Supplementary Materials for

False positives in reverse transcription PCR testing for SARS-CoV-2

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Methods

Estimating a conservative false positive rate (FPR)

Absent data on the clinical specificity of SARS-CoV-2 RT-PCR assays, we estimated the false positive rate (FPR) through a meta-analysis of external quality assessments (EQAs) of similar assays. We searched online for reports on EQAs of diagnostic laboratories conducting RT-PCR assays for other RNA viruses. We excluded EQAs prior to 2004, since many of the assays relied on older RT-PCR methods that may be less accurate. For each remaining EQA we extracted or calculated the total number of negative samples assayed, the total number of positive results returned on negative samples, and the resulting FPR for the EQA. Where we could only determine a range, we conservatively took the FPR as the lower bound of the range. In EQAs where no negative samples were reported as positive, we reported the FPR in Tables 1 and S5 as below a detection limit equal to the reciprocal of the total number of negative samples, but for statistical analysis treated the FPR as zero. We calculated the median value and interquartile range for these FPR data and also for a subset restricted to EQAs with >100 negative samples. We used the lower of the 25th percentile values from these two data sets as an estimate of the FPR in SARS-CoV-2 RT-PCR testing programs in order to model the effect of FPR on the reliability of test results.

Estimating the false negative rate (FNR)

We searched on-line for studies that estimated FNRs in SARS-CoV-2 RT-PCR testing. We used the midpoint of the rounded-off range of reported FNR estimates to model the effect of FPR on test results, and performed a sensitivity analysis across the rounded-off range.

Calculation of test positivity rates

We obtained online test data for countries and US states and calculated the test positivity rate on a cumulative and 7-day-moving-average basis.

Derivation of formulae

To model the impact of the FPR on the reliability of test results, we derived formulae for calculating the relevant test statistics from the test positivity rate, FNR and FPR.

Let: N = the number of samples tested

Prev = the **Test Prevalence Rate** (the number of infected individuals that are tested divided by the number of individuals that are tested)

Pos = the **Test Positivity Rate** (the number of positive test results divided by the number of individuals that are tested);

FPR = the **False Positive Rate** (the number of uninfected individuals that test positive divided by the number of uninfected individuals that are tested); = 1–*Specificity* (*Specificity*=the fraction of uninfected individuals that test negative)

FNR = the **False Negative Rate** (the number of infected individuals that test negative divided by the number of infected individuals that are tested); = 1–*Sensitivity* (*Sensitivity*=the fraction of infected individuals that test positive)

PPV = the **Positive Predictive Value** (the number of true positive test results divided by the number of positive (true positive + false positive) test results)

NPV = the **Negative Predictive Value** (the number of true negative test results divided by the number of negative (true negative + false negative) test results)

with all rate functions limited to values between 0 and 1.

The number of infected individuals among those tested is $Prev \cdot N$; the number of these that test negative (false negatives) is $FNR \cdot Prev \cdot N$, and the number that test positive (true positives) is $(1\text{-}FNR) \cdot Prev \cdot N$.

Also, the number of uninfected individuals is $(1\text{-}Prev) \cdot N$ and the number of these that test positive (false positives) is $FPR \cdot (1\text{-}Prev) \cdot N$, and the number that test negative (true negatives) is $(1\text{-}FPR) \cdot (1\text{-}Prev) \cdot N$.

The total number of individuals that test positive is the sum of the true positives and the false positives = $(1\text{-}FNR) \cdot Prev \cdot N + FPR \cdot (1\text{-}Prev) \cdot N$. Dividing this sum by N gives the **Test Positivity Rate**:

$$Pos = \frac{(1-FNR)\cdot Prev\cdot N+FPR\cdot(1-Prev)\cdot N}{N}$$

$$Pos = (1 - FNR) \cdot Prev + FPR \cdot (1 - Prev) \qquad \text{Eq. 1}$$

Rearranging Equation 1 yields the **Test Prevalence Rate**:

$$Prev = \frac{Pos-FPR}{1-FNR-FPR} \qquad \text{Eq. 2}$$

Equation 2 yields negative values for $Prev$ when $FPR > Pos$, and values >1 when $FNR > 1\text{-}Pos$. As such values are not allowed for rate functions, $Prev$ should be constrained to 0 when $FPR > Pos$ and to 1 when $FNR > 1\text{-}Pos$.

The **Positive Predictive Value** (the true positives divided by the total positives) is:

$$PPV = \frac{(1-FNR)\cdot Prev\cdot N}{(1-FNR)\cdot Prev\cdot N+FPR\cdot(1-Prev)\cdot N}$$

$$= \frac{(1-FNR)\cdot Prev}{(1-FNR)\cdot Prev+FPR\cdot(1-Prev)}$$

Substituting in *Pos* from equation 1,

$$PPV = \frac{(1-FNR)\cdot Prev}{Pos}$$

Substituting for *Prev* from equation 2 and rearranging yields:

$$PPV = \frac{FNR\cdot Pos+FPR-FNR\cdot FPR-Pos}{(FNR+FPR-1)\cdot Pos} \qquad \text{Eq. 3}$$

The **Negative Predictive Value** (the true negatives divided by the total negatives) is:

$$NPV = \frac{(1-FPR)\cdot(1-Prev)\cdot N}{(1-FPR)\cdot(1-Prev)\cdot N+FNR\cdot Prev\cdot N}$$

$$= \frac{(1-FPR)\cdot(1-Prev)}{(1-FPR)\cdot(1-Prev)+FNR\cdot Prev}$$

$$= \frac{(1-FPR)\cdot(1-Prev)}{1-((1-FNR)\cdot Prev+FPR\cdot(1-Prev))}$$

Substituting in *Pos* from equation 1,

$$NPV = \frac{(1-FPR)\cdot(1-Prev)}{1-Pos}$$

Substituting for *Prev* from equation 2 and rearranging yields:

$$NPV = \frac{FNR+FPR+Pos-FPR\cdot Pos-FNR\cdot FPR-1}{(FNR+FPR-1)\cdot(1-Pos)} \quad \text{Eq. 4}$$

Sample-based and individual-based data

The meta-analysis of EQAs yields FPR estimates on a sample basis. In our modeling, we apply an FPR estimate derived from the EQA data to available state and national test data. These test data are usually reported on an individual basis, with an individual classified as positive if testing positive in a single RT-PCR test (*12, 14*).

If some individuals are tested more than once, then the FPR on a sample basis (that is, the number of samples from uninfected individuals that test positive divided by the number of samples from uninfected individuals that are tested) can differ from the FPR on an individual basis (the number of uninfected individuals that test positive at least once divided by the number of uninfected individuals that are tested). We show here that the FPR on a sample basis will tend to be less than or equal to the FPR on an individual basis, so that our application of a sample-based FPR estimate to individual-based data will tend to understate the impact of false positives.

We define an infected individual as an individual who is shedding virus at the time of at least one test, and an uninfected individual as an individual who is not shedding virus at the time of any of the tests.

Let: N_{Uninf} = the number of uninfected individuals tested

FP = the number of uninfected individuals who test positive at least once, i.e. the number of false positive individuals

FP_1 = the number of uninfected individuals who test positive on their first test

FPR_S = the false positive rate on a sample basis

FPR_I = the false positive rate on an individual basis.

Consider the set of samples from the first tests of the tested individuals. There are N_{Uninf} samples taken from uninfected individuals in this set, and the expected number of false positive samples is:

$$FP_1 \approx FPR_S \cdot N_{Uninf} \quad \text{Eq. 1}$$

Now if some individuals are tested more than once, these re-tests will be distributed in some fashion over the individuals tested: some may be tested twice, some three times, etc. First consider the case where any false positives that occur in a re-test happen either to an infected individual (that is, an individual who was shedding virus during at least one test but not at the time of the false positive test) or to an uninfected individual who tested positive on the first test. These false positives are thus "wasted" in the sense that they don't produce any additional false positive individuals, so:

$$FP = FP_1$$

So the FPR on an individual basis is:

$$FPR_I = \frac{FP}{N_{Uninf}} = \frac{FP_1}{N_{Uninf}} \approx FPR_S$$

Now consider the other case, where one or more of the false positives that occur in a re-test happen to an uninfected individual who did not test positive on the first test. Then these false positives produce additional false positive individuals, so:

$$FP > FP_1$$

$$FPR_I = \frac{FP}{N_{Uninf}} > \frac{FP_1}{N_{Uninf}}$$

And from Equation1:

$$FPR_I > FPR_S$$

So FPR_I is always either about equal to or greater than FPR_S, and applying an estimate of FPR_S to data aggregated on an individual basis will tend to underestimate the effect of a given FPR.

At least one U.S. state (New York) reports its test data as data on individuals but defines an "individual" as follows: if multiple samples are taken from an individual on a single day and tested this counts as one individual tested, but if the individual is sampled and tested on multiple days these are counted as multiple individuals tested. By a proof similar to the one given above, the FPR on an "individual" basis will then be either about equal to or greater than the FPR on a sample basis.

Italy initially reported "mixed" test data, that is, the number of tests were reported on a sample basis (*tamponi*) while the results were reported on an individual basis (*casi totali*). Beginning on April 23 Italy also reported the number of tests on an individual basis (*casi testati*). For modeling, we estimated the number of tests on an individual basis for dates prior to April 23 by multiplying the reported number of *tamponi* by the ratio between cumulative number of *casi testati* and *tamponi* on April 23.

It is not always clear how test data are reported by a state or country, and in some cases the reporting method may confound the application of a sample-based FPR estimate to the test data. However, if the number of re-tests is small relative to total tests the error should be small.

Supplementary Text

We searched Google Scholar for studies published in any language from Jan 1, 2020 to April 25, 2020 using the terms "SARS-CoV-2", "COVID-19", "coronavirus" or "nCoV" AND "false positive" or "specificity" AND "PCR". We found 34 papers that mentioned false positives or specificity in the context of SARS-CoV-2 testing, including unpublished preprints and one retracted study. Twenty-five of these studies made only brief or incidental mention of false positives or specificity. One published study, three unpublished studies and one retracted study assumed or roughly estimated false positive rates between 0% and 10% as inputs to models, including two pooled-sampling optimization models and three models exploring the effects of false positives on certain epidemiological statistics. One published and three unpublished studies (listed in Tables S3 and S4) mentioned false positives encountered while conducting sensitivity analyses or cross-reactivity assessments of SARS-CoV-2 RT-PCR assays.

Guidance documents from the World Health Organization (WHO) (*12, 15, 16*) and the U.S. Centers for Disease Control and Prevention (CDC) (*13*) on RT-PCR testing for SARS-CoV-2 make no mention of false positives or any concerns about specificity.

There have been several studies and considerable media coverage of false negative results in SARS-CoV-2 RT-PCR tests (Table S2) (*4*) and of false positive results in SARS-CoV-2 antibody tests (*17-19*), but we found only limited media discussion of false positive results in SARS-CoV-2 RT-PCR tests. Most of this was in regard to three incidents: **1)** initial false positives in the CDC's RT-PCR test caused by a contaminated reagent produced in a CDC laboratory (*20, 21*), **2)** U.S. health officials stating that a study found that WHO's or China's SARS-CoV-2 test had a false positive rate of 47% (*22, 23*) (though the study didn't find that (*24*)), and **3)** a dispute involving the Malaysian and Cambodian governments and the CDC over whether a cruise ship passenger's test result was a true positive or false positive (*25*). There are also a small but rising number of records of apparent (*26-33*) or possible (*34-36*) false positives occurring during regular SARS-CoV-2 RT-PCR testing.

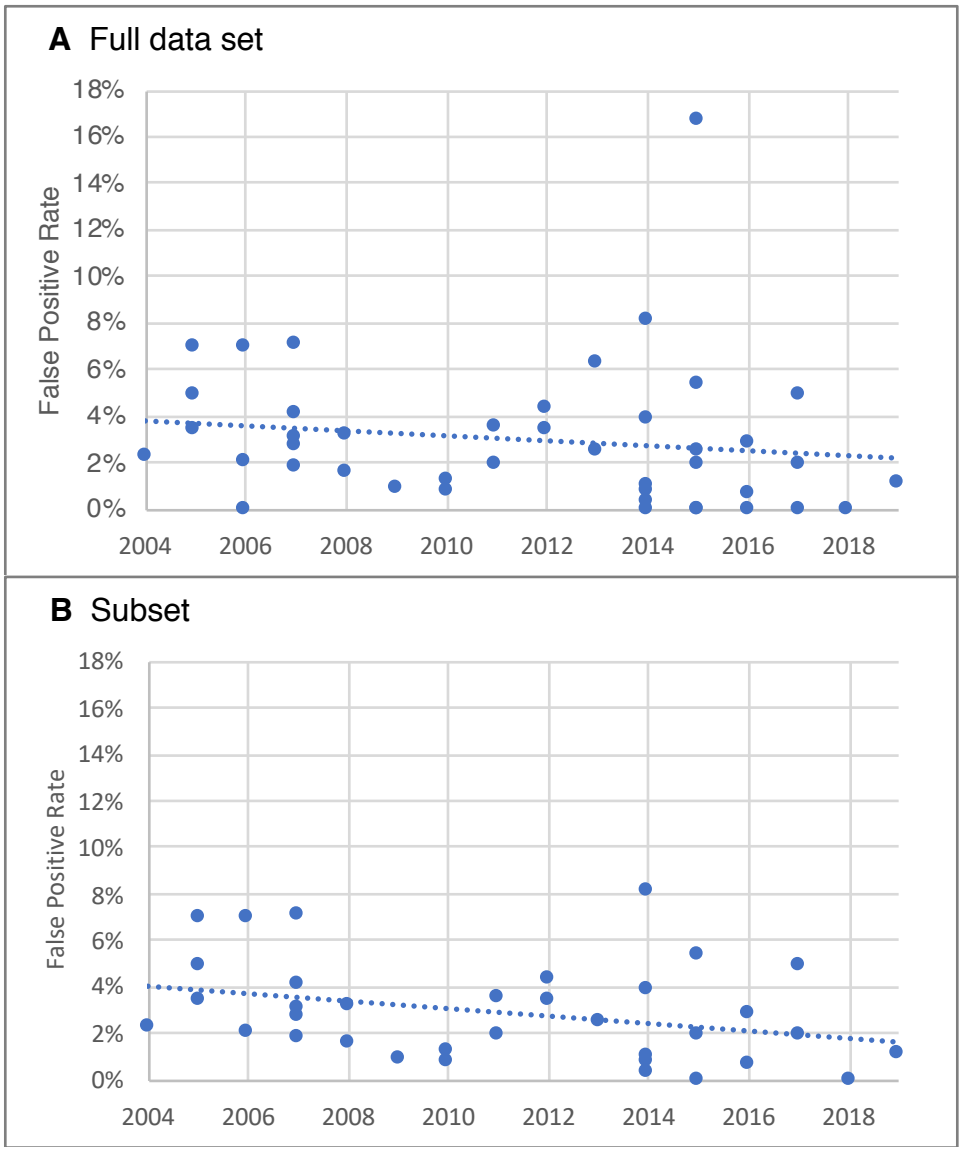

Figure S1. False positive rates in external quality assessments of RT-PCR assays of RNA viruses over time. (A) Full data set; linear regression shown as a dotted line (n=43, r=0.147, p=0.346). (B) Same as A, but for a subset comprising EQAs with >100 negative samples (n=37, r=0.327, p=0.056).

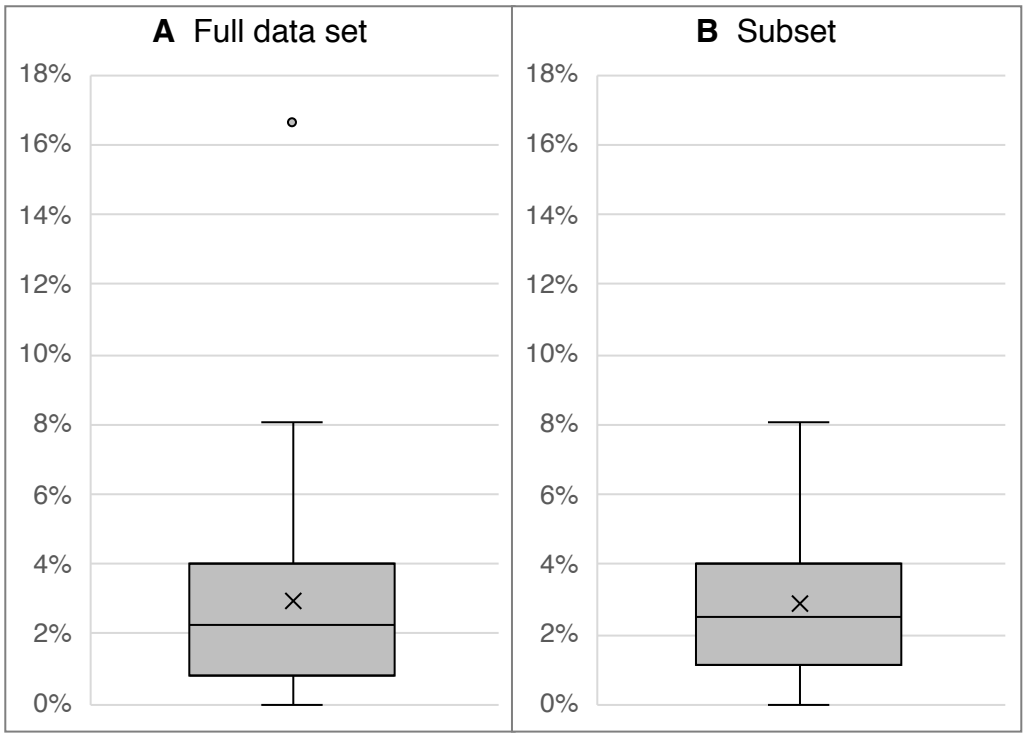

Figure S2. Distributions of false positive rates in external quality assessments of RT-PCR assays of RNA viruses. (A) Full data set. (B) Subset comprising EQAs with >100 negative samples.

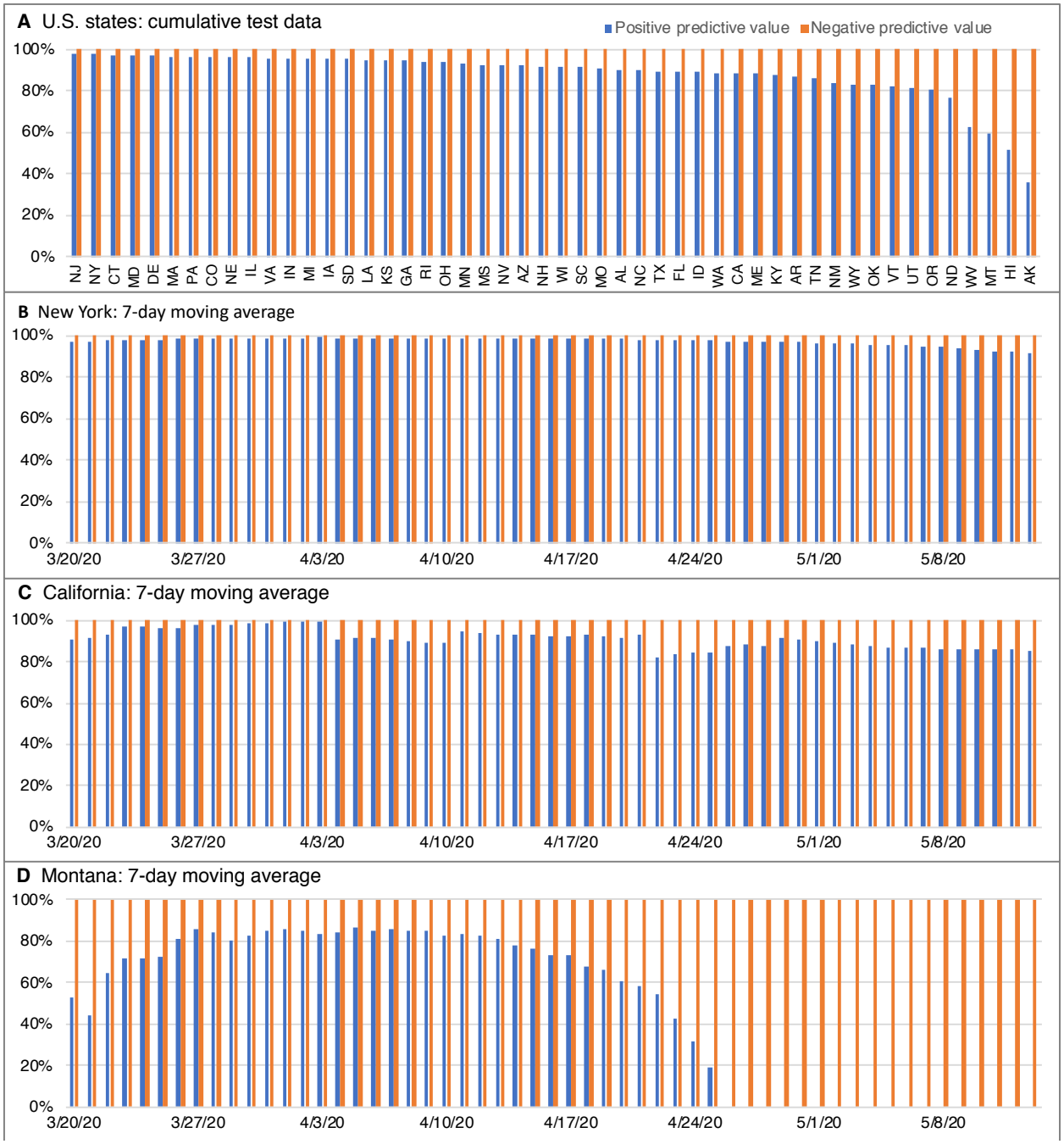

Figure S3. Reliability of SARS-CoV-2 test results in the United States: sensitivity tests with a false negative rate of 0%. As in Figure 1 but with a false negative rate of 0%. Positive predictive value (the probability that a positive result is true) and negative predictive value (the probability that a negative result is true) calculated with a false positive rate of 0.8%. (A) Results for the 50 U.S. states based on cumulative test data through May 13, 2020. States arranged left to right in order of decreasing test positivity. (B-D) Reliability trajectories based on the previous-7-day moving average for states with positive test results with high reliability (New York), reliability starting to decline (California), and steeply declined reliability (Montana). Test data are from The COVID Tracking Project (https://covidtracking.com/about-data accessed May 14, 2020).

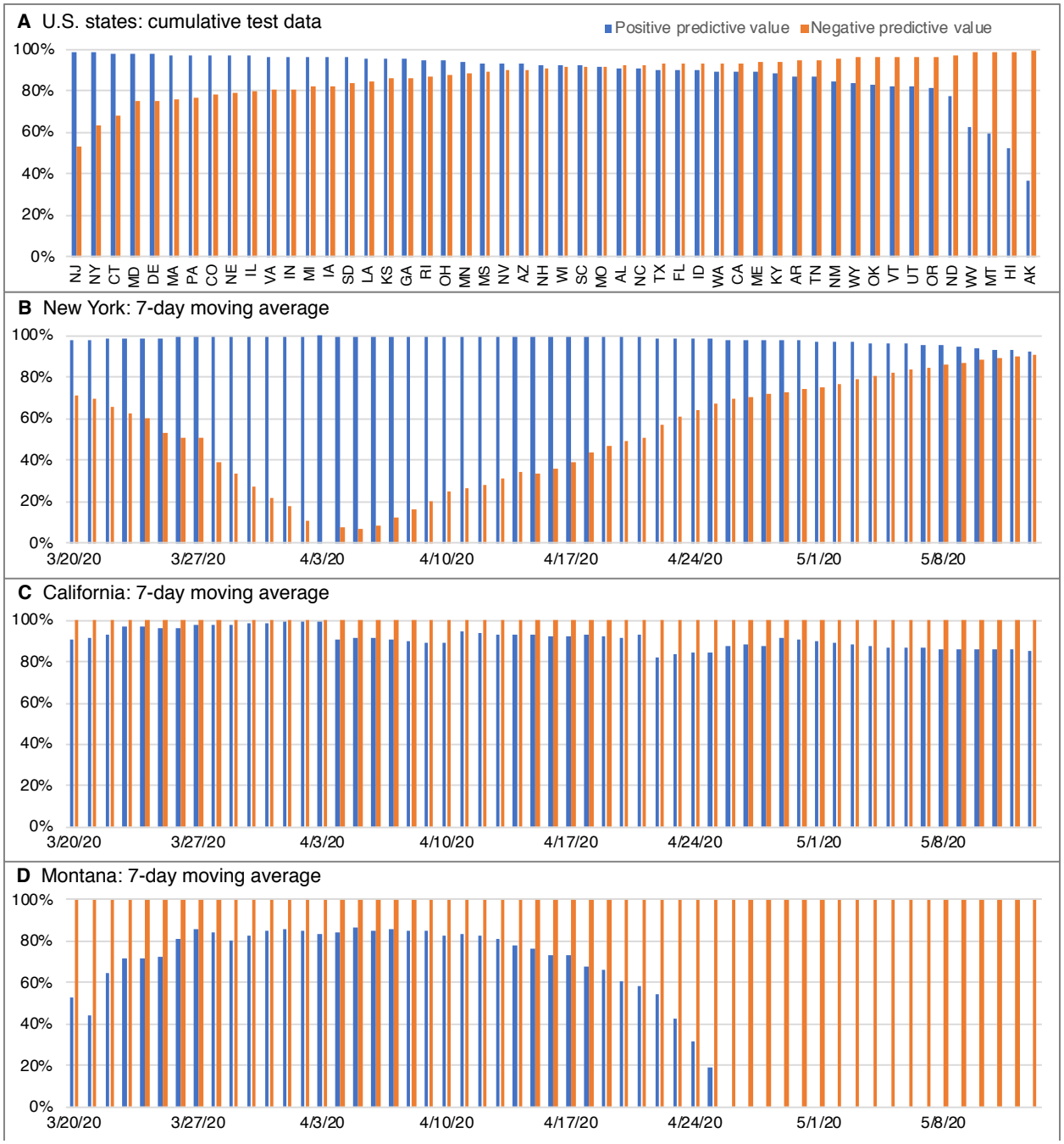

Figure S4. Reliability of SARS-CoV-2 test results in the United States: sensitivity tests with a false negative rate of 50%. As in Figure 1 but with a false negative rate of 50%. Positive predictive value (the probability that a positive result is true) and negative predictive value (the probability that a negative result is true) calculated with a false positive rate of 0.8%. (A) Results for the 50 U.S. states based on cumulative test data through May 13, 2020. States arranged left to right in order of decreasing test positivity. (B-D) Reliability trajectories based on the previous-7-day moving average for states with positive test results with high reliability (New York), reliability starting to decline (California) and steeply declined reliability (West Virginia). Test data are from The COVID Tracking Project (https://covidtracking.com/about-data accessed May 14, 2020).

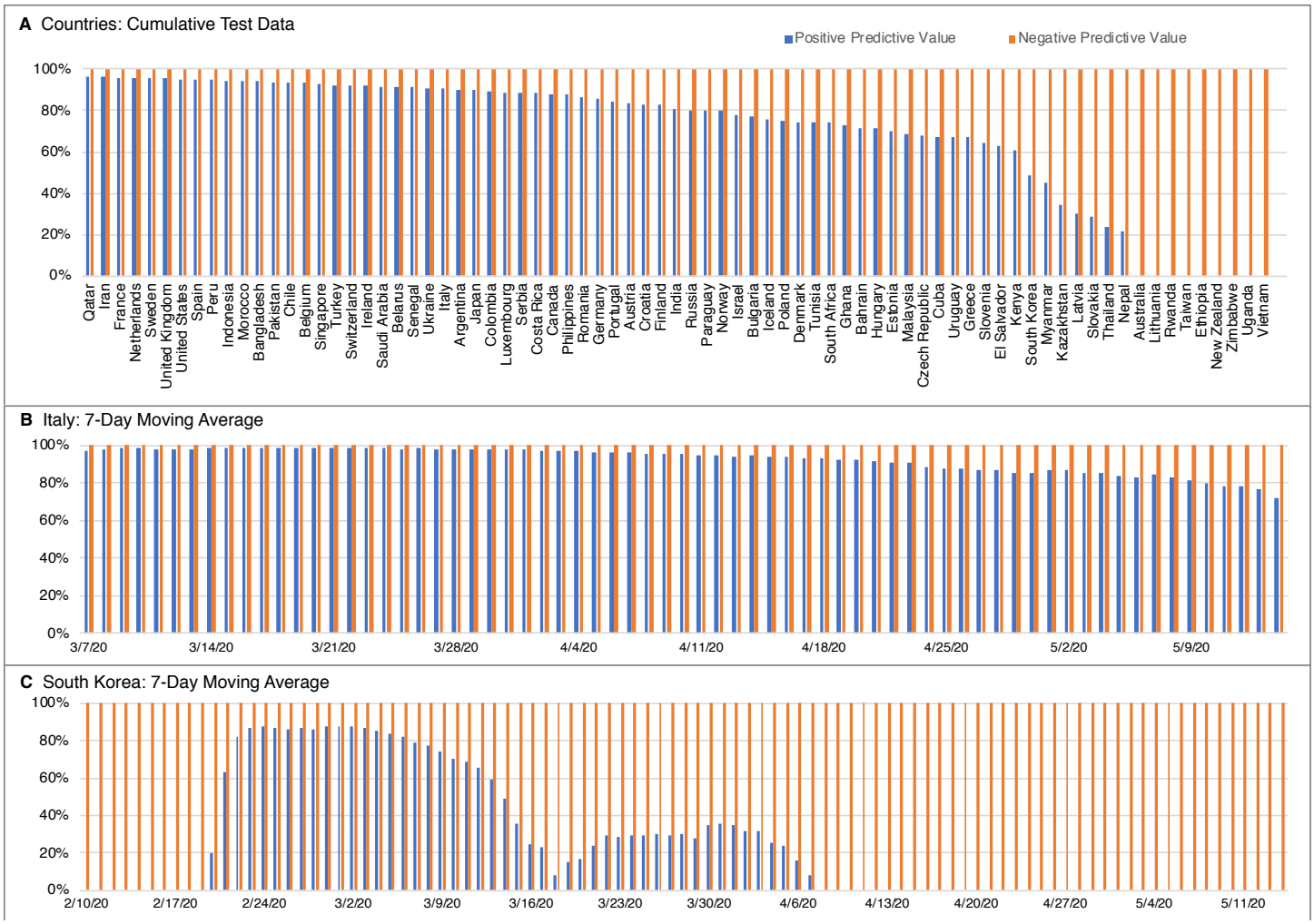

Figure S5. Reliability of SARS-CoV-2 test results in different countries: sensitivity tests with a false negative rate of 0%. As in Figure 2 but with a false negative rate of 0%. Positive predictive value (the probability that a positive result is true) and negative predictive value (the probability that a negative result is true) calculated with a false positive rate of 0.8%. (A) Results for 77 countries based on cumulative test data through the most recent available date (between April 29 and May 14, 2020). Countries arranged left to right in order of decreasing test positivity. (B-C) Reliability trajectories based on the previous-7-day moving average for countries with positive test results with declining reliability (Italy) and sharply declined reliability (South Korea). Cumulative test data are from Our World in Data (https://github.com/owid/covid-19-data/tree/master/public/data/ accessed May 14, 2020). Daily test data are from the Italian Ministry of Health (http://www.salute.gov.it/portale/nuovocoronavirus/archivioNotizieNuovoCoronavirus.jsp?lingua=italiano&menu=notizie&p=dalministero&area=nuovocoronavirus&notizie.page=0 accessed May 14, 2020) and the South Korean Centers for Disease Control and Prevention (https://www.cdc.go.kr/board/board.es?mid=&bid=0030 accessed May 14, 2020).

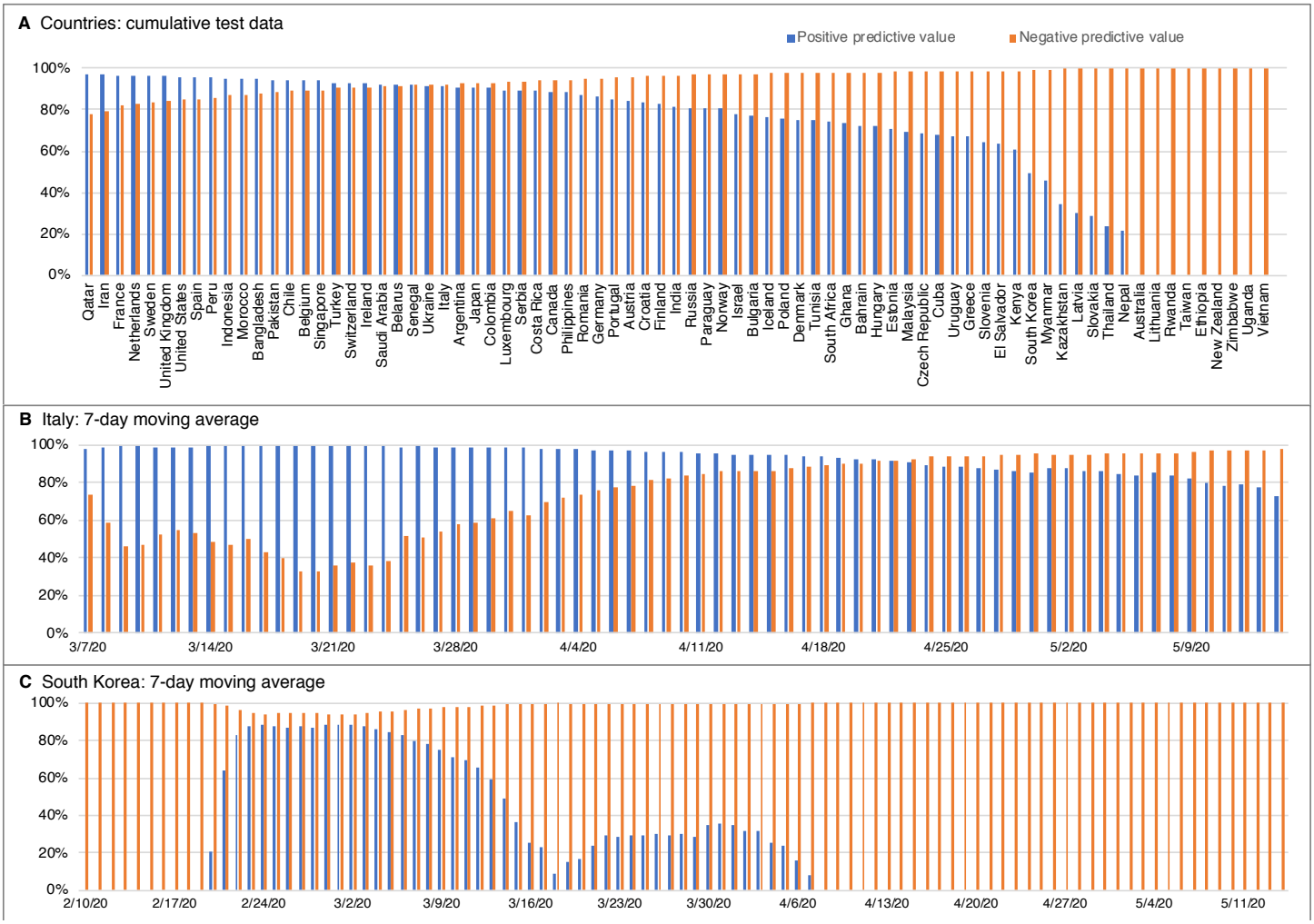

Figure S6. Reliability of SARS-CoV-2 test results in different countries: sensitivity tests with a false negative rate of 50%. As in Figure 2 but with a false negative rate of 50%. Positive predictive value (the probability that a positive result is true) and negative predictive value (the probability that a negative result is true) calculated with a false positive rate of 0.8%. (A) Results for 77 countries based on cumulative test data through the most recent available date (between April 29 and May 14, 2020). Countries arranged left to right in order of decreasing test positivity. (B-C) Reliability trajectories based on the previous-7-day moving average for countries with positive test results with declining reliability (Italy) and sharply declined reliability (South Korea). Cumulative test data are from Our World in Data (https://github.com/owid/covid-19-data/tree/master/public/data/ accessed May 14, 2020). Daily test data are from the Italian Ministry of Health (http://www.salute.gov.it/portale/nuovocoronavirus/archivioNotizieNuovoCoronavirus.jsp?lingua=italiano&menu=notizie&p=dalministero&area=nuovocoronavirus&notizie.page=0 accessed May 14, 2020) and the South Korean Centers for Disease Control and Prevention (https://www.cdc.go.kr/board/board.es?mid=&bid=0030 accessed May 14, 2020).

Table S1. Reported specificity of SARS-CoV-2 RT-PCR assays based on *in vitro* cross-reactivity assessments. These include 20 of the 68 RT-PCR assays that received U.S. Food and Drug Administration Emergency Use Authorizations through April 30, 2020, and all four of the assays that received World Health Organization Emergency Use Listings by that date.

Laboratory or manufacturer	Test	Authorization	Negative samples	Positive results	Specificity	Reference
Abbott Diagnostics Scarborough, Inc.	ID NOW COVID-19	EUA/Commercial 3/27/20	30	0	100%	37
Abbott Molecular, Inc.	Abbott RealTime SARS-CoV-2 assay	EUA/Commercial 3/18/20, EUL 4/9/20	150	0	100%	38
Altona Diagnostics GmbH	RealStar SARS-CoV02 RT-PCR Kits U.S.	EUA/Commercial 4/22/20	63	0	100%	39
Altru Diagnostics, Inc.	Altru Dx SARS-CoV-2 RT-PCR assay	EUA/Single Lab 4/30/20	66	0	100%	40
Biocerna	SARS-CoV-2 Test	EUA/Single Lab 4/28/20	30	0	100%	41
Centers for Disease Control and Prevention	CDC 2019-nCoV Real-Time RT-PCR Diagnostic Panel	EUA/Commercial 2/4/20	181	0	100%	42
Charité–Universitätsmedizin Berlin/German Center for Infection Research	"WHO Test"[b]	-	430	0	100%	43
Diagnostic Molecular Laboratory, Northwestern Medicine	SARS-Cov-2 Assay	EUA/Single Lab 4/2/20	58	0	100%	44
Hologic, Inc.	Panther Fusion SARS-CoV-2 Assay	EUA/Commercial 3/16/20	243	0	100%	45
Infectious Disease Diagnostics Laboratory, Children's Hospital of Philadelphia	SARS-CoV-2 RT-PCR test	EUA/Single Lab 4/2/20	30	0	100%	46
LabGenomics Co., Ltd.	LabGun COVID-19 RT-PCR Kit	EUA/Commercial 4/29/20	229	0	100%	47
Nationwide Children's Hospital	SARS-CoV-2 Assay	EUA/Single Lab 4/27/20	60	0	100%	48
PerkinElmer, Inc.	New Coronavirus Nucleic Acid Detection Kit	EUA/Commercial 3/24/20, EUL 4/24/20	319	0	100%	49

Table S1. continued

Laboratory or manufacturer	Test	Authorization	Negative samples	Positive results	Specificity	Reference
Primerdesign Ltd.	COVID-19 genesig Real-Time PCR assay	EUA/Commercial 3/20/20, EUL 4/7/20	158	0	100%	50
Rheonix, Inc.	Rheonix COVID-19 MDx Assay	EUA/Commercial 4/29/20	60	0	100%	51
Roche Molecular Systems, Inc.	cobas SARS-CoV-2	EUA/Commercial 3/12/20, EUL 4/3/20	283	0	100%	52
SD Biosensor, Inc.	Standard M nCoV Real-Time Detection Kit	EUA/Commercial 4/23/20	126	0	100%	53
SeaSun BioMaterials	U-TOP COVID-19 Detection Kit	EUA/Commercial 4/27/20	181	0	100%	54
Thermo Fisher Scientific, Inc.	TaqPath COVID-19 Combo Kit	EUA/Commercial 3/13/20	96	0	100%	55
Wadsworth Center, New York State Department of Public Health	New York SARS-CoV-2 Real-time Reverse Transcriptase (RT)-PCR Diagnostic Panel	EUA/Commercial 2/29/20	165	0	100%	56
Yale New Haven Hospital, Clinical Virology Laboratory	SARS-CoV-2 PCR test	EUA/Single Lab 3/31/20	16	0	100%	57

[a] EUA = Emergency Use Authorization by the U.S. Food and Drug Administration, issued either for commercial products or for use by a single laboratory. EUL = Emergency Use Listing by the World Health Organization.

[b] Protocol for a test distributed by the World Health Organization (WHO), often referred to as the WHO test.

Table S2. Estimates of false negative rates.

Basis for estimate of false negative rate[a]	Estimated rate[a]	Refer-ence
RT-PCR detected 24 of 24 infected patients (apparently based on clinical observations).	0%	58
Of 601 patients that tested positive by RT-PCR, 15 initially tested negative (2.5%); of 748 patients that tested positive by RT-PCR or were considered highly likely cases based on clinical symptoms and positive chest CT scans with dynamic changes on serial scans, 162 initially tested negative (21.7%).	2.5-21.7%	59
Of 167 infected patients that tested positive by RT-PCR, 5 with positive chest CT had tested negative 2-8 days earlier.	3.0%	60
Throat swabs from 128 patients were tested by RT-PCR every 2 days until all were positive on the 6th test. 36 (28.1%) were negative on the first swab, and the average over the first five tests was 11 (8.6%) negative.	8.6%-28.1%	61
Of 64 patients that tested positive by RT-PCR, 6 initially tested negative.	9.4%	62
The pooled false negative rate in a meta-analysis of SARS-CoV-2 RT-PCR tests was 11%.	11%	63
Of 71 pharyngeal swabs that tested positive by digital RT-PCR, 8 (11.3%) tested negative by RT-PCR; of 104 samples (including stool, serum and 1 sputum sample) that tested positive by digital RT-PCR, 19 (18.3%) tested negative by RT-PCR.	11.3-18.3%	64
Of 102 patients that tested positive by RT-PCR, 12 initially tested negative.	11.8%	65
Of 36 patients that tested positive by RT-PCR, 6 initially tested negative.	16.7%	66
Of 34 patients that tested positive by RT-PCR, 7 initially tested negative.	20.6%	67
Of 35-37 paired samples that included a saliva sample, a nasopharyngeal swab or both that tested positive by RT-PCR, 8 nasopharyngeal swabs tested negative.	21.6-22.9%	68
Of 87 patients that tested positive by RT-PCR, 19 initially tested negative.	21.8%	69
Of 219 nasal swab samples taken 0-7 days after the onset of symptoms from 213 patients confirmed by the Guangdong CDC as infected, 51 tested negative by RT-PCR.	23.3%	70
Of 51 patients that tested positive by RT-PCR, 15 tested negative 0-6 days after symptom onset.	29.4%	71
Reported that the 5th edition of China's COVID-19 prevention and control guidelines states that the real-time RT-PCR test for SARS-CoV-2 has a false negative rate of at least 30%.	≥30%	72
Estimated a 38% false negative rate in RT-PCR tests on the day of symptom onset.	38%	73
Of 28 patients diagnosed as infected by the criteria of China's National Heath Commission, 11 tested negative by RT-PCR.	39.3%	74
Of 80 patients that tested positive by RT-PCR, 39 initially tested negative.	48.8%	75
Of 43 paired samples that included a sputum sample, a throat swab or both that tested positive by RT-PCR, 21 throat swabs tested negative.	48.8%	76
Of 1,324 patients that tested positive by RT-PCR, 691 initially tested negative.	52.2%	77

[a] From an online search for studies reporting false negative rates in SARS-CoV-2 RT-PCR testing, excluding studies with less than 20 infected patients.

Table S3. False positives reported in four sensitivity or cross-reactivity assessments of SARS-CoV-2 RT-PCR assays: results per target gene.

Test	Target genes	Negative samples	Positive results	Reference
Charité	E and RdRp	1198	4	43
Charité	E	24	0	78, 79
Charité	RdRp	24	0	78, 79
HKU	N	24	0	78, 79
HKU	nsp14	24	0	78, 79
China CDC	N	24	15	78, 79
China CDC	nsp10	24	6	78, 79
US CDC	N1	24	0	78, 79
US CDC	N2	24	6	78, 79
US CDC	N3	24	18	78, 79
Charité	E	7	0	80
Charité	RdRp S	7	0	80
Charité	RdRp NS	7	0	80
Charité	N	7	7	80
HKU	N	7	0	80
HKU	ORF	7	0	80
China CDC	N	7	0	80
China CDC	ORF	7	0	80
US CDC	N1	7	0	80
US CDC	N2	7	7	80
US CDC	N3	7	0	80
Institut Pasteur	Ip2 Multiplex	7	0	80
Institut Pasteur	Ip2 Multiplex	7	0	80
Charité	E	60	0	81
Charité	RdRp	60	0	81
Charité	N	60	60	81
US CDC	N1	60	0	81
US CDC	N2	60	60	81
US CDC	N3	60	13	81

Table S4. False positives rates in four sensitivity or cross-reactivity assessments of SARS-CoV-2 RT-PCR assays.

Tests	Negative samples	Positive results	False positive rate	Reference
Charité	1198	4	0.3%	43
Charité, HKU, China CDC, US CDC	216	45	20.8%	78, 79
Charité, HKU, China CDC, US CDC, Institut Pasteur	91	14	15.4%	80
Charité, US CDC	360	133	36.9%	81

Table S5. External quality assessments of RNA virus assays.

Virus	Date	Labor-atories	Panels	Negative samples /panel	Negative samples	False positives	False positive rate[a]	Labor-atories with false positives	Refer-ence
SARS	2004?	58	58	3	174	4-12	2.3-6.8%	4	82
MERS	spring 2014	99	189	6	1,134	11[b]	1.0%	8	83
MERS	2015?	56	56	3	168	0	<0.6%	0	84
MERS	2017?	49	49	1	49	0	<2.0%	0	85
Influenza A viruses	Feb-Mar 2007	64	64	2	128	9	7.0%	5-9	86
Influenza A viruses	Aug-Oct 2007	83	83	4	332	9	2.7%	3-9	86
Influenza A viruses	Jan-Feb 2008	95	95	2	190	3	1.6%	2-3	86
Influenza A viruses	Jun-Jul 2008	109	109	2	218	7	3.2%	4-7	86
Influenza A viruses	Jan-Feb 2009	114	114	1	114	1	0.9%	1	87
Influenza A viruses	Jan-Mar 2010	138	138	1	138	1	0.7%	1	88
Influenza A viruses	Jun-Aug 2010	158	158	1	158	2	1.3%	2	88
Influenza A viruses	Jan-Mar 2011	158	316	2	316	11	3.5%	3-11	89
Influenza A viruses	Jun-Jul 2011	159	159	1	159	3	1.9%	3	89
Influenza A viruses	Apr-Jun 2012	163	163	1	163	7	4.3%	7	90
Influenza A viruses	Apr-Jun 2013	158	158	1	158	4	2.5%	4	91
Influenza A viruses	Apr-Jun 2014	156	156	1	156	6	3.8%	6	92
Influenza A viruses	Apr-Jun 2015	153	153	1	153	3	2.0%	3	93
Influenza A viruses	Apr-Jun 2016	151	151	1	151	1	0.7%	1	94
Influenza A viruses	Apr-Jun 2017	160	160	1	160	3	1.9%	3	95
Influenza A viruses	May-Jun 2018	174	174	1	174	0	<0.6%	0	96
Influenza A viruses	May-Jul 2019	172	172	1	172	2	1.2%	2	97
HCV	Jan 2005	78	78	9	702	49	7.0%	6-49	98
HCV	Feb 2005	84	84	7	588	29	4.9%	5-29	98
HCV	2005?	5	119	1	119	4	3.4%	3	99
HCV	Jan 2006	96	96	7	672	47	7.0%	7-47	98
HCV	Feb 2006	89	89	6	534	11	2.1%	2-11	98
HCV	2006?	20	21	1	21	0	<4.8%	0	100
HCV	Jan 2007	104	104	7	728	22	3.0%	4-22	98
HCV	Feb 2007	99	99	7	693	28	4.0%	4-28	98
Hepatitus Delta virus	2015?	28	56	4	112	6	5.4%	5	101
Chikungunya virus	2007?	31	36	3	108	2-6	1.9-5.6%	2	102
Chikungunya virus	Sep 2014	56	60	5	297	24	8.1%	18	103

Table S5. continued

Virus	Date	Labor-atories	Panels	Negative samples /panel	Negative samples	False positives	False positive rate[a]	Labor-atories with false positives	Refer-ence
Chikungunya, Dengue	Feb-May 2015	20	20	2	40	1	2.5%	1	104
Dengue virus	May-Jul 2013	16	16	1	16	1[c]	6.3%	1	105
Zika virus	Oct-Nov 2016	50	85	6	504[c]	14[d]	2.8%	12	106
Rift Valley fever virus	2012	30	39	3	117	4	3.4%	3	107
Measles virus	Aug 2014	41	41	3	123	1	0.8%	1	108
Ebola virus	Aug 2014	82	106[e]	3	317[e]	1	0.3%	1	109
Ebola virus	Dec 2014	19	20	3	60	0	<1.7%	0	110
Ebola virus	Apr 2015	3	3	1	3	0	<33.3%	0	5
Ebola virus	Nov 2014	6	6	1	6	1	16.7%	1	5
Ebola virus	Mar 2016	9	9	1	9	0	<11.1%	0	5
4 arboviruses[f]	Nov 2017	51	51	4	204	10	4.9%	6	111

[a] "<" indicates a false positive rate below the detection limit (calculated as the reciprocal of the number of negative samples); treated as zero in the analyses.

[b] A majority of the laboratories in this study used a confirmatory second target in accordance with a World Health Organization recommendation; some used sequencing for confirmation.

[c] This was an equivocal result by a laboratory using real-time RT-PCR, scored as a positive result by the external quality assessment.

[d] Inconclusive results are not included in these figures.

[e] Not including two panels that were tested only for filovirus.

[f] Toscana virus, West Nile virus, Usutu virus and Tick-borne Encephalitis virus.

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