

RESEARCH

Open Access



Comparing swab- and different symptoms-based strategies to ascertain COVID-19 recovery in healthcare workers: a cost-effectiveness analysis

Roberto Benoni^{1,2*}, Irene Campagna¹, Francesca Moretti² and Stefano Tardivo²

Abstract

Objective: Given the human and economic cost of the COVID-19 pandemic, protecting healthcare workers (HCW) and ensuring continuity of care is critical. The aim of this study is to evaluate the cost-effectiveness of different strategies to ascertain COVID-19 recovery in HCWs.

Methods: Data were collected from the hospital health surveillance program on HCWs at the University Hospital of Verona between 29/02/2020 and 14/04/2021. The diagnosis of SARS-CoV-2 infection and the assessment of the recovery were made through RT-PCR on oro-nasopharyngeal swab-sample. Recovery time and probability were estimated through Kaplan–Meier estimate. For each recovery assessment strategy costs (laboratory diagnostics and human resources), expressed in local currency (euro—€), and working days saved (WDS—effectiveness) were estimated. A decision-tree was created where each knot was a time point scheduled by the different recovery assessment strategies. A Monte Carlo simulation method was used, and probabilistic sensitivity analysis assessed the effect of input uncertainty.

Results: In the study period 916 (9.9%) HCWs tested positive. Recovery time through symptom-based strategy (21 days 0.95 CI 16–24) was significantly lower compared to swab-based one (25 days 0.95 CI 23–28, $p < 0.001$). The swab-based strategy was dominated by all symptoms-based ones. Symptoms-based with a swab on days 14 and 17 had an ICER of 2 €/WDS and 27 €/WDS compared to the one scheduled on days 10 and 17 and with only one swab on the 17th day.

Conclusions: Scheduling swabs on days 14 and 17 in a symptom-based strategy was the most cost-effective, saving 7.5 more working days than the standard one with swabs on days 10 and 17.

Keywords: Cost-effectiveness, COVID-19, Recovery time, Healthcare workers, Economic evaluation

Background

Since the beginning of the coronavirus disease 2019 (COVID-19) pandemic more than 4,812,000 people in Italy have been infected by SARS-CoV-2 and more than 132,000 have died because of it [1]. Healthcare workers (HCWs), due to the nature of their profession, have been among the most affected by the pandemic, especially at its onset, when knowledge about its means of

*Correspondence: roberto.benoni90@gmail.com

² Department of Diagnostics and Public Health, Section of Hygiene, University of Verona, Strada Le Grazie, 8, 37134 Verona, Italy
Full list of author information is available at the end of the article



© The Author(s) 2022. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

transmission and containment was scarce [2]. According to reports sent by member States to the World Health Organization (WHO) during the first wave of the pandemic (March–May 2020) HCWs experienced more than triple the risk of infection compared to that of the general population [3]. As of November 8, 2021, in Italy 146,691 HCWs have been infected [4]. The WHO estimated that between January 2020 and May 2021 in Italy 3970 HCWs may have died [3].

Premature mortality cost COVID-19-associated was estimated as €137,789 per excess death across Europe with Italy and Spain being the most burdened countries during the first wave [5]. Striking the right balance between public health measures to control the spread of infection and the broader needs of society and the economy should be a priority.

The dimensions of the phenomenon had unprecedented and costly consequences on the sustainability of the National Healthcare System [6]. Preserving the health of HCWs has been considered a priority since the onset of the pandemic. To this avail, the University Hospital of Verona, a main hub in the Veneto region in Italy's Northeast, following national and regional guidelines [7] had set up a surveillance program in March 2020 [8]. Along with regular testing screening of all staff and close contacts' surveillance, it entailed the execution of periodical swabs for HCWs who resulted positive in order to allow their as prompt as possible return to work. In October 2020 the program was revised according to National guidelines [9].

Following WHO assessments [10] a symptoms-based strategy was implemented, reducing the number of swab tests required to return to work. This happened before the beginning of the second wave of the pandemic, which in Italy occurred between October and December 2020 and was characterized by a much higher number of cases than the first wave and less restrictive containment measures. A study conducted in Switzerland demonstrated that a regular testing regime of HCWs is optimal to prevent transmission among coworkers while keeping work output high and economic cost low [11], but, to our knowledge, few data are available on the most cost-effective testing strategy of positive HCWs.

The aims of this study were to describe the infected HCWs characteristics and recovery time between the two waves of the pandemic and to evaluate the costs and effectiveness of different recovery assessment strategies.

Methods

A retrospective study was conducted using data from health surveillance program (HSP) of the University Hospital of Verona (UHV) located in the Veneto Region (Italy). Data referred to the period between February 29,

2020 (date of the first swab collected in the UHV) and April 14, 2021.

Health surveillance program

The HSP was established at a national level [7] and implemented in regional setting according to local procedures [12], as described in another study [13].

The HSP provided the swab test based on three ways (Fig. 1): HCWs with COVID-19 related symptoms, HCWs with a close contact with a SARS-CoV-2 infected individual and through a screening program for all remaining HCWs. Close contact was defined as either a contact with a SARS-CoV-2 infected individual without any personal protective equipment, within two meters and for more than 15 min; furthermore, close contact could also be considered as an unprotected direct contact with secretions of a SARS-CoV-2 infected case. High-risk wards were screened every 10 days, all the others clinical and surgical wards every 20 days, whereas the employees of the administrative sector were tested every 30 days. In the UHV, Intensive Care Units, Infectious and Respiratory Diseases wards and COVID Units were considered at high-risk.

If an HCW tested positive to any of the swabs carried out by the HSP a home self-isolation was recommended for different periods depending on the recovery strategies adopted.

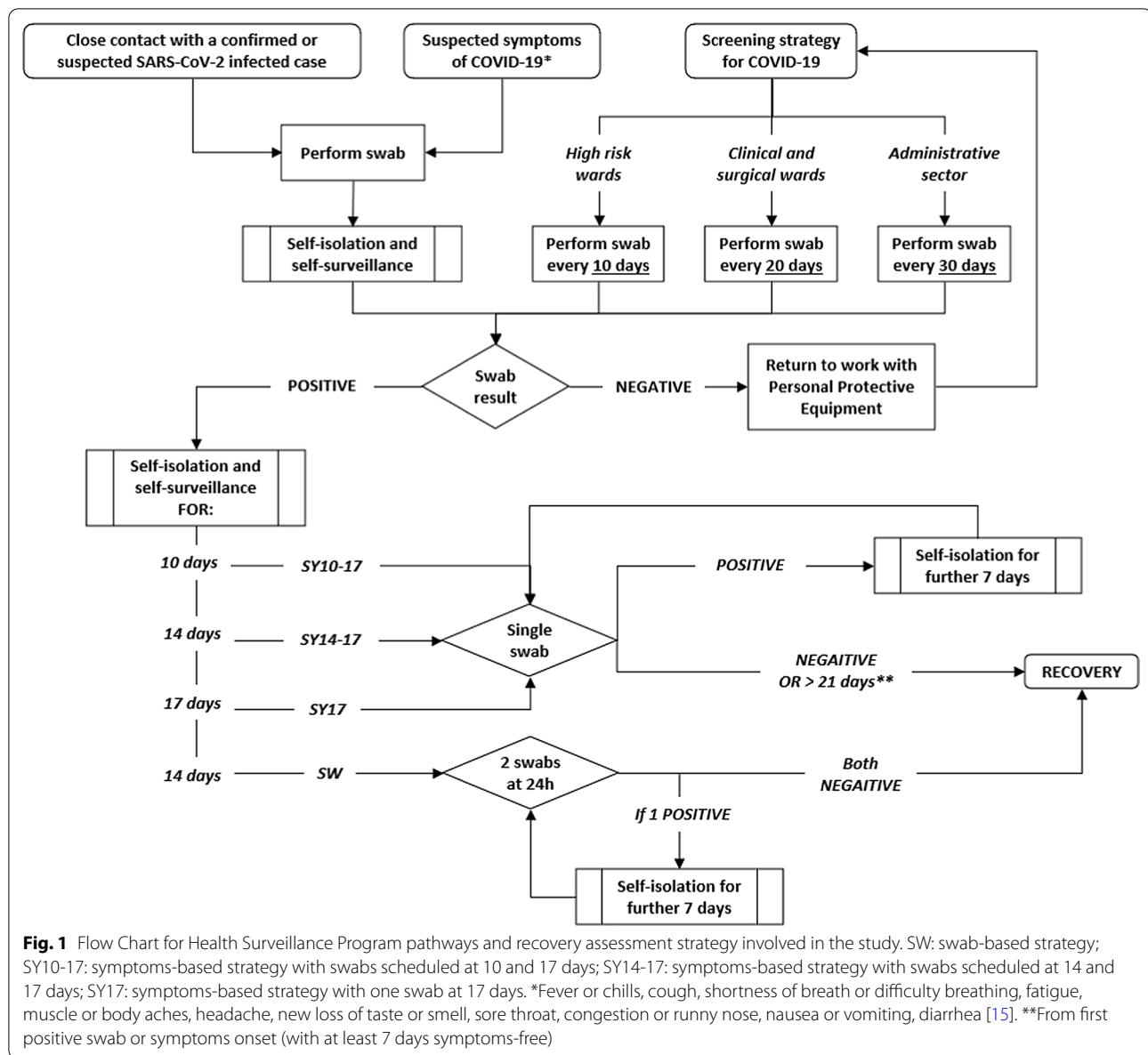
Recovery assessment strategies

Swab-based strategy was used from February 28, 2020, until October 12, 2020. According to this, positive HCWs required to isolate for at least 14 days (or longer until symptoms resolution) and then to perform two swabs taken 24 h apart. Only if both swabs resulted negative, the HCW was considered recovered. In case one of the two swabs tested positive, the HCW had to repeat both swabs after 7 days [14].

From October 12, 2020, the Italian government adopted the symptoms-based strategy suggested by the World Health Organization to ascertain the COVID-19 recovery [9]. An infected asymptomatic individual was considered recovered if the RT-PCR swab test performed 10 days after the first positive one tested negative. In case of symptomatic patients, the swab had to be taken 10 days after the symptoms' onset, after at least three days symptoms-free. If this first swab tested positive, it had to be repeated after 7 days until it proved negative or 21 days (with at least 7 days symptoms-free) since the first positive swab or onset of symptoms.

Ethics

According to Law Decree N.14 of March 9, 2020, personal data were collected to guarantee public health and



to ensure the diagnosis and the assistance of the infected subjects in the context of COVID-19 emergency [16]. Data were collected exclusively for the purpose of the HSP, it was anonymized and presented in an aggregated format as to ensure privacy of the subjects. This research was performed following the ethical standards of the 1964 Declaration of Helsinki and was launched and approved by the Institutional Board of the Veneto Regional Health Authority [17].

Cost-effectiveness analysis (CEA)

Strategies included

The recovery assessment strategies included in the CEA were standard swab-based (SW) and symptoms-based

(SY10-17) strategies. Kaplan–Meier estimate for right censored data was applied to explore the median recovery time. According to Kaplan–Meier recovery probability estimation, two different symptoms-based strategies with swabs scheduled at 14 and 17 days (SY14-17) and with only one swab at 17 days (SY17) were explored in this analysis. A total of four strategies were included in the analysis (Fig. 1).

Costs

All costs were collected and analysed as local currency (euro—€). The relevant costs included in the CEA were: the resources needed to provide the microbiological infection diagnosis and human resources workload per

day (Table 1). Costs related to SARS-CoV-2 diagnosis were considered as the cost of the swabs and reagents for sample processing, cost of personal protective equipment and cost of maintenance. Cost of human resources was estimated as the cost of a half work shift (4 h), according to Italian national collective agreement [18], calculated for the staff implemented to get the diagnosis (i.e., 2 nurses to run the swab sampling clinic and 1 laboratory technicians for specimens' analysis), divided by the mean number of HCWs needed to be tested per day.

Outcome (effectiveness)

Effectiveness was considered as the amount of working days saved (WDS) in a three-month period, starting from the first positive swab, thanks to the early reintroduction of HCW into his workplace through the different recovery assessment strategies.

Analysis

A decision tree was created. Every node was a time point scheduled by the four competing strategies with different probabilities of proved positive or negative estimated through the previous survival analysis (see Additional file 1: Fig. S1). Triangular distribution was applied for recovery probability (see Additional file 1: Table S1). Monte Carlo simulation, estimating the effect of parameters variability in recovery trajectory and individual responsiveness to recovery assessment strategies, was used with number of iterations set at 10,000 [22, 23]. Steps of the algorithm used in the Monte Carlo simulation were shown in the Additional file 1, while parameters variability for the recovery probability at every knot of the decision tree and the costs included in the analysis were reported in Additional file 1: Table S1 and Table 1, respectively. Costs were assumed with a gamma distribution. Number of WDS had a normal distribution.

Willingness to pay (WTP) was set at €160, estimating as the maximum cost of microbiological infection diagnosis and human resources per day per WDS paid by the hospital.

Data were analysed by comparing the four competing strategies reporting crude and incremental costs, incremental effectiveness, and efficiency indicators: Incremental cost-effectiveness ratio (ICER) and incremental net monetary benefit (INMB). Incremental measures were estimated with a 0.95 confidence interval. To consider the uncertainty of parameters, one-way sensitivity analysis (OWSA) and probabilistic sensitivity analysis (PSA) were performed. Results were showed as tornado diagram, cost-effectiveness scatterplot, ICER plot and acceptability curve of cost-effectiveness [24, 25].

Statistical analysis

In the descriptive analysis, frequency rates and percentages were used for categorical variables and medians with interquartile range for continuous variables. Clopper Pearson method with an established 95% confidence interval was used for cumulative incidence of positive HCWs. Fisher's exact test and χ^2 test, as appropriate, and Mann–Whitney-U non-parametric test were used to compare categorical and continuous variables, respectively. The association between time of recovery, as dependent variable, and clinical and demographic characteristics was investigated via Cox proportional hazard regression. To evaluate the trend over time of recovery assessment costs in relation with the number of infected cases, a linear regression model was fitted. Regression coefficient beta was shown with standard error (SE). Interaction term was fitted between number of daily infected HCWs and the types of strategies as independent variables; dependent variable was the daily recovery assessment cost.

A p-value < 0.05 was considered significant. All analyses were performed using R software (version 4.1.1).

RESULTS

Infected healthcare workers characteristics

In the study period 9174 HCWs (male 2828—30.8%; female 6346—69.2%) were tested for SARS-CoV-2 and 916 (9.9%; 0.95 CI 9.4–10.6%) of these were positive.

Table 1 Mean cost with 0.95 confidential interval (CI) for gamma distribution estimated for the recovery assessment of a SARS-CoV-2 infected health care workers

	Mean cost (€)	Variation (0.95 CI)	References
SARS-CoV-2 diagnosis			
SARS-CoV-2 Test Kit (unit)	14,15	(11.82, 16.63)	[19]
Maintenance costs	20.0	(16.0, 24.0)	[20]
PPE/pppd (KN95 + gloves)	2,62	(1.02, 5.39)	[19, 21]
Human resources			
Nurse (4 h)	36,51	(34.71, 38.20)	[18]
Laboratory technician (4 h)	31,88	(29.48, 34.31)	[18]

PPE: personal protective equipment; pppd: per person per day

Positive rate was not significantly different between sexes (male n=258—28.2%; female n=658—71.8%; p=0.072). SARS-CoV-2 infected HCWs had a median age of 46.1 years and were older than non-infected individuals (41.1 years; p<0.001). Symptoms were reported by 508 HCWs (55.2%) with no differences based on sex (p=0.987). Symptomatic HCWs had a median age of 47.3 years and were significantly older than asymptomatic ones (43.8; p=0.003). Eighty-two HCWs (16.6%) developed symptoms after the execution of the positive swab test with a median time of 2 days (IQR1-3). In the overall period 18 (2.0%) of the SARS-CoV-2 infected HCWs needed hospitalization with a median age of 64.7 years and were significantly older compared to non-hospitalized ones (45.7 years; p=0.005).

During the first phase (from February 2020 to October 2020) 8049 HCWs were tested and 255 (3.2%; 0.95 CI 3.0%-3.6%) resulted positive; during the second period (from October 2020 to April 2021) 8486 HCWs were tested and 661 (7.8%; 0.95 CI 7.2%-8.4%) were positive. No differences were found between infected HCWs during the first and second waves based on age (p=0.526). There was a weak evidence of a difference based on sex (p=0.056). Symptom's development was not significantly different between the two periods (p=0.240). Job position of the HCWs tested positive was not different between the two periods considered in the analysis

(p=0.086, Table S2). In the first period 12 HCWs (4.9%) needed hospitalization while 6 HCWs (0.9%) were hospitalized during the second one (p<0.001).

Recovery time

Median time of recovery, considering both strategies together, was 21.0 days (0.95 CI 20–21). Considering the swab- and symptom-based strategies, the median recovery time was 25 days (0.95 CI 23–28) and 21 days (0.95 CI 16–24), respectively. Considering the symptom-based strategy, 17% and 41% of HCWs tested negative at 10 and at 17 days, respectively, from the first positive swab or the symptoms' onset.

In cox-regression model, symptoms-based strategy showed a significantly lower time to ascertain the COVID-19 recovery (p<0.001, Table 2). HCWs with symptoms and those who needed hospitalization had a median recovery time of 21 (0.95 CI 21–21) and 36 days (0.95 CI 31–49), respectively, and it was significantly longer compared to asymptomatic HCWs and non-hospitalized ones (17 days, p<0.001 and 21 days p=0.017), regardless of the strategies used to ascertain the recovery.

Cost-effectiveness

The crude cost for the four competing strategies (SW, SY10-17, SY14-17, SY17) was €3688.9 (SD 48,496.9),

Table 2 Kaplan Meier estimation of recovery time and recovery Hazard Ratios (HR) estimated in the multivariate Cox Proportional hazard model

	Kaplan-Meier estimates			Cox regression		
	N Events	Median (days)	0.95 CI	HR	0.95 CI	p-value
Overall	913	21	20–21			
Sex						
Male	257	21	20–21	0.99	0.85–1.14	0.862
Female	656	21	20–21	Reference		
Age (years)				1.00	0.99–1.00	0.514
22–29	116	18	17–21			
30–39	221	20	18–21			
40–49	203	21	19–21			
50–59	294	21	19–21			
60–67	79	21	20–21			
Recovery assessment strategy						
Swab-based	210	25	23–28	0.18	0.14–0.22	<0.001
Symptoms-based	26	21	16–24	Reference		
Symptoms						
Yes	508	21	21–21	0.65	0.56–0.74	<0.001
No	405	17	17–18	Reference		
Hospitalization						
Yes	18	36	31–49	0.15	0.09–0.26	0.017
No	895	21	20–21	Reference		

€1180.9 (SD 15,413.1), €1198.8 (SD 15,690.8) and €722.8 (SD 9433.8), respectively. The mean number of WDS (effectiveness) was 140.7 (SD 1.5) for the SW strategy, 184.3 (SD 1.3), 191.7 (SD 1.4) and 171.7 SD (0.9) for the SY10-17, SY14-17 and SY17 strategies (Fig. 2A). SW strategy was dominated by all three symptoms-based strategies since had positive incremental cost and negative effectiveness (Fig. 2B). Incremental

cost and effectiveness were shown in Table 3. Comparing the symptoms-based strategies, SY14-17 proved to be more cost-effective when compared to both SY10-17 and SY17 with an ICER of 2 €/WDS and 27 €/WDS and an INMB of €11,820 and €2730 respectively.

The tornado plot (Fig. 2) showed that estimate ICER was robust around parameters variability comparing SY14-17 and SY17 with SY10-17 strategy. The greatest

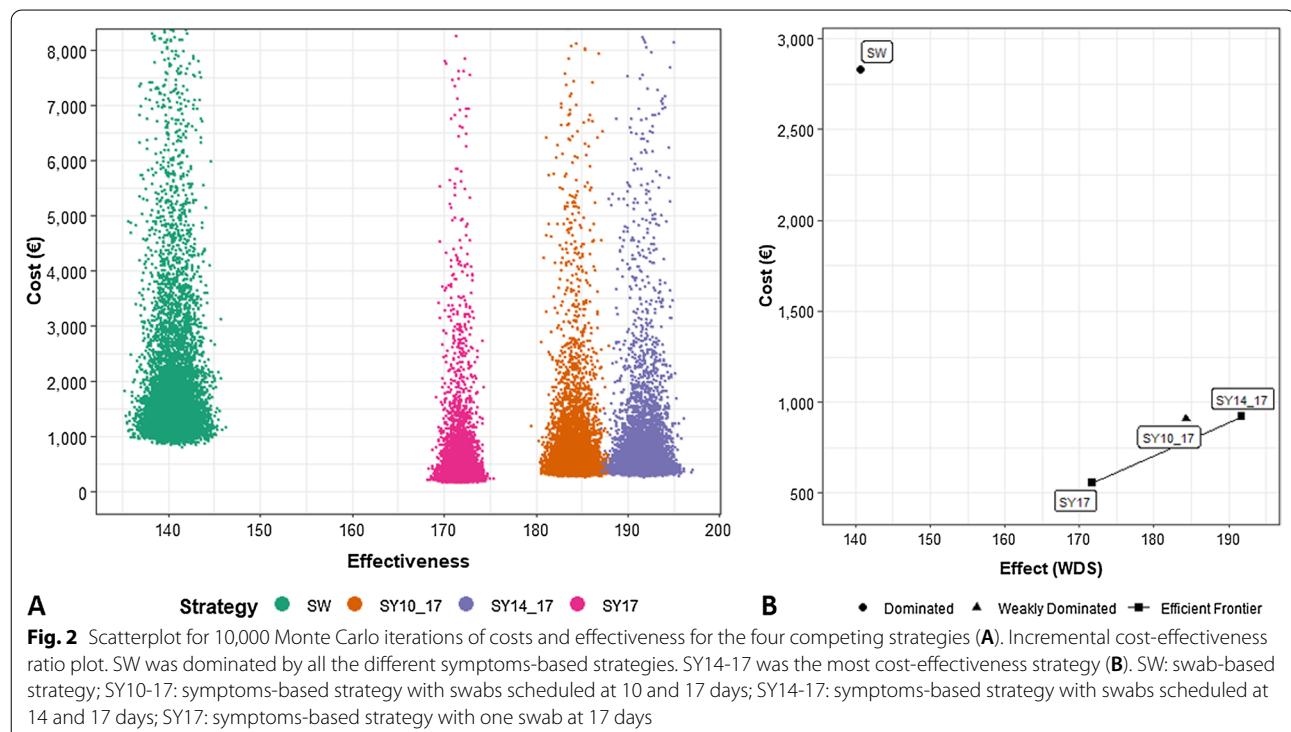


Table 3 Incremental (Δ) number of working days saved (WDS) thanks to the different recovery assessment strategies (effectiveness), incremental (Δ) cost, incremental cost-effectiveness ratio (ICER) and incremental net monetary benefit (INMB) between swab-based strategy (SW) and the three different symptoms-based and comparing the competing symptoms-based strategies with swabs scheduled at 10 and 17 days (SY10-17), 14 and 17 days (SY14-17) or only 17 days (SY17)

	Δ effectiveness (WDS)	Δ cost (€)	ICER (€/WDS)	INMB (€)
Strategies				
SW	Reference	Reference	Reference	Reference
SY10-17	43.6 (39.7; 47.5)	-2508 (-8100; -666)	Dominates	9480 (7231; 15,349)
SY14-17	51.1 (47.1; 55.2)	-2490 (-8043; -662)	Dominates	10,662 (8408; 16,314)
SY17	31.0 (27.6; 34.6)	-2966 (-9589; -789)	Dominates	7933 (5420; 14,647)
Strategies				
SY10-17	Reference	Reference	Reference	Reference
SY14-17	7.5 (3.8; 11.2)	18 (4; 55)	2	1182 (590; 1779)
SY17	-12.5 (-15.6; -9.5)	-458 (-1484; -122)	37	-1547 (-2306; -473)
Strategies				
SY14-17	Reference	Reference	Reference	Reference
SY17	-20.0 (-23.3; -16.8)	-476 (-1551; -126)	24	-2730 (-3529; -1612)

impact on ICER was the variability in recovery probability at the first time point of SY10-17 and SY17 (Fig. 3 panel B).

Acceptability curve demonstrated higher probabilities of SY14-17 to be cost effectiveness compared to the other recovery assessment strategies for a WTP range between €30 and €160 (Fig. 4). This result was consistent with previous efficiency indicators and sensitivity analysis.

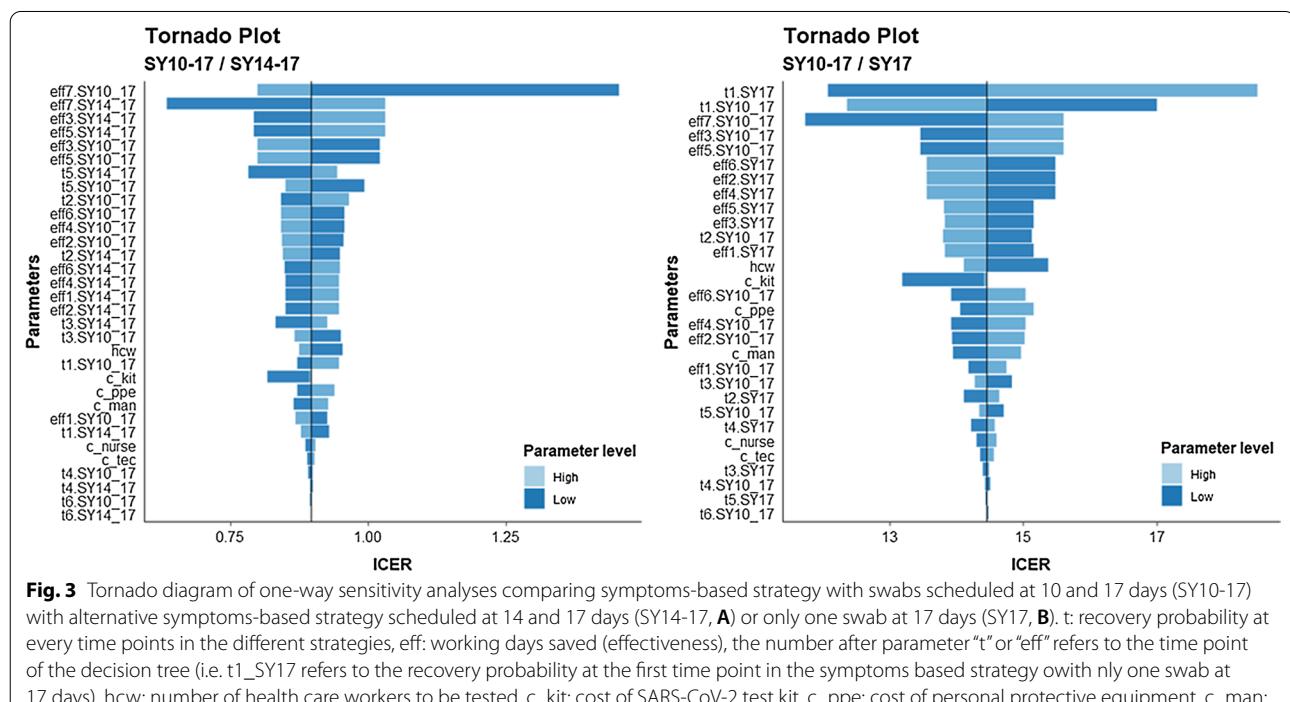
Daily recovery assessment costs were associated with the number of daily infected HCWs ($p < 0.001$), increasing of €28.3 ($SE = 7.6e^{-12}$) as the number of daily infected individuals increase by one unit in both strategies (Fig. 5). As the number of infected HCWs increased, recovery assessment costs raised more in the swab-based strategy when compared with the standard symptoms-based (SY10-17) ($\beta = 14.2$ $SE = 1.5e^{-11}$; $p < 0.001$).

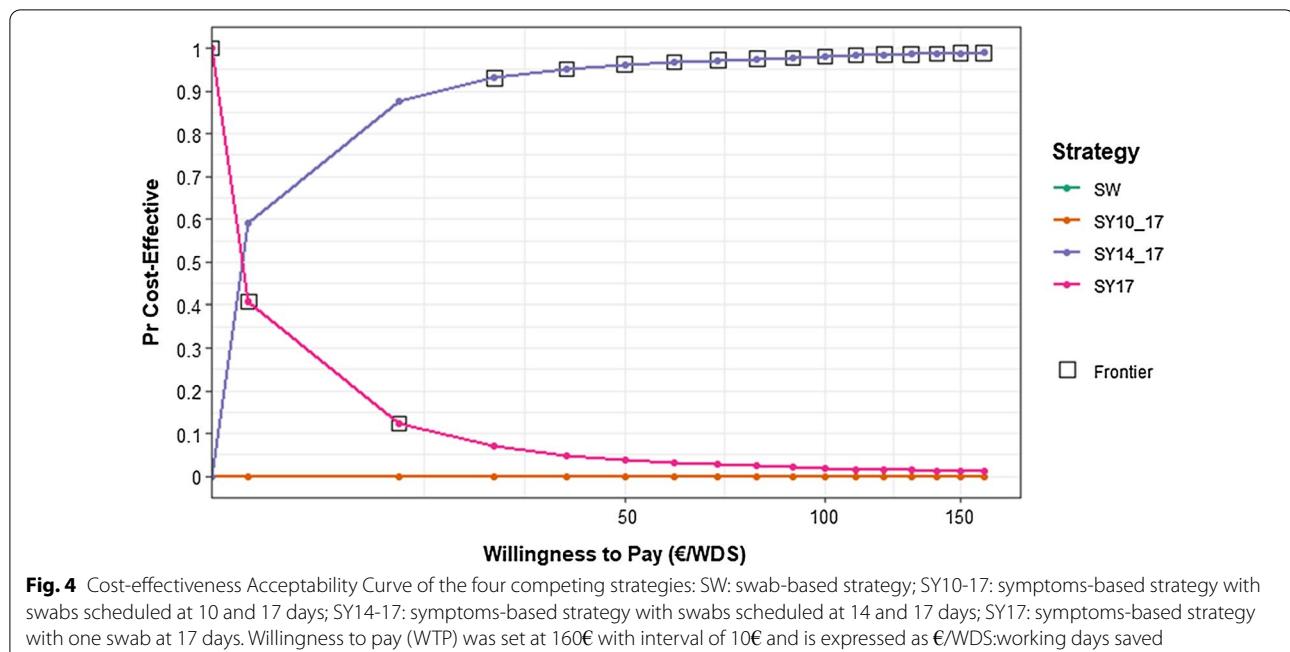
Discussion

The COVID-19 pandemic impacted the health care system of many countries at different levels. The cost in terms of patient's health, human and financial resources was unprecedented. Fear of infection prevented people from seeking timely healthcare. This led to a 70% reduction in primary care visits [26]. The economic crisis resulting from COVID-19 pandemic and worldwide lockdown measures jeopardised the job of many people

with a further burden for health. The 40% of respondents to a Commonwealth Fund survey declared they had health insurance through the job that was lost [27]. Moreover, HCWs were one of the most severely affected categories with a high risk of exposure to SARS-CoV-2 infection. This resulted in difficulties to ensure healthcare [28]. Median estimated recovery time was 21 days (Table 2). Similar results were shown by other authors with median time of viral clearance ranging from 17 to 24 days [29, 30]. This prolonged absence from work forced health facilities to reallocate human resources by prioritizing emergency and intensive care services. In a recent WHO survey of 39 European countries, it was found that the most affected sector was non-communicable diseases (NCDs) prevention and treatment. The disruption was consequent to a decline in inpatient volume from cancellation of elective care (reported by 75% of the countries), suspension of population screening services and closure of outpatient services [31]. In order to adequately plan the level of safe staffing, stakeholders and management should consider longer recovery time for those HCWs showing symptoms or being hospitalized. The severity of the disease was an independent risk factor for a longer recovery time and viral clearance [29, 32].

One of the greatest challenges posed by the COVID-19 pandemic has been finding the right balance between public health measures and restriction and the broader





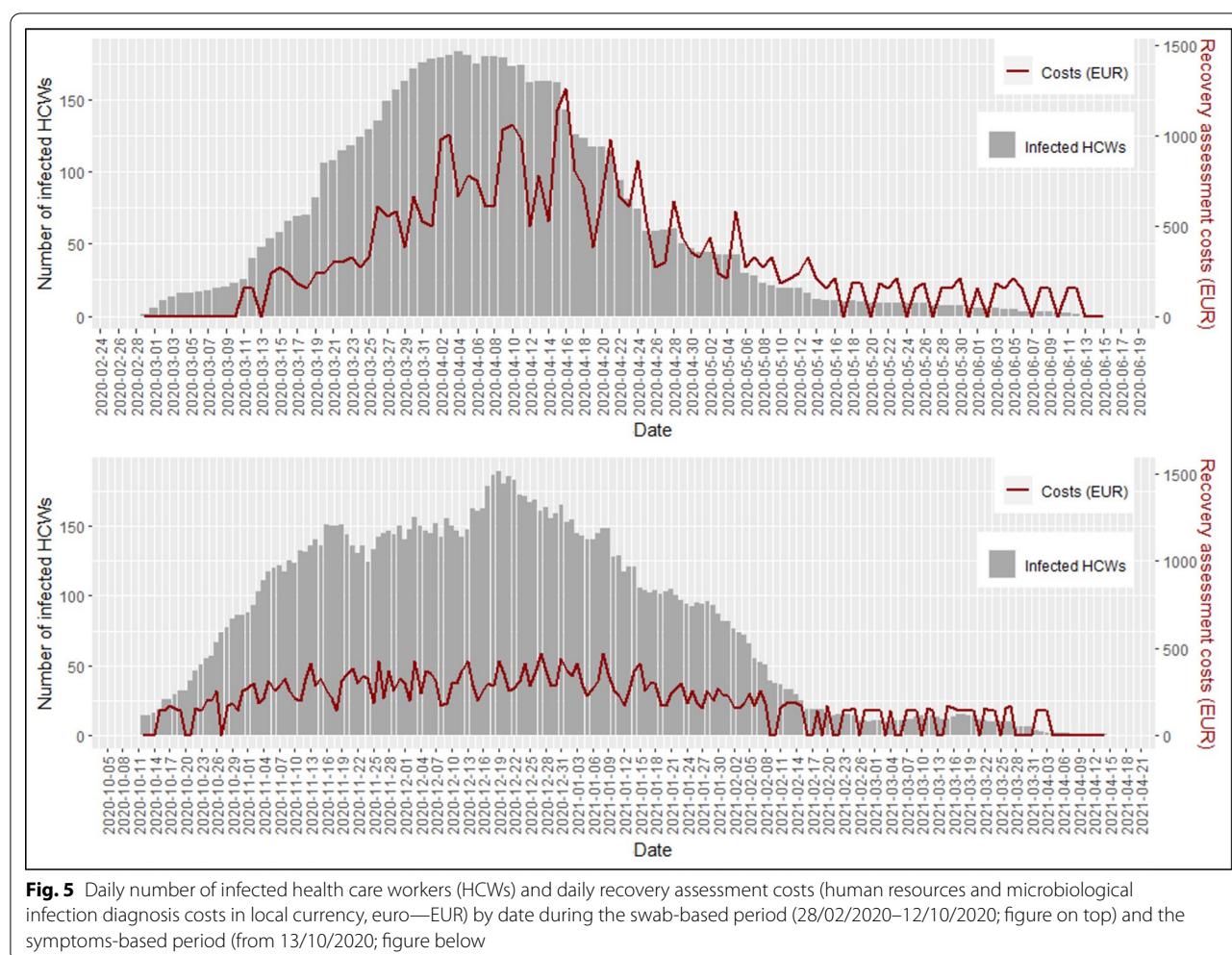
needs of society and the economy. In this perspective this study tries to explore the most cost-effectiveness recovery assessment strategy. Growing evidence showed that SARS-CoV-2 infected individuals are no longer infective after 21 days, except for specific categories such as the immunocompromised [33]. A symptoms-based strategy is therefore recommendable. Swab-based strategy proved to be dominated by the symptom-based one with an incremental cost of €2,508 and a negative incremental effectiveness when compared to the standard symptoms-based strategy with swab scheduled at 10 and 17 days. A symptoms-based strategy should be applied especially for those categories deemed essential such as HCW to shorten periods of isolation. When defining the infected HCWs management, an effective governance should aim to preserve adequate health assistance while safeguarding HCWs physical and mental health and preventing transmission to the patients and hospital staff [34].

When comparing different swabs scheduled for the symptoms-based strategy, the most cost-effective was the one with the swabs scheduled at 14 and 17 days. Similar results were obtained in a recent cost-effectiveness analysis of mass-testing screening in the general population [35]. At high transmission rates, the strategy with the best cost-effectiveness was the one with weekly swab test and a 14-days isolation period for the positive individuals. Interestingly, at low-moderate transmission rates, a 7-days isolation period was more cost-effective than either 10-day or 2-week periods. In the study sample, the symptoms-based strategy showed better performance as the number

of infected HCWs increased compared to the swab-based strategy (Fig. 5). A shorter isolation period and recovery assessment with a single swab allowed faster reintroduction of HCWs to the workplace and avoided the addition of infected HCWs with increasing testing costs.

Currently, in Italy, high rates of vaccination and the spread of less severe variants have radically changed the epidemiological scenario. However, assessing the recovery of HCWs remains of primary importance, as for this particular population, according to Italian regulation, a negative swab test is still necessary to allow readmission at work. In addition, particular job categories such as healthcare workers deserve special attention. Returning to work prematurely after a SARS-CoV-2 infection could put the health of patients and colleagues at risk. For this reason, safe and effective yet cost-effective strategies to ensure recovery deserve to be investigated. The present results will allow to organize more cost-effective epidemic control strategies in the event of future pandemics.

This study has several limitations. First, the retrospective design and context-specificity of the included data may limit the generalizability of the results. Additionally, data on the vaccination status of HCWs were not considered because the vaccination campaign was in its beginning stages. However, this could have affected time and recovery probability. Data regarding the economic evaluation of nonpharmacological measures to contain COVID-19 pandemic are still scarce [36]. This implies uncertainty and a preliminary nature of many of the input parameters in this model. However, the PSA and OWSA were applied



considering this uncertainty and giving robustness to the findings. In the cost effectiveness analysis were included only the directed costs related to the swab testing and the outcome was the number of working days saved for the infected HCWs. Future studies should try to explore the lost in Quality Adjusted Life Years (QALYs) of patients due to the reduction in the provision of health services related to the high burden of infected HCWs forced to stay on sick leave. This has a high level of complexity depending on the context and type of patient and disease. Moreover, many of the health and economic consequences of COVID-19 pandemics are not yet known.

Conclusions

Since it has been proposed that we are in a transitional phase between pandemic and endemic, policymakers should maintain appropriate levels of vigilance. Especially for at-risk and strategically important groups such as HCWs, appropriate reintroduction measures after infection should be considered. In particular, the

symptom-based strategy has been confirmed to be the most cost-effective and a 14- and 17-day swab schedule should be recommended. Moreover, the symptom-based strategy allowed the cost of recovery assessment to be contained as the rate of transmission and, consequently, the number of cases increased.

Few data exist on the evaluation of the economic impact of measures taken to counter the COVID-19 pandemic both at hospital level and broader levels. More insight should be given to these issues both for the present situation and for possible future similar scenarios.

Abbreviations

CEA: Cost-effectiveness analysis; HSP: Health Surveillance Program; HCW: Healthcare workers; ICER: Incremental cost-effectiveness ratio; INMB: Incremental net monetary benefit; OWSA: One-way sensitivity analysis; PSA: Probabilistic sensitivity analysis; SY10-17: Standard symptoms-based strategies; SW: Swab-based; SY14-17: Symptoms-based strategies with swabs scheduled at 17 days; SY14-17: Symptoms-based strategies with swabs scheduled at 14 and 17 days; UHV: University Hospital of Verona; WTP: Willingness to pay; WDS: Working days saved; WHO: World Health Organization.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12962-022-00385-w>.

Additional file 1. Supplementary materials including additional data, graphic representation of the decision tree and the pseudocode of the algorithm used in the Monte Carlo simulation are provided.

Acknowledgements

We want to thank all colleagues of the Postgraduate Schools of Occupational Medicine, Forensic Medicine and Hygiene who worked with us in the health surveillance and collaborated in collecting this important data, as well as all technicians of the Microbiology Unit. A special thanks goes to all healthcare workers involved in the study and the management of Verona University Hospital for their support and participation in such difficult and challenging times.

Author contributions

RB: Data collection, statistical analysis, writing, editing. IC: Data collection, writing. FM: editing, review. ST: supervision, editing, review. All authors read and approved the final manuscript.

Funding

None.

Availability of data and materials

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The research was launched and approved by the Institutional Board of the Veneto Regional Health Authority.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

¹Postgraduate School of Hygiene and Preventive Medicine, University of Verona, 37134 Verona, Italy. ²Department of Diagnostics and Public Health, Section of Hygiene, University of Verona, Strada Le Grazie, 8, 37134 Verona, Italy.

Received: 14 March 2022 Accepted: 13 August 2022

Published online: 12 September 2022

References

- Protezione Civile. COVID-19 Situazione Italia. <https://opendatadpc.maps.arcgis.com/apps/dashboards/b0c68bce2cce478eaac82fe38d4138b1> (2021). Accessed 06 Dec 2021.
- Nguyen LH, Drew DA, Graham MS, Joshi AD, Guo CG, Ma W, Mehta RS, Warner ET, Sikavi DR, Lo CH, Kwon S, Song M, Mucci LA, Stampfer MJ, Willett WC, Eliassen AH, Hart JE, Chavarro JE, Rich-Edwards JW, Davies R, Capdevila J, Lee KA, Lochlann MN, Varsavsky T, Sudre CH, Cardoso MJ, Wolf J, Spector TD, Ourselin S, Steves CJ, Chan AT, COVID-19 Pandemic Epidemiology Consortium. Risk of COVID-19 among front-line healthcare workers and the general community: a prospective cohort study. Lancet Public health. 2020;5(9):e475–83. [https://doi.org/10.1016/S2468-2667\(20\)30164-X](https://doi.org/10.1016/S2468-2667(20)30164-X).
- World Health Organization (WHO). The impact of COVID-19 on health and care workers: a closer look at deaths. <https://apps.who.int/iris/handle/10665/345300>. 2021. Accessed 06 Dec 2021.
- Istituto Superiore di Sanità (ISS). EpiCentro, dati della Sorveglianza integrata COVID-19 in Italia. <https://www.epicentro.iss.it/coronavirus/sars-cov-2-dashboard>. 2021. Accessed 26 Jan 2022.
- Hanly P, Ahern M, Sharp L, Ursul D, Loughnane G. The cost of lost productivity due to premature mortality associated with COVID-19: a Pan-European study. Eur J Health Econ. 2021. <https://doi.org/10.1007/s10198-021-01351-8>.
- Istituto Nazionale per l'assicurazione contro gli infortuni sul lavoro (INAIL). Monitoraggio sugli operatori sanitari risultati positivi a COVID-19 dall'inizio dell'epidemia fino al 30 aprile 2020: studio retrospettivo in sette regioni italiane. <https://www.inail.it/cs/internet/comunicazione/pubblicazioni/catalogo-generale/pubbl-monitoraggio-operatori-sanitari-studio.html>. 2021. Accessed 06 Dec 2021.
- Italian Government. Decreto legge 9 marzo 2020 n. 14, Disposizioni urgenti per il potenziamento del Servizio sanitario nazionale in relazione all'emergenza COVID-19, Gazzetta Ufficiale. https://www.gazzettaufficiale.it/ricercaArchivioCompleto/serie_generale/2020. 2020. Accessed 02 Dec 2021.
- Benoni R, Panunzi S, Campagna I, Moretti F, Lo Cascio G, Spiteri G, Porru S, Tardivo S. The effect of test timing on the probability of positive SARS-CoV-2 swab test results: mixed model approach. JMIR Public Health Surveill. 2021;7(6):e27189. <https://doi.org/10.2196/27189>.
- Italian Ministry of Health. Circolare n. 0032850 del 12 Ottobre 2020. COVID-19: indicazioni per la durata ed il termine dell'isolamento e della quarantena. <https://www.trovonorme.salute.gov.it/norme/renderNormSanPdf?anno=2020&codLeg=76613&parte=1%20&serie=null>. 2020. Accessed 02 Dec 2021.
- World Health Organization (WHO). Criteria for releasing COVID-19 patients from isolation. <https://www.who.int/news-room/commentaries/detail/criteria-for-releasing-covid-19-patients-from-isolation>. 2021. Accessed 02 Dec 2021.
- Sanchez-Taltavull D, Castelo-Szekely V, Murugan S, Hamley J, Rollenske T, Ganal-Vonarburg SC, Büchi I, Keogh A, Li H, Salm L, Spari D, Yilmaz B, Zimmermann J, Gerfin M, Roldan E, Beldi G, UVC-M-COVID researchers. Regular testing of asymptomatic healthcare workers identifies cost-efficient SARS-CoV-2 preventive measures. PLoS ONE. 2021;16(11):e0258700. <https://doi.org/10.1371/journal.pone.0258700>.
- Veneto Region. Nuovo Coronavirus (Sars-Cov-2). Istruzioni Operative per la sorveglianza del personale del Sistema Sanitario Regionale Rev 02 del 22 Aprile 2020. <https://www.regione.veneto.it/web/sanita/covid-19-documenti-regionali-operatore>. 2020. Accessed 02 Dec 2021.
- Benoni R, Campagna I, Panunzi S, Varalta MS, Salandini G, De Mattia G, Turrina G, Moretti F, Lo Cascio G, Spiteri G, Porru S, Tardivo S, Poli A, Bovo C. Estimating COVID-19 recovery time in a cohort of Italian healthcare workers who underwent surveillance swab testing. Public Health. 2021;196:52–8. <https://doi.org/10.1016/j.puhe.2021.05.014>.
- Italian Ministry of Health. Circolare n. 0006607 del 29 Febbraio 2020. Parere del Consiglio Superiore di Sanità: definizione di Paziente guarito da Covid-19 e di paziente che ha eliminato il virus SARS-CoV-2. Gazzetta Ufficiale. https://www.gazzettaufficiale.it/ricercaArchivioCompleto/serie_generale/2020. 2020. Accessed 02 Dec 2021.
- Centers for Disease Control and Prevention (CDC). Symptoms of COVID-19. <https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/symptoms.html>. 2022. Accessed 20 Apr 2022.
- Italian Government. Decreto-legge n. 14 del 9 marzo 2020. Informativa Privacy per emergenza covid-19 a seguito delle Disposizioni sul Trattamento dei Dati Personalisi nel contesto emergenziale. https://www.gazzettaufficiale.it/ricercaArchivioCompleto/serie_generale/2020. 2020. Accessed 02 Dec 2021.
- Veneto Region. Prevention, Food Safety, Veterinary Department. New coronavirus (SARS-CoV-2) regional procedure. Rev 03. https://hsancamillo.it/wp-content/uploads/2020/03/Procedura-regionale-Covid-19_rev_03-13.3.2020.pdf. 2020. Accessed 06 Dec 2021.
- Agenzia per la Rappresentanza Negoziale delle Pubbliche Amministrazioni (ARAN). Contratto Collettivo Nazionale di Lavoro 2016–2018. Comparto Sanità. <http://www.quotidianosanita.it/allegati/allegato6301726.pdf>. 2019. Accessed 06 Oct 2021.
- World Health Organization (WHO). Coronavirus reagent calculator. <https://webcache.googleusercontent.com/search?q=cache:ZrPusbh4o9sj>; <https://www.who.int/docs/default-source/coronavirus/reagent-calcu>

- lator-for-portal-v2.xlsx%3Fsvrsn%3Dd1e63ac8_1%26download%3Dtrue+&cd=1&hl=it&ct=clnk&gl=et. 2020. Accessed 06 Dec 2021.
20. Ebigbo A, Römmel C, Bartenschlager C, Temizel S, Kling E, Brunner J, Messmann H. Cost-effectiveness analysis of SARS-CoV-2 infection prevention strategies including pre-endoscopic virus testing and use of high risk personal protective equipment. *Endoscopy*. 2021;53(2):156–61. <https://doi.org/10.1055/a-1294-0427>.
 21. Centers for Disease Control and Prevention (CDC). Factors to consider when planning to purchase respirators from another country. <https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/international-respirator-purchase.html>. 2020. Accessed 06 Dec 2021.
 22. Richter A, Mauskopf J. MM1 Monte Carlo Simulation in Health Care Models. *Value in Health*. 1998;1(1):84–5. <https://doi.org/10.1046/j.1524-4733.1998.1100841.x>.
 23. Doubilet P, Begg CB, Weinstein MC, Braun P, McNeil BJ. Probabilistic sensitivity analysis using Monte Carlo simulation. A practical approach. *Med Decis Making*. 1985;5(2):157–77. <https://doi.org/10.1177/0272989X8500500205>.
 24. Baio G, Dawid AP. Probabilistic sensitivity analysis in health economics. *Stat Methods Med Res*. 2015;24(6):615–34. <https://doi.org/10.1177/096228211419832>.
 25. Barton GR, Briggs AH, Fenwick EA. Optimal cost-effectiveness decisions: the role of the cost-effectiveness acceptability curve (CEAC), the cost-effectiveness acceptability frontier (CEAF), and the expected value of perfection information (EVPI). *Value Health*. 2008;11(5):886–97. <https://doi.org/10.1111/j.1524-4733.2008.00358.x>.
 26. Roy, S. Economic impact of COVID-19 pandemic. https://www.researchgate.net/publication/343222400_ECONOMIC_IMPACT_OF_COVID-19_PANDEMIC. 2020. Accessed 26 Jan 2022.
 27. Blumenthal D, Fowler EJ, Abrams M, Collins SR. Covid-19—implications for the Health Care System. *N Engl J Med*. 2020;383(15):1483–8. <https://doi.org/10.1056/NEJMsb2021088>.
 28. Kaye AD, Okeagu CN, Pham AD, Silva RA, Hurley JJ, Arron BL, Sarfraz N, Lee HN, Ghali GE, Gamble JW, Liu H, Urman RD, Cornett EM. Economic impact of COVID-19 pandemic on healthcare facilities and systems: International perspectives. *Best Pract Res Clin Anaesthesiol*. 2021;35(3):293–306. <https://doi.org/10.1016/j.bpa.2020.11.009>.
 29. Qi L, Yang Y, Jiang D, Tu C, Wan L, Chen X, Li Z. Factors associated with the duration of viral shedding in adults with COVID-19 outside of Wuhan, China: a retrospective cohort study. *Int J Infect Dis*. 2020;96:531–7. <https://doi.org/10.1016/j.ijid.2020.05.045>.
 30. Carmo A, Pereira-Vaz J, Mota V, Mendes A, Morais C, da Silva AC, Camilo E, Pinto CS, Cunha E, Pereira J, Coucelo M, Martinho P, Correia L, Marques G, Araújo L, Rodrigues F. Clearance and persistence of SARS-CoV-2 RNA in patients with COVID-19. *J Med Virol*. 2020;92(10):2227–31. <https://doi.org/10.1002/jmv.26103>.
 31. World Health Organization. COVID-19 and the disruption of noncommunicable diseases (NCDs) services: snapshot of survey results for the European Region. 8 July 2020. Copenhagen: WHO Regional Office for Europe. <https://www.euro.who.int/en/health-topics/health-emergencies/coronavirus-covid-19/publications-and-technical-guidance/2020/covid-19-and-the-disruption-of-noncommunicable-disease-services-snaps-hot-of-survey-results-for-the-european-region-2020-produced-by-who-europe>. 2020. Accessed 30 Oct 2021.
 32. Xu K, Chen Y, Yuan J, Yi P, Ding C, Wu W, Li Y, Ni Q, Zou R, Li X, Xu M, Zhang Y, Zhao H, Zhang X, Yu L, Su J, Lang G, Liu J, Wu X, Guo Y, Li L. Factors associated with prolonged viral RNA shedding in patients with Coronavirus Disease 2019 (COVID-19). *Clin Infect Dis*. 2020;71(15):799–806. <https://doi.org/10.1093/cid/ciaa351>.
 33. Centers for Disease Control and Prevention (CDC). Overview of Testing for SARS-CoV-2 (COVID-19). <https://www.cdc.gov/coronavirus/2019-ncov/hcp/testing-overview.html#ConsiderationsWhenTesting>. 2022. Accessed 26 Jan 2022.
 34. Bielicki JA, Duval X, Gobat N, Goossens H, Koopmans M, Tacconelli E, van der Werf S. Monitoring approaches for health-care workers during the COVID-19 pandemic. *Lancet Infect Dis*. 2020;20(10):e261–7. [https://doi.org/10.1016/S1473-3099\(20\)30458-8](https://doi.org/10.1016/S1473-3099(20)30458-8).
 35. Du Z, Pandey A, Bai Y, Fitzpatrick MC, Chinazzi M, Pastore Y, Piontti A, Lachmann M, Vespignani A, Cowling BJ, Galvani AP, Meyers LA. Comparative cost-effectiveness of SARS-CoV-2 testing strategies in the USA: a modelling study. *Lancet Public Health*. 2021;6(3):e184–91. [https://doi.org/10.1016/S2468-2667\(21\)00002-5](https://doi.org/10.1016/S2468-2667(21)00002-5).
 36. Vandepitte S, Alleman T, Nopens I, Baetens J, Coenen S, De Smedt D. Cost-effectiveness of COVID-19 policy measures: a systematic review. *Value Health*. 2021;24(11):1551–69. <https://doi.org/10.1016/j.jval.2021.05.013>.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ready to submit your research? Choose BMC and benefit from:

- fast, convenient online submission
- thorough peer review by experienced researchers in your field
- rapid publication on acceptance
- support for research data, including large and complex data types
- gold Open Access which fosters wider collaboration and increased citations
- maximum visibility for your research: over 100M website views per year

At BMC, research is always in progress.

Learn more biomedcentral.com/submissions

