tiruppur-farmers-market-121618>
- Timesnownews.com (2020). Innovation and technology in the age of COVID-19. <https://www.timesnownews.com/technology-science/article/innovation-and-technology-in-the-age-of-covid/592598>
- The News Minute (2020). Now, a disinfection tunnel sprays an organic fumigant in Karnataka. <https://www.thenewsminute.com/article/now-disinfection-tunnel-sprays-organic-fumigant-karnataka-122255>
- Ministry of Commerce and Industry (2020). StartupIndia. <https://www.startupindia.gov.in/>
- Amarujala (2020). AMU engineering college prepares face shield. <https://translate.google.com/translate?hl=en&sl=hi&u=https://www.amarujala.com/uttar-pradesh/aligarh/amu-engineering-college-has-made-a-face-shield-to-protect-from-corona-virus-city-office-news-ali2312230184&prev=search&pto=auae>
- Kumar, D (2020). Beyond India’s coronavirus unlock 1.0: An age of innovation - The Financial Express. <https://www.financialexpress.com/opinion/beyond-indias->

- coronavirus-unlock-1-0-an-age-of-innovation/1982951/
- [23]. Edexlive (2020). IIT Hyderabad-incubated start-up develops “Jivan Lite”, a low-cost, portable emergency use ventilator. <https://www.edexlive.com/campus/2020/apr/03/iit-hyderabad-incubated-start-up-develops-jivan-lite-a-low-cost-portable-emergency-use-ventilator-11086.html>
- [24]. REVA University (2020). REVA varsity unveils affordable ventilator. <https://reva.edu.in/press/reva-varsity-unveils-affordable-ventilator-jeeva-setu>
- [25]. The Economic Times (2020). Indian startup, Nocca Robotics, plans to ship COVID-19 ventilator from May-end. <https://economictimes.indiatimes.com/small-biz/startups/newsbuzz/indian-startup-nocca-robotics-plans-to-ship-covid-19-ventilator-from-may-end/articleshow/75626184.cms?from=mdr>
- [26]. Readers Digest (2020). 4 Low-cost Indian innovations that can lead our fight against coronavirus. <https://www.readersdigest.in/features/story-4-low-cost-indian-innovations-that-can-lead-our-fight-against-coronavirus-125779>
- [27]. Press Information Bureau (2020). Team led by IIT Bombay student develops low-cost mechanical ventilator Ruhuhaar. <https://pib.gov.in/PressReleaseDetail.aspx?PRID=1618375>
- [28]. Sahasranamam, S (2020). Indian startups are riding an innovation wave amid COVID-19 pandemic. <https://scroll.in/article/960783/indian-startups-are-fighting-covid-19-with-innovation>
- [29]. Fortune India (2020). Mylab: The startup in the limelight. <https://www.fortuneindia.com/technology/mylab-the-startup-in-the-limelight/104373>
- [30]. IITG.ac.in (2020). IIT Guwahati: COVID-19 research initiatives. <https://www.iitg.ac.in/covid-19/>
- [31]. Covid19.iisc.ac.in (2020). IISc’s response to COVID-19. <https://covid19.iisc.ac.in/>
- [32]. Covid19.iisc.ac.in (2020). IISc’s response to COVID-19. <https://covid19.iisc.ac.in/iisc-ventilator-effort-2/>
- [33]. The Sunday Guardian Live (2020). India using innovation as arsenal to fight coronavirus. <https://www.sundayguardianlive.com/business/india-using-innovation-arsenal-fight-coronavirus>
- [34]. Bloomberg Quint (2020). Startup Street: Dozee’s contactless monitor is limiting frontline health workers’ exposure to COVID-19. <https://www.bloombergquint.com/business/startup-street-dozees-contactless-monitor-is-limiting-frontline-health-workers-exposure-to-covid-19>
- [35]. Theconversation.com (2020). India: How coronavirus sparked a wave of innovation. <https://theconversation.com/india-how-coronavirus-sparked-a-wave-of-innovation-135715>
- [36]. The Economic Times (2020). Students turn tech innovators to fight Covid-19, come up with touchless doorbell, sanitisation bands. <https://economictimes.indiatimes.com/magazines/panache/students-turn-tech-innovators-to-fight-covid-19-come-up-with-touchless-doorbell-sanitisation-bands/articleshow/75757775.cms>
- [37]. Press Information Bureau (2020). Oxygen Enrichment Unit (OEU). <https://pib.gov.in/PressReleaseDetail.aspx?PRID=1612414>
- [38]. Ministry of Science & Technology (2020). Scientists develop indigenous nasopharyngeal swabs. <https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1629957>
- [39]. Ministry of Electronics and Information Technology (2020). EMCD effort towards building products countering COVID-19 pandemic. <https://meity.gov.in/emcd-effort-towards-building-products-countering-covid-19-pandemic>
- [40]. Times of India (2020). Scientists develop super-absorbent material to check droplet infections from COVID-19 patients | India News. <https://timesofindia.indiatimes.com/india/scientists-develop-super-absorbent-material-to-check-droplet-infections-from-covid-19-patients/articleshow/75090378.cms>
- [41]. Times of India (2020). CSIR lab develops robot for hospitals treating COVID-19 patients. <https://timesofindia.indiatimes.com/gadgets-news/csir-lab-develops-robot-for-hospitals-treating-covid-19-patients/articleshow/75448551.cms>
- [42]. The Economic Times (2019). Indian Sugar Mills Association: ISMA cuts India’s 2018-19 sugar production estimate to 307 lakh tonnes. <https://economictimes.indiatimes.com/news/economy/agriculture/isma-cuts-indias-2018-19-sugar-production-estimate-to-307-lakh-tonnes/articleshow/67622494.cms?from=mdr>
- [43]. The Economic Times (2020). Coronavirus: COVID-19: 100 distilleries expected to begin manufacturing of hand sanitisers. https://economictimes.indiatimes.com/industry/healthcare/biotech/healthcare/covid-19-100-distilleries-expected-to-begin-manufacturing-of-hand-sanitisers/articleshow/74835238.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst
- [44]. Al Jazeera (2020). India’s toaster-sized ventilator to help in fight against virus | India News. <https://www.aljazeera.com/news/2020/04/india-toaster-sized-ventilator-fight-virus-200402090302355.html>
- [45]. Harris, M, Bhatti, Y, Buckley, J and Sharma, D (2020). Fast and frugal innovations in response to the COVID-19 pandemic. *Nat. Med. Nature Research.* **26** 814–7. www.nature.com/naturemedicine
- [46]. Ahmedabad Mirror (2020). Made in Rajkot: Auto N-95 mask-making machine. <https://ahmedabadmirror.indiatimes.com/ahmedabad/others/made-in-rajkot-auto-n-95-mask-making-machine/articleshow/75523814.cms>
- [47]. Mitra, A (2020). *Harnessing Science, Technology and Innovation in India for Tackling COVID-19*. https://ris.org.in/sites/default/files/RIS_Diary-3rd_Special_Issue_on_COVID_19_Website_mini_0.pdf
- [48]. The Economic Times (2020). Beyond contact-tracing, Aarogya Setu may find use in policy inputs. <https://economictimes.indiatimes.com/news/economy/policy/beyond-contact-tracing-aarogya-setu-may-find-use-in-policy-inputs/articleshow/75078678.cms>
- [49]. Mygov.in (2020). Aarogya Setu Mobile App. <https://www.mygov.in/aarogya-setu-app/>
- [50]. Future Medicine India (2020). Bione launches at-home rapid screening test kit for COVID-19 in India | Future Medicine India. <https://futuremedicineindia.com/bione-launches-at-home-rapid-screening-test-kit-for-covid-19-in-india/>
- [51]. Marico Innovation Foundation (2020). Innovate2BeatCovid - Marico Innovation Foundation. <https://www.maricoinnovationfoundation.org/innovate2beatcovid/>
- [52]. Innovate.mygov.in (2020). MyGov Innovation | COVID-19 Solution Challenge. <https://innovate.mygov.in/covid19/>
- [53]. Industrial Automation india (2020). Startups | The innovations Indian startups are coming up with to combat COVID-19. <https://www.industrialautomationindia.in/startupsitm/9430/The-Innovations-Indian-Startups-are-Coming-up-with-to-Combat-Covid-19/startups>
- [54]. Defence Research and Development Organisation (2020). Counter COVID-19 Technologies. <https://www.drdo.gov.in/counter-covid-19-technologies>
- [55]. India.com (2020). DRDO develops WiFi-enabled UV disinfection tower for sanitising coronavirus-prone areas. <https://www.india.com/viral/drdo-develops-wifi-enabled-uv-disinfection-tower-for-sanitising-coronavirus-prone-areas-4019989/>
- [56]. Defence Research and Development Organisation (2020). Master list, DRDO, GoI. <https://drdo.gov.in/master-list>
- [57]. Act Grants (2020). Act Grants – An initiative to defeat COVID-19 together. <https://actgrants.in/>
- [58]. Marico Innovation Foundation (2020). HOME. <https://www.maricoinnovationfoundation.org/>
- [59]. Ministry of Defence (2020). Patenting of innovative low cost PPE developed by Indian Navy paves way for rapid mass production. <https://pib.gov.in/PressReleasePage.aspx?PRID=1623776>
- [60]. Livemint (2020). Indian Railways coaches converted to isolation wards for coronavirus patients.

- <https://www.livemint.com/news/india/see-pics-indian-railways-coaches-converted-to-isolation-wards-for-coronavirus-patients-11585573012954.html>
- [61]. The Economic Times (2020). Railways converts 5000 coaches into isolation wards for COVID-19 patients, awaits govt direction on deployment. <https://economictimes.indiatimes.com/industry/transportation/railways/railways-converts-5000-coaches-into-isolation-wards-for-covid-19-patients-awaits-govt-direction-on-deployment/articleshow/75099355.cms?from=mdr>
- [62]. Thebetterindia.com (2020). 8 Indian innovations that could prove crucial in tackling COVID-19. <https://www.thebetterindia.com/223156/coronavirus-covid19-india-innovation-ventilator-iit-startup-iisc-indian-railways-nor41/>
- [63]. Livemint (2020). Coronavirus: Indian Railways sets target to make 1000 PPE per day in 17 workshop. <https://www.livemint.com/news/india/coronavirus-indian-railways-sets-target-to-make-1000-ppp-per-day-in-17-workshop-11586250200318.html>
- [64]. ET Now (2020). Maharashtra: Doctors design “Covisafe” to transport coronavirus patients - The Economic Times Video. <https://economictimes.indiatimes.com/news/politics-and-nation/maharashtra-doctors-design-covisafe-to-transport-coronavirus-patients/videoshow/74978246.cms>
- [65]. Mumbai Mirror (2020). ‘Phone booths’ for faster, safer COVID-19 testing. <https://mumbaimirror.indiatimes.com/coronavirus/news/phone-booths-for-faster-safer-covid-19-testing/articleshow/75018828.cms>
- [66]. Timesnownews.com (2020). COVID-19 has given rise to jugaad vehicles in India: Will they become the norm? <https://www.timesnownews.com/auto/features/article/covid-19-has-given-rise-to-jugaad-vehicles-in-india-will-they-become-the-norm/593707>
- [67]. The Indian Express (2020). Pune teacher’s ‘jugaad’ to live stream classes wins praise online. <https://indianexpress.com/article/trending/trending-in-india/pune-teacher-creative-desi-jugaad-to-conduct-online-classes-wins-praise-online-6452154/>
- [68]. Worldbank.org (2020). In India, women’s self-help groups combat the COVID-19 (Coronavirus) pandemic. <https://www.worldbank.org/en/news/video/2020/04/13/women-self-help-groups-combat-covid19-coronavirus-pandemic-india>
- [69]. Hindustan Times (2020). COVID-19: In times of crisis, women self-help groups lead the way - analysis. <https://www.hindustantimes.com/analysis/covid-19-in-times-of-crisis-women-self-help-groups-lead-the-way/story-SyXJVNPLUdVbSjkeaszN.html>
- [70]. Thestatesman.com (2020). SHGs in Nadia make hand sanitisers to meet demands. <https://www.thestatesman.com/bengal/shgs-nadia-make-hand-sanitizers-meet-demands-1502871086.html>
- [71]. Bhadauria, C S (2020). Idea from Youtube, sanitizer made from Mahua - trending clicks AajTak. <https://aajtak.intoday.in/gallery/desi-liquor-unique-wonders-tribal-area-mahua-sanitizer-youtube-alirajpur-tsts-1-49540.html>
- [72]. The Economic Times (2020). IMF projects sharp contraction of 4.5% in Indian economy in 2020; a historic low. <https://economictimes.indiatimes.com/news/economy/indicators/imf-projects-sharp-contraction-of-4-5-in-indian-economy-in-2020-a-historic-low/articleshow/76567795.cms>
- [73]. Kamath, S, Kamath, R and Salins, P (2020). COVID-19 pandemic in India: Challenges and silver linings. Postgrad. Med. J. BMJ Publishing Group. **96** 422–3. <https://pmj.bmj.com/content/96/1137/422.abstract>
- [74]. Singh, S, Prakash, C and Ramakrishna, S (2020). Three-dimensional printing in the fight against novel virus COVID-19: Technology helping society during an infectious disease pandemic. Technol. Soc. Elsevier Ltd. **62** 101305. <https://doi.org/10.1016/j.techsoc.2020.101305>
- [75]. ET Health World (2020). India ramps up production of COVID-19 protective gears, medical equipment, Health News. <https://health.economictimes.indiatimes.com/news/medical-devices/india-ramps-up-production-of-covid-19-protective-gears-medical-equipment/75514109>
- [76]. Etzkowitz, H and Zhou, C (2017). *The Triple Helix: University-Industry-Government Innovation and Entrepreneurship*, 2nd ed. Taylor and Francis, London. <https://www.taylorfrancis.com/books/9781315620183>
- [77]. Galvao, A, Mascarenhas, C, Marques, C, Ferreira, J and Ratten, V (2019). Triple helix and its evolution: a systematic literature review. J. Sci. Technol. Policy Manag. Emerald Group Publishing Ltd. **10** 812–33
- [78]. Simona, C, Rossella, S, Julia, F and Margherita, V (2016). Using the quadruple helix approach to accelerate the transfer of research and innovation results to regional growth. 163