Original research

Biological risk in Italian prisons: data analysis from the second to the fourth wave of COVID-19 pandemic

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Received 9 August 2022
Accepted 4 March 2023

ABSTRACT

Background The management of COVID-19 in Italian prisons triggered considerable concern at the beginning of the pandemic due to numerous riots which resulted in inmate deaths, damages and prison breaks. The aim of this study is to shed some light, through analysis of the infection and relevant disease parameters, on the period spanning from the second to the fourth wave of the outbreak in Italy's prisons.

Methods Reproductive number (Rt) and Hospitalisation were calculated through a Eulerian approach applied to differential equations derived from compartmental models. Comparison between trends was performed through paired t-test and linear regression analyses.

Results The infection trends (prevalence and Rt) show a high correlation between the prison population and the external community. Both the indices appear to be lagging 1 week in prison. The prisoners' Rt values are not statistically different from those of the general population. The hospitalisation trend of inmates strongly correlates with the external population's, with a delay of 2 weeks. The magnitude of hospitalisations in prison is less than in the external community for the period analysed.

Conclusions The comparison with the external community revealed that in prison the infection prevalence was greater, although Rt values showed no significant difference, and the hospitalisation rate was lower. These results suggest that the consistent monitoring of inmates results in a higher infection prevalence while a wide vaccination campaign leads to a lower hospitalisation rate. All three indices demonstrate a lag of 1 or 2 weeks in prison. This delay could represent a useful time-window to strengthen planned countermeasures.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ In Italy during the COVID-19 pandemic prisons experienced riots due to the disease spread in a confined overcrowded environment. However, the information of COVID-19 dynamics among prison inmates is scarce. The epidemiological models behind SARS-CoV-2 spread and how they are applied to the entire population are known. The epidemiological picture of the Italian population is well known.

WHAT THIS STUDY ADDS

⇒ This study is a descriptive analysis of the epidemiological situation in Italian prisons.
⇒ Prisons are a good research model of a controlled environment to evaluate the spread of communicable diseases and the effectiveness of counteractive measures.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The outcomes of this study are valuable for stakeholders in the selection of the most effective counteractive measures to be adopted and to take possible preventive actions considering the outbreak delay in prison.

INTRODUCTION

At 2 years since the start of the COVID-19 pandemic, we can attempt a retrospective examination of the outbreak management in the Italian prison system through an analysis and inference on epidemiological aspects related to Italian correctional facilities.

The COVID-19 began to spread in Italy between January and February 2020. Both the Italian government and prison service have since established a detailed strategy to confront this threat. At the very beginning, this strategy evoked the prisoners' disappointment which subsequently led to violence and rebellion in at least 30 prison facilities throughout Italy, causing 13 inmate casualties, millions of Euros in damages and countless prison breaks.[1]

The adopted countermeasures have been adjusted to adhere to the specific biological features of this new virus and to the related disease caused by its spread.[1]

COVID-19 is an airborne transmitted disease whose aetiological agent, the SARS-CoV-2, is carried by saliva droplets. The virus particles target nasal, oral or conjunctival mucosa cells through direct deposition, inhalation or secondary transfer.[2] The novel virus is transmitted more efficiently compared with the previous species (belonging to the Coronoviridae family) which threatened worldwide health in 2002 (SARS-CoV) and in 2012 (MERS-CoV), respectively.[3] This aspect is, at least in part, due to the greater viability of the virion on external surfaces where it preserves its pathogenicity for up to 9 days.[4] At the same time, the late onset of symptoms or the presence of mild or absent symptomatology in a wide number of infected people has led to an uncontrollable spread of the virus (eg, especially for those cases in which

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To cite: Franchi C, Rossi R, Malizia A, *et al*. *Occup Environ Med* Epub ahead of print: [please include Day Month Year]. doi:10.1136/oemed-2022-108599

the upper respiratory tract is more affected).[5] Moreover, the appearance of new variants may overcome host immunity and cause reinfection, which contributes to maintaining a high prevalence rate among the population.[6]

The abovementioned characteristics depict a virus which is capable of initiating an uncontrolled outbreak with devastating effects in terms of deaths, hospitalisations and, ultimately, the collapse of health services. In February 2020, the Italian prison service had to face this kind of biological threat within a closed and controlled environment, where poor health conditions, a higher prevalence of communicable diseases,[7 8] lack of hygiene, individuals with a history of drug and alcohol abuse and smoking-related diseases are very common.[9 10] Many refined preventive and protective measures and procedures were implemented. These were aimed at achieving the following main goals[11]:

1. To ensure sufficient social distancing among inmates.
2. To isolate positive-tested inmates.
3. To reduce inmates' transfer and visits.
4. To provide widespread and continuous sanitisation and personal protective equipment (PPE).
5. To perform extensive and continuous molecular or rapid testing.
6. To provide information and psychological support.
7. To prioritise the vaccination campaign.

The above outlined strategy is adopted by the most relevant worldwide scientific literature that is focused on COVID-19 risk reduction in correctional facilities.[12] A few papers have described the Italian prison system's management of the SARS-CoV-2 spread[11 13] and have shown that prevalence of infected individuals among inmates seems to be lower than the values from the staff[11] and lagging 1–2 weeks during the second and third waves of the outbreak.

In this context, our study was aimed at depicting two infection-related parameters: the Point Prevalence (PP) and the Reproductive number over time (Rt) from, approximately, the second to the fourth wave (October 2020 to February 2022) of COVID-19 in Italian prisons (the first wave was excluded due to lack of shared data). These two indices, over time, also highlight the effectiveness of the adopted countermeasures. Similarly, we wanted to analyse a disease-related index—the Hospitalisation (H) rate—during the same time frame. This provided an additional measurement of the promptness and quality of healthcare in prisons. Finally, a comparison was made between the prisoners' outcomes and those related to the staff and external community.

METHODOLOGY

Data on PP, H, vaccinations, prison and staff size, and inmate sex and age stratification were obtained from the website of the Italian Ministry of Justice.[14] The Italian PP and H data were collected from the Civil Protection's website.[15] Data of new weekly hospitalisations were extrapolated from the National Institute of Health's online publications (ie, the national epidemiological bulletins). The Italian population size and its age stratification were obtained from the website of the National Statistics Service (ISTAT).[16] The Rt was calculated by means of the derivative of the logarithm of the prevalence trend according to the susceptible infectious recovered (SIR) compartmental model,[17 18] and the following equation rearrangement.[19]

Starting from the three differential equations described in the original model, the variation over time of the infected is given by:

$$\frac{dI(t)}{dt} = \beta\frac{I(t)S(t)}{N} - \gamma I(t) \quad (1.1)$$

in which:

- I: the number of infected persons.
- S: the number of susceptible persons.
- N: the whole population.
- β: the transmission rate, and represents the likelihood of infection times the number of suitable meetings for an infection result.
- γ: the inverse of the recovery rate that we have posed, to 9 days from the onset of symptoms (after that time-window

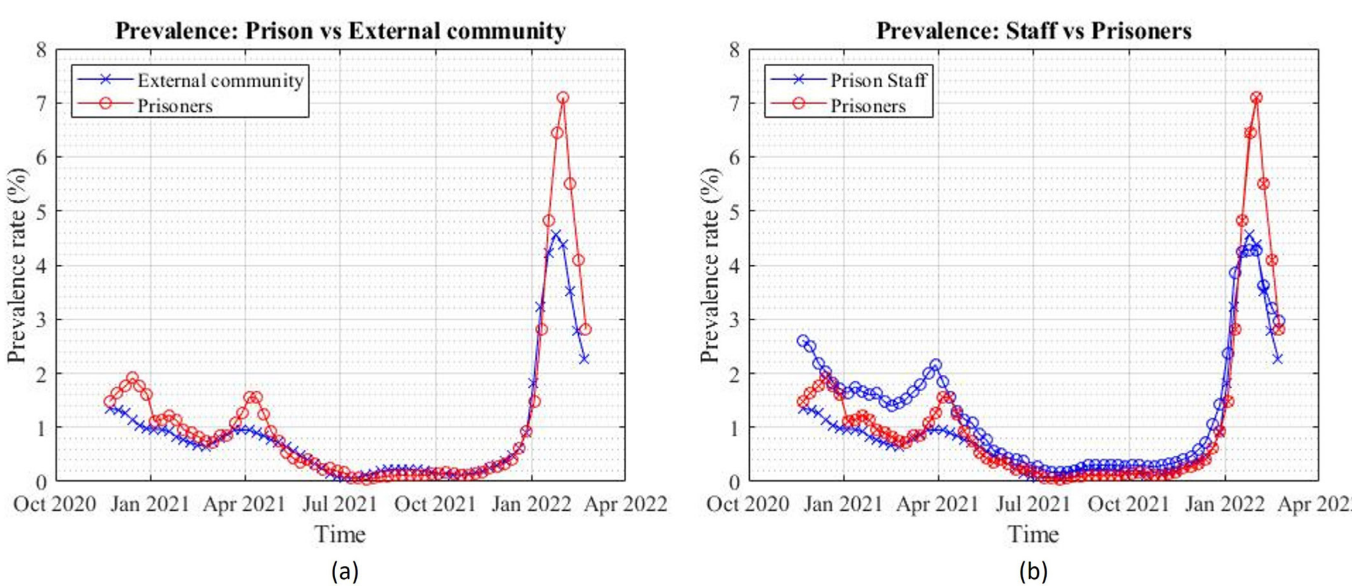

Figure 1 (A) Prevalence rate of SARS-CoV-2 infection in prison and in the external community. The reference population is (a) the total amount of prisoners, which has remained consistent, after the first wave of the pandemic (around 53 000 people) (red line) and (b) the total amount of Italians (blue line—data source ISTAT website). The external community point prevalence was lower than the prisoners' prevalence (paired t-test: 3.25, p<0.05, df: 65). (B) Prevalence rate of SARS-CoV-2 infection among prisoners (red line) and staff (blue line). The plot shows that prison prevalence is lagging. The magnitude of infections among the staff is significantly greater than prisoners' prevalence (paired t-Student: t=2.3, p<0.05, df: 64).

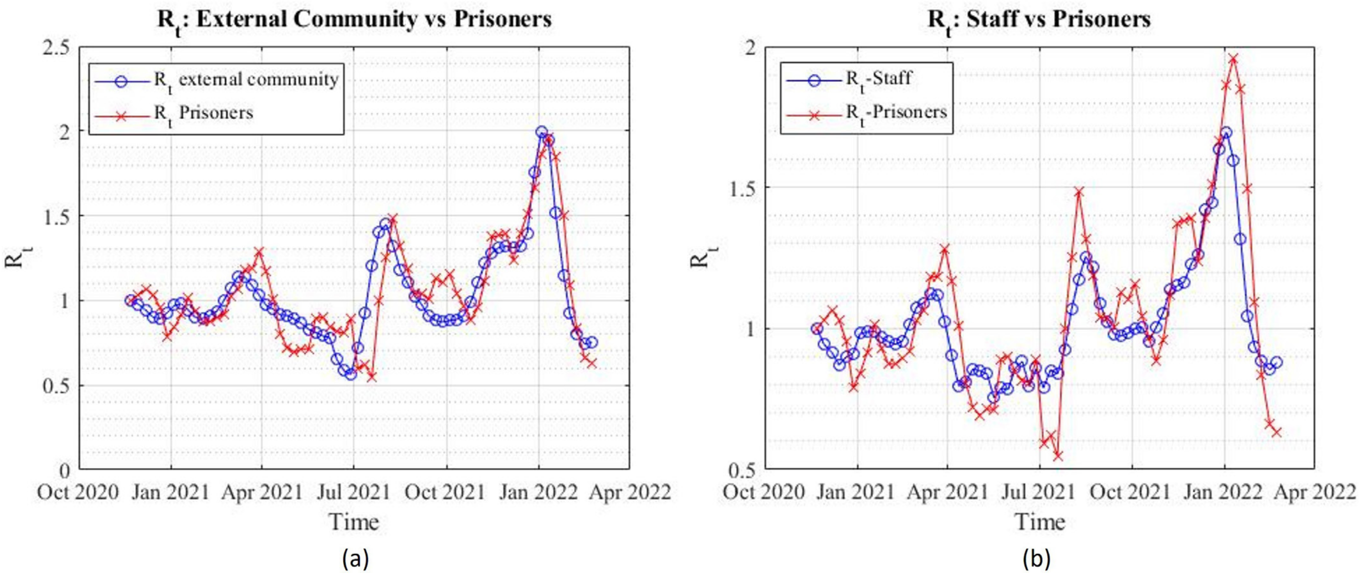

Figure 2 (A) Rt data trends, external community (blue line) and prisoners (red line). (B) The plot shows that prison (red line) Rt values are still lagging with respect to staff data (blue line). Also, in this case, the Rt magnitude of the two data arrays is overlapping (H_0 cannot be rejected).

we assume that the infected individual has moved to the recovered compartment and has either been cured, is no longer considered infectious, or is deceased).

The (eq. 1.1) can be rearranged to give

$$R(t) = \frac{\beta}{\gamma} = 1 + \frac{\frac{dI(t)}{I(t)dt} + \gamma}{\gamma} \qquad (1.2)$$

assuming that $\frac{S(t)}{N} \simeq 1$.

The R(t) CI was assessed by means of a Monte Carlo approach,[20] assuming a noise of 5% of the PP values.

The Incidence of Hospitalisation (H_{new}), data not provided, was derived from its Prevalence (H) by means of the following expression:

$$\frac{dH}{dt} = H_{new} - \delta H \qquad (1.3)$$

in which:

- δ is the inverse of the average hospitalisation duration which for this analysis is 6 days (chosen from the literature).[21 22]
- dt is the time between two observations (fixed at 7 days).

In this case, we considered the Italian population ranging from 20 to 69 years of age, which represented 97.5% of the prison population in 2021, or 98.2% if we also include individuals aged 18–19.[23]

Statistical assessment for PP, Rt and H magnitude was performed through paired t-test, and linear correlation between trends was evaluated according to Pearson. Smoothing of trend curves was performed by means of a 7 days-moving mean. Calculation and plotting were conducted using MATLAB (R2021b).

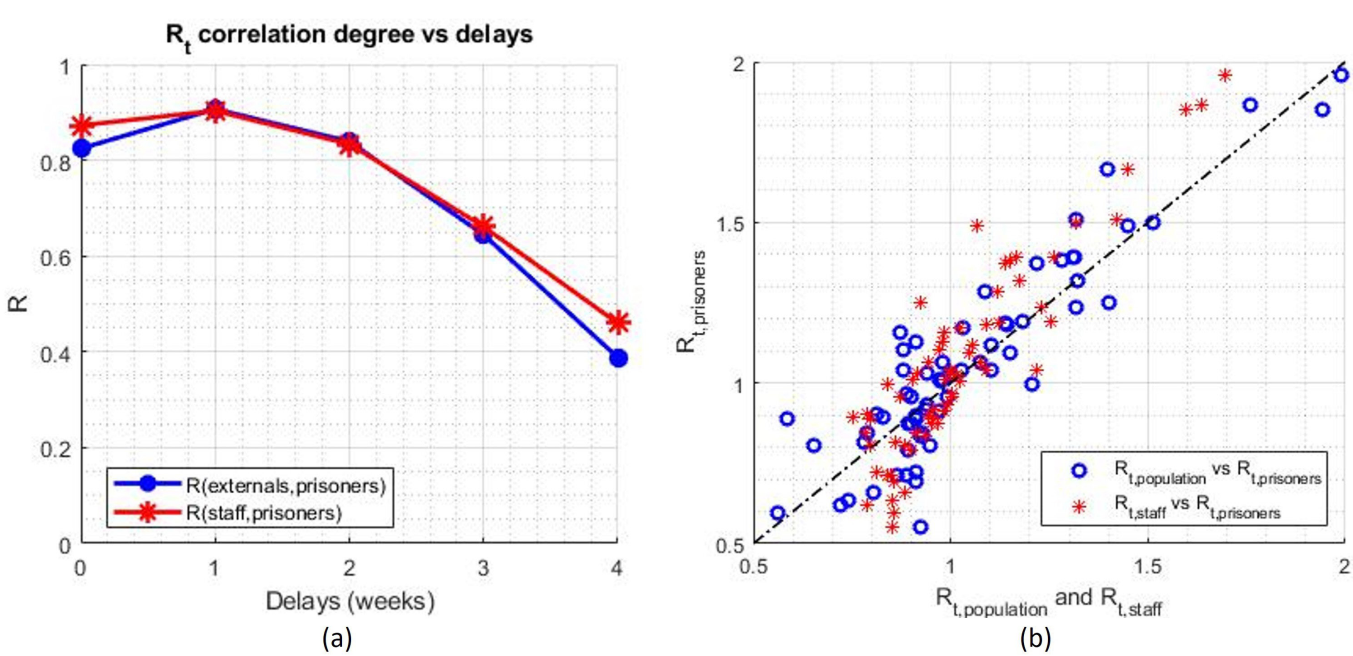

Figure 3 The plots show that after 1 week the coefficient of linear regression between the Rt values is maximum (R=0.907, p=2.6e−25).

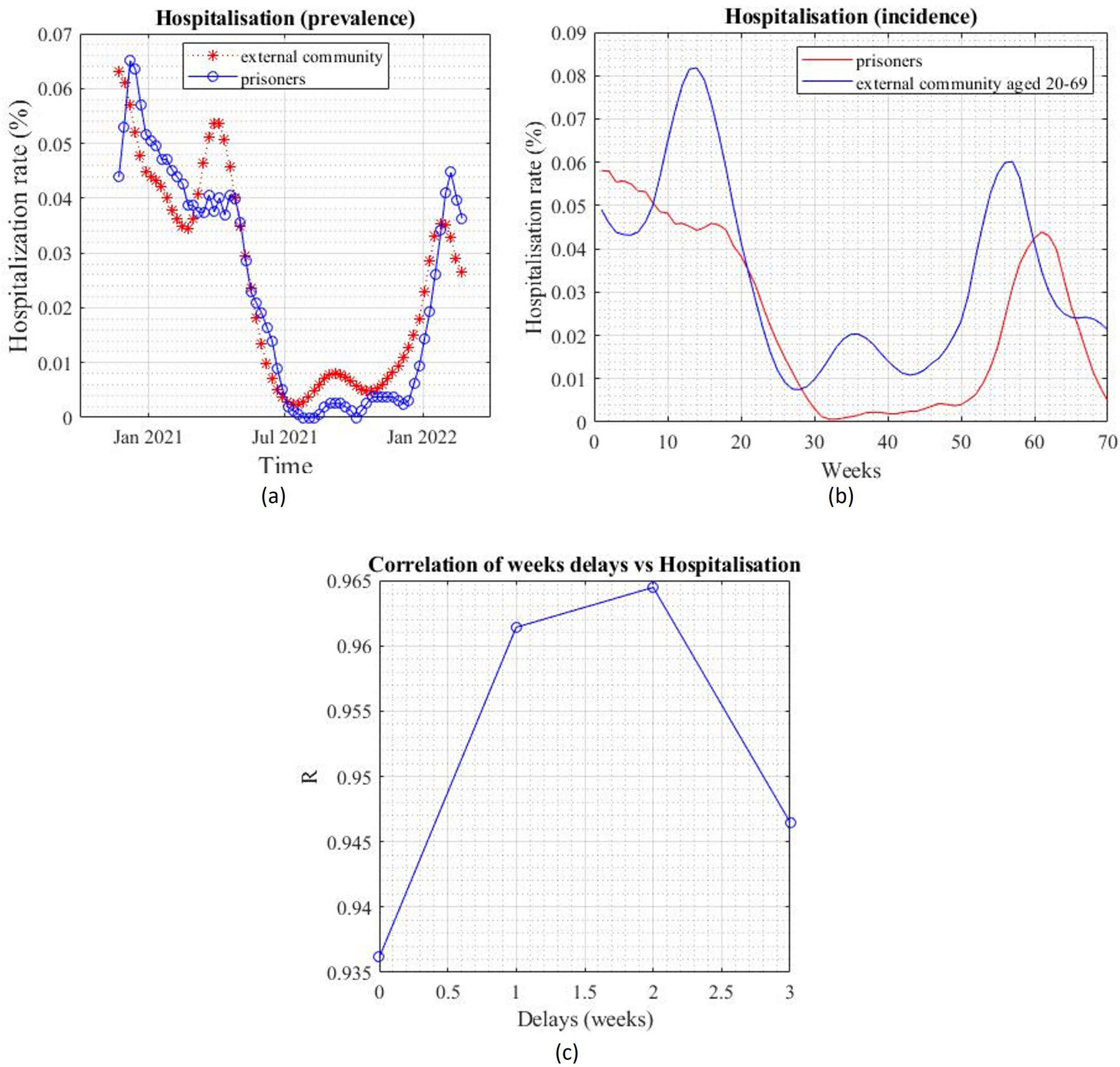

Figure 4 (A) COVID-19 hospitalisation rate in prison and in the external community. The plot shows that prisoners' rate is lagging. The magnitude of prisoners' hospitalisation (blue line) is significantly less than that of the external community's (red line). (Student statistics for paired values is t-test=2,76, $p<0.05$, df: 60). (B) The plot shows the trend of incidence of hospitalisations across 70 weeks, beginning in January 2021 until May 2022. (C) The plot shows the trend of incidence of hospitalisations across 70 weeks starting from January 2021 until May 2022.

RESULTS

The infection parameters

Point Prevalence (PP) was measured for prisoners, staff (represented by prison & probation police) and the external community. Data on general population prevalence were released daily by the Civil Protection, while data from the Ministry of Justice were counted and released weekly. To reduce this discrepancy, we used a 'moving mean' set on 7 days that was also able to smooth the daily fluctuations related to the general population.

Comparison of values magnitude permitted to assess that (figure 1):

1. PP values of prison inmates were greater than those of the general population in Italy.
2. PP values of prison staff were greater than those of the inmates.

Qualitative lagging of PP trend in prison with respect to the other communities (ie, the external population and the staff) was quantified by means of a linear regression analysis performed after multiple shifts of the trend curves. In both cases ('Prison vs External Community' and 'Prison vs Staff') we inferred that the maximum regression values were gained after a 1 week shift backward of the prisoners' trend.

The Reproductive number over time (Rt) trends were also measured for these three groups (prisoners, staff and external community) (figure 2). The comparison between Rt among the prisoners and the staff or the external community could not

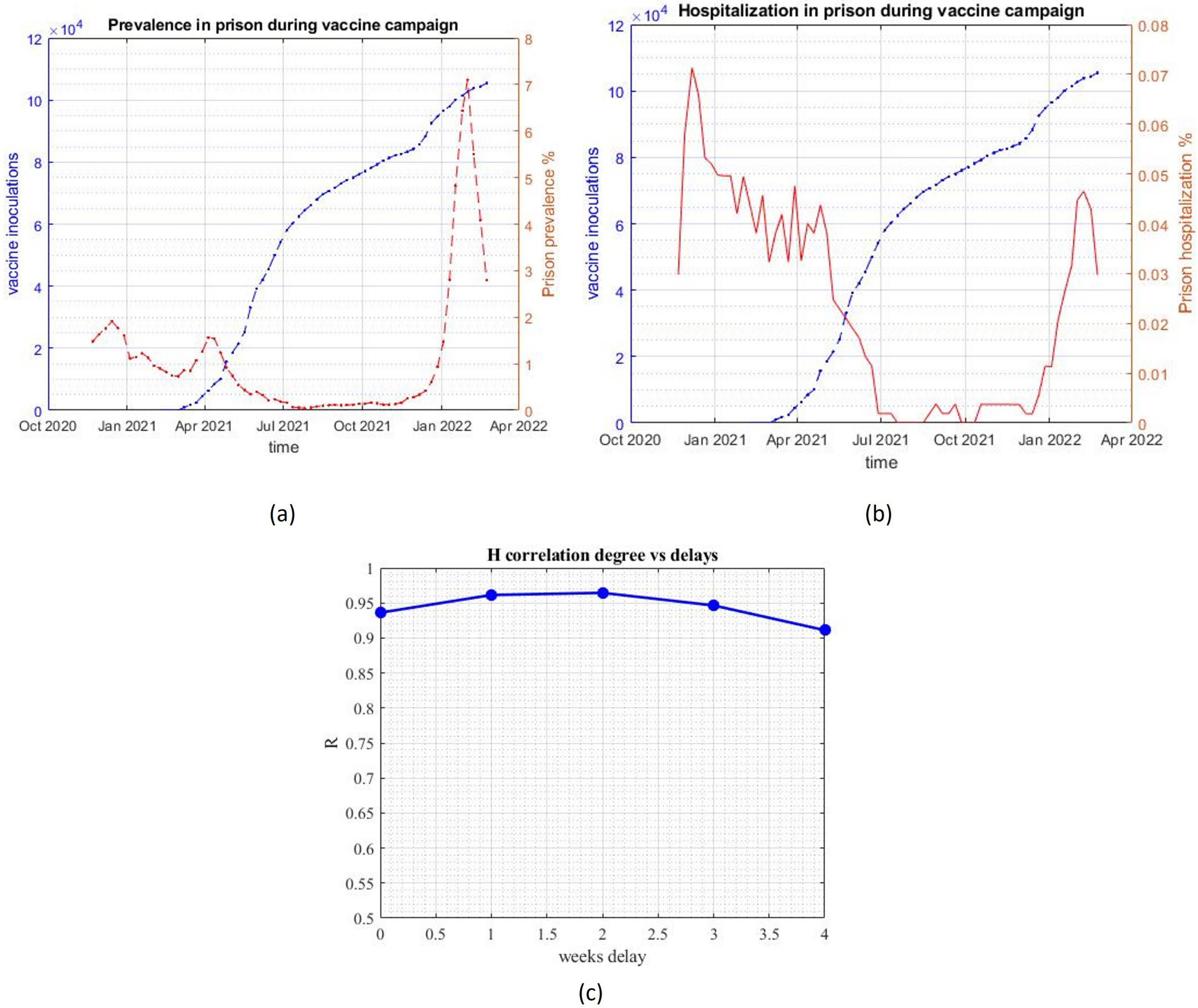

Figure 5 (A) The plot shows that the prevalence trend seems unaffected by the increasing number of vaccine shots, especially in winter 2021–2022 during which the Omicron variant was prevalent. (B) Vaccinations were effective in lowering the hospitalisation trend in prisons. (C) Further analysis reveals that vaccinations were also more effective in lowering the relative number of hospitalised/infected people in prisons.

provide any statistically significant difference (ie, $p>0.05$ and the hypothesis H_0 could not be refused). The same outcome was obtained from the comparison of Rt values among the prisoners and staff (ie, $p>0.05$ and the hypothesis H_0 could not be refused).

The curves that outline the Rt trends for the three groups are quite overlapping. However, they also show some delay in the prisoners' curve in this case. The evaluation of the maximum R index per week-shift permitted the assessment that the highest regression value was obtained after a 1-week backward slippage of the prisoners' Rt array (figure 3).

The disease parameter

Hospitalisation rate (H) showed a trend that was less harsh in prison than in the external community (figure 4).

Interestingly, the comparison of this parameter between the staff and the inmates shows that H values were significantly less in the first group during the whole period under consideration, with major relevance in the fourth wave.

Also in this case, the H trend in prison seems to be lagging for a certain quantity of time with respect to both the staff and the external population. The plot shown in figure 4C indicates that the highest value of correlation between the H trends, related to the comparison of prisoners and the external community, was achieved after shifting the prisoners' H 2 weeks backward.

We also performed a further evaluation of 'new' hospitalisations (incidence) among the prisoners and the external community. The comparison between the two trends permitted us to assess that the 'incidence' of hospitalisation in Italian prisons was significantly less than in the external society (t-test: 5.76, p0.01, df:69).

Moreover, we plotted two indices' trends for inmates (figure 5):

1. The number of vaccinations versus the Point Prevalence.
2. The number of vaccine doses versus the Hospitalisation rate.

Following a qualitative evaluation, it appears that an increase in vaccinations did not seem to cause a decrease in the spread of infections (figure 5A). On the other hand, the hospitalisation rates show a clear decrease during the fourth wave with respect to the second and third ones. Moreover, this result is even more evident if we consider the hospitalisation rate of only the infectious prisoners instead of the entire population of inmates.

DISCUSSION

During the state of emergency[24] that was declared by the Italian Government from 31 January 2020 to 31 March 2022, the Italian Prison Service adopted a wide range of countermeasures in an attempt to control the spread of the virus in their facilities, where the close coexistence of inmates is aggravated by overcrowding and by many pre-existing threats to inmates' health (poor health conditions, drug and alcohol abuse, communicable diseases, poor hygiene and nutrition and so on).[25]

Following the first wave of the pandemic—in late October 2020—the Ministry of Justice began sharing data related to the point prevalence of positive test cases and the number of hospitalisations among the inmates, the prison police officers and the administrative staff.

Our study was aimed at highlighting the trend of two infection-related parameters: the infection prevalence and the Reproductive number over time, and one disease-related parameter: the hospitalisation rate. Current literature on our topic is lacking; there are few papers depicting the prison epidemiological parameters in Italy.[13] Several studies are limited to specific regions[26] or facilities[27] and are primarily focused on the first wave of the pandemic. Our study seems to both confirm and strengthen the results published in the previous papers while innovative in applying mathematical models to measure the epidemiological indices (eg, the Rt evaluation).

According to our results, the prevalence of infections in prison during the whole period analysed, was higher with respect to the external community, while it was less when compared with the staff. The Rt magnitude has shown no statistical difference among the three subgroups. The comparison between hospitalisation prevalence and incidence rates has shown that values from prisoners were less than those from the Italian community. On the contrary, it was significantly greater in comparison to the staff's rate, especially during the fourth wave of the pandemic. Finally, Prevalence, Rt and Hospitalisation trends were always linearly correlated. The maximum correlation values were achieved when both the Prevalence and the Rt of the prisoners were shifted 1 week backward, and the hospitalisation rate was shifted 2 weeks backward. We can infer that, while the prevalence rate was higher in prison than in the external community, the Rt trends had the same magnitude in both communities and among the prison staff, indicating that the virus's spread had not accelerated in prison.

This result led us to conclude that the higher prevalence observed among inmates, in comparison to the external community, could only have been caused by large-scale testing in prisons (eg, inmates were tested before moving from one cell to another, before moving to another section and before their release). This is generally considered one of the most effective actions to fight against COVID-19.[28 29]

This hypothesis is supported by the evidence that the staff, who are also subjected to mandatory testing, show prevalence results which are significantly higher than the prisoners.

Furthermore, the hospitalisation rate is relevant to assess the capability of the countermeasures put in place to fight against the virus. In this case, the result for Italian penitentiaries shows a significant decrease with respect to the Italian population (while it is higher than the staff's rate). However, comparison of the prisoners to the whole external population presents several complications: (1) COVID-19 has been demonstrated to cause more severe effects with increased age[30] and (2) the prison population is largely represented by men aged 18–69 (the prison subgroup aged 70 and over, represented the mean value of 1.8%[2] in the last 2 years), (3) subsequently, comparison with the prison staff is also challenging because police officers are expected to maintain good health and must be under the age of 60 and (4) it is not possible to exclude that in some cases and for security reasons, the adopted threshold that needed to be achieved before a prisoner was taken to an external hospital was slightly higher with respect to the external community For this reason, we focused our analysis on a subgroup of the external population whose age ranged from 20 to 69 years, thus comparing a more homogeneous demographic with that of the inmate community. The evaluation of 'new hospitalisation' trends (incidence of hospitalisation) was possible from January 2021 using available data which confirmed that the values were less in prison compared with outside.

Finally, most of the limitations of this study reside in the typology of data that has been shared by the Ministry of Justice: much information is lacking, such as the number of inmate deaths, the incidence of positive tests and hospitalisations. Furthermore, data are aggregated and refer to the whole Italian prison system, therefore concealing potential differences among geographical regions and prison facilities. This last feature could be, at least in part, counterbalanced by the fact that Italian correctional facilities are nationalised, and therefore, policies are uniformly applied to all prisons. Moreover, the comparison between the magnitude of the infection and disease parameters (PP and H, respectively) could be quite controversial, as the three reference populations are not equivalent, and neither are the testing strategies nor the hospital access procedures. On the other hand, the strength of this study lies in the broad period of time analysed, and in the implementation of a mathematical approach for parameters evaluation and comparison.

CONCLUSION

It is impossible to achieve complete isolation in prisons. As such, correctional facilities can be considered controlled systems, where specific categories of people (ie, prison police, new inmates, healthcare workers, lawyers, prosecutors and so on) represent a sort of 'bridge' between the external and the internal communities. In fact, it is evidenced that there is a shift in infection trends for which prison data are always lagging by 1 week with respect to the staff and the external community. Moreover, this result is strengthened by the consequent shift of the disease trend (H), in which the prison community is lagging by 2 weeks. The Rt values demonstrate that the virus's spread did not accelerate in the prison environment. The most probable cause for this is the risk mitigation efforts that have been implemented. Furthermore, some indications confirm that the disease parameters were less severe in prison than in the outside community.

Finally, the lessons learnt from our study can be summarised as: (a) counteractive measures are effective in curbing the virus spread and its consequences, also in closed and controlled places, and (b) prison outbreaks are carried by 'bridge' categories of people and offer a time-window delay which could be exploited to strengthen preventive measures and begin medical treatment as soon as initial symptoms appear.

Acknowledgements We are deeply grateful to Mrs Grace P Xerri for her assistance in the revision of this paper. We are also deeply grateful to Mr Alessandro Albano for the continuous discussion on this topic.

Contributors CF, RR, AM, PG and DDG equally contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. DDG is the guarantor of this research.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. https://www.giustizia.it/giustizia/it/mg_2_27.page https://github.com/pcm-dpc/COVID-19/tree/master/dati-andamento-nazionale http://dati.istat.it/ https://www.giustizia.it/giustizia/it/mg_1_14.pagehttps://www.giustizia.it/giustizia/it/mg_1_14.page.

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