Hong Kong. "The countries now facing their first wave [of infections] need to know this," he says.

Nature talked to epidemiologists about whether the lockdowns really worked, if encouraging people to avoid large gatherings would have been enough and what other regions can learn from China's experience.

What happened after the lockdowns?

Before the interventions, scientists estimated that each infected person passed on the coronavirus to more than two others, giving it the potential to spread rapidly. Early models of the disease's spread, which did not factor in containment efforts, suggested that the virus, called SARS-CoV-2, would infect 40% of China's population — some 500 million people.

But between 16 and 30 January, a period that included the first 7 days of the lockdown, the number of people to whom each infected individual gave the virus dropped to 1.05, estimates Adam Kucharski at the London School of Hygiene and Tropical Medicine, who models infectious-disease spread. "That was amazing," he says.

The number of new daily infections in China seems to have peaked on 25 January — just two days after Wuhan was locked down.

As of 24 March, roughly 81,000 cases have been reported in China, according to the WHO. Some scientists think that many cases there were unreported — either because symptoms were not severe enough for people to seek medical care, or because tests were not carried out. But it seems clear that measures implemented during this time did work, says Christopher Dye, an epidemiologist at the University of Oxford, UK.

Could China's response have worked better?

Epidemiologists say China's mammoth response had one glaring flaw: it started too late. In the initial weeks of the outbreak in December and January, Wuhan authorities were slow to report cases of the mysterious infection, which delayed measures to contain it, says Howard Markel, a public-health researcher at the University of Michigan in Ann Arbor. "The delay of China to act is probably responsible for this world event," says Markel.

A model simulation by Lai Shengjie and Andrew Tatem, emerging-disease researchers at the University of Southampton, UK, shows that if China had implemented control measures a week earlier, it could have prevented 67% of all cases there (go.nature.com/393nbr3). Implementing the measures 3 weeks earlier, from the beginning of January, would have cut the number of infections to 5% of the total.

Data from other cities also show the benefits of speed. Cities that suspended public transport, closed entertainment venues and banned public gatherings before their first COVID-19 case had 37% fewer cases than cities that did not, according to a preprint[1] by Dye and his colleagues on the containment measures used in 296 Chinese cities.

Were China's travel bans effective?

Multiple analyses of air travel suggest that the Hubei travel bans, which stopped people leaving the province in planes, trains or cars, slowed the virus's spread, but not for long[2]. A 6 March study[3] published in *Science* by researchers in Italy, China and the United States found that cutting off Wuhan delayed disease spread to other cities in China by roughly four days.

The bans had a more lasting effect internationally, stopping four of five cases from being exported from China for two to three weeks, the team found. But after that, travellers from cities with no travel bans in place took the virus outside China, seeding new outbreaks. The team's model suggests that blocking 90% of travel slows the virus's spread only moderately, unless other measures are introduced.

Because travel bans can only slow the spread of this type of disease, it's important that bans foster trust, says Justin Lessler, an epidemiologist at Johns Hopkins University in Baltimore, Maryland. "If you encourage people to lie or try to circumvent the ban, it is destined to fail," he says.

Dozens of countries and regions across Europe, the Americas, Africa and Asia have now introduced travel restrictions.

What are the lessons?

Tatem and Lai's model assesses the combined effect of China's early detection and isolation, the resulting drop in contact between people and the country's intercity travel bans. Together, these measures prevented cases from increasing by 67-fold — otherwise, there would have been nearly 8 million cases by the end of February.

The effect of the drop in contact between people was significant on its own. Using mobile-phone location data from Chinese Internet giant Baidu, the team found a dramatic reduction in people's movements, which they say represents a drop in person-to-person contact. Without this decrease, there would have been about 2.6 times as many people infected at the end of February, they say.

But early detection and isolation were the chief factors in reducing COVID-19 cases. Without those efforts, China would have had five times as many infections at the end of February. "If you are to prioritize, early detection and isolation are the most important," says Tatem.

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2. Wells, C. *et al. Proc. Natl Acad. Sci. USA* https://doi.org/10.1073/pnas.2002616117 (2020).
3. Chinazzi, M. *et al. Science* https://doi.org/10.1126/science.aba9757 (2020).

SCIENTISTS EXPOSED TO CORONAVIRUS WONDER: WHY WEREN'T WE TOLD?

US authorities are failing to test people and notify their contacts, a cornerstone of outbreak response.

By Amy Maxmen

"I've been in the ICU fighting … wait for it … Coronavirus!" tweeted a 38-year-old geneticist last week. Clement Chow, from the University of Utah in Salt Lake City, was in a hospital intensive care unit (ICU). Pretty soon, two dozen geneticists who had attended a meeting with him nine days earlier saw the tweet. Many were upset that this was how they found out.

The worried researchers from 16 states scrambled to work out who they had spent time with since returning home from the meeting. They were upset that four days had passed between when their colleague was hospitalized with symptoms of COVID-19 and when they found out, through Twitter, that he had the disease. With every passing minute, the virus has a chance to move to someone else.

"In the middle of a known pandemic, how is this not moving faster?" asks David Pollock, an evolutionary genomicist at the University of Colorado School of Medicine in Aurora who attended the meeting.

Across the United States, overwhelmed health departments are failing to diagnose people with COVID-19 and do the detective work usually used to contain outbreaks of contagious disease. This involves rapidly identifying the people with whom infected individuals have been in contact, requesting that close contacts quarantine themselves in their homes for two weeks and testing them as soon as they have symptoms. The World Health Organization (WHO) considers these containment

JEFF PACHOUD/AFP VIA GETTY

Health departments around the world are struggling to test for coronavirus.

measures crucial because they reveal chains of transmission, and close them down before people have time to spread infections.

Analyses of successful coronavirus responses in China, Singapore, Hong Kong and South Korea suggest that these regions curbed their outbreaks largely because of rapid testing, contact tracing and quarantine.

But US health officials seem to be deprioritizing this targeted approach in favour of social-distancing measures, as is the United Kingdom. Such behaviour is a matter of concern for the WHO, which recommends both strategies. "We have not seen an urgent enough escalation in testing, isolation and contact tracing, which is the backbone of the response," said director-general Tedros Adhanom Ghebreyesus at a press briefing on 16 March. "We cannot stop this pandemic if we don't know who is infected," he said.

Policy on investigating contacts and quarantining them varies from city to city in the United States. In Denver, Colorado, where there were 49 confirmed cases as of 19 March, health officials reach out to people who might have been exposed only if they are elderly or have health conditions; they recommend that these people stay at home if they can. Health departments in at least two counties in California – Sacramento County and Placer Country – have decided not to quarantine contacts who show no symptoms, despite a growing body of evidence that asymptomatic carriers might transmit the coronavirus. And in Seattle, Washington, the health department is no longer routinely investigating contacts, because cases are proliferating rapidly and contact tracing is labour-intensive.

Once a population is saturated with the virus, it might no longer make sense to identify contacts, says Jonathan Eisen, a microbiologist at the University of California, Davis, but he doesn't believe that the United States has reached that point yet. One study estimates that there had been as many as 53,000 cases of COVID-19 in the United States by 14 March, more than the number of cases officially confirmed so far (see go.nature.com/3dsmgiu). But even if the estimate is correct, testing people and tracking their close contacts to the greatest extent possible prevents a significant number of people from spreading the disease further, says WHO spokesperson Margaret Ann Harris. "China had shown that even with greater numbers, this is doable," she says.

One root of the problem is a lack of rapid diagnostic testing, and a shortage of people to investigate confirmed cases. Ranu Dhillon, an epidemic-response specialist and physician at Harvard Medical School, who is based in the San Francisco Bay Area in California, says test results are taking up to three days to come through – longer than they did in 2015 in West Africa during the Ebola outbreak, even though the basic methods are the same.

If the United States forgoes contact tracing – or does it very poorly – in favour of aggressive social-distancing measures alone, the country risks the outbreak worsening, and lockdown measures such as school and business closures dragging on for longer than they would otherwise. And that, says Dhillon, will seriously damage people's livelihoods and the economy.

Meanwhile, the geneticists who learnt of their exposure through Twitter are taking their own temperatures. Another attendee at the recent meeting, a population geneticist in Oregon, tweeted: "we are all now self-quarantined. a few are showing symptoms."

Additional reporting by Elizabeth Gibney and Giuliana Viglione

News explainer

Coronavirus vaccines: key questions

Do people develop immunity?
Most researchers assume that people who have recovered from SARS-CoV-2 infection will be protected from reinfection. But evidence is needed. In studies, laboratory animals do not seem to become reinfected when exposed to the virus for a second time. Researchers will be looking for evidence that humans react in the same way. How long any immunity might last is another big unknown.

What kind of immune response should vaccine developers look for?
A clinical trial that began last week focuses on a vaccine developed by Moderna, a company based in Cambridge, Massachusetts. The vaccine consists of an RNA molecule that is designed to train the immune system to make antibodies that recognize and block the protein that the virus uses to enter human cells. However, a successful SARS-CoV-2 vaccine might also need to prompt the body to generate antibodies that block other viral proteins, or make T cells that can kill infected cells.

How do we know whether a vaccine will work?
Normally, vaccines go into human trials after tests for safety and effectiveness in animals. But vaccines being developed by US drug firms Moderna and Inovio Pharmaceuticals are being tested in animals in parallel with human phase I trials. Vaccinated animals will be infected with the virus to see whether they are protected. As researchers learn more about the infection from human and animal studies, they will get a better sense of which vaccines are likely to work best.

Will it be safe?
Researchers' main safety concern is to avoid 'disease enhancement', in which vaccinated people who do get infected develop a more severe form of the disease than people who have never been vaccinated. Larger human studies of the Moderna vaccine will begin only once human and animal studies confirm that the vaccine is safe.

By Ewen Callaway