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Research Article

# Cost-effectiveness analysis of mRNA COVID-19 vaccine versus inactivated COVID-19 vaccine for mass vaccination in Jordan using a decision tree model

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## Abstract

**Objectives:** The purpose of this study was to present data regarding the most cost-effective vaccine for preventing COVID-19-related deaths.

**Methods:** A mass immunization campaign using mRNA and inactivated COVID-19 vaccines was compared to no vaccination in a cost-effectiveness analysis. A hypothetical population of Jordanians aged 18 and over in 2021 was used to create a decision-tree model from the provider's point of view. The main result was the prevention of COVID-19-related deaths. Government reports, observational primary costing studies employing the micro-costing approach, systematic reviews, and secondary data analysis at the national level were the sources of the model's inputs. To take uncertainty into consideration, scenario analysis and one-way sensitivity analysis (OWSA) were performed.

**Results:** mRNA vaccination, inactivated vaccination, and no vaccination strategies have corresponding total costs of 339,035,352.00 JOD, 643,192,339.62 JOD, and 1,110,731,145.64 JOD. It is anticipated that these strategies will result in 952, 6,505, and 29,324 deaths, respectively. The inactivated strategy's incremental cost-effectiveness ratio (ICER) is 20,489.01 JOD per death averted, whereas the mRNA strategy's is 27,199.20 JOD per death averted, making it the dominant strategy. The ICER was 54,773.45 JOD saved for every extra mortality prevented when comparing mRNA to the inactivated approach. When compared to the other techniques, the mRNA strategy maintained its dominance throughout alterations in the analysis, as demonstrated by the OWSA and the worst-case scenario analysis, suggesting robust outcomes.

**Conclusion:** The mRNA vaccination strategy outperformed the inactivated vaccine and no-vaccination strategies in this study's context in terms of preventing COVID-19 mortalities.

## Keywords

cost-effectiveness analysis, COVID-19 vaccines, mass vaccination, decision tree model, Jordan

# Introduction

The World Health Organization (WHO) declared COVID-19 a pandemic on 11 March 2020 (Hagens et al. 2021), after it was discovered in December 2019 (Oksuz et al. 2021). By July 2022, there had been nearly 600,000 confirmed cases and 6.4 million fatalities worldwide (Jordan: WHO Coronavirus Disease (COVID-19) Dashboard With Vaccination Data 2022). March 3, 2020, saw the detection of the first COVID-19 case in Jordan. By July 2022, there were 1,709,879 confirmed cases and 14,074 fatalities (Jordan: WHO Coronavirus (COVID-19) Dashboard 2022). During the COVID-19 outbreak, educational institutions were closed, and students worldwide were confined to their homes (Alia 2022). Based on what is currently understood about the composition and mechanisms of coronaviruses that cause illnesses, including Middle East respiratory syndrome (MERS) and severe acute respiratory syndrome (SARS). Early in 2020, the WHO expedited the development of multiple vaccine platforms, and by December 2020, many COVID-19 vaccines had been registered through an "Emergency Use Listing" (Clemens et al. 2022).

The cost-effectiveness of vaccination was questioned, despite the fact that it offered an alternate strategy to stop the pandemic. This was due to the fact that vaccines typically vary in their effectiveness and that newer vaccines are typically more costly than older ones. Furthermore, cost-effectiveness analysis (CEA) was necessary to determine which of the available vaccinations was most appropriate for usage during the pandemic due to the restricted financial capability of many nations for healthcare (Verguet et al. 2016). According to a Taiwanese study, mass vaccination with the BNT162b2, mRNA-1273, and AZD1222 COVID-19 vaccines is an economical way to save money and save more lives (Wang et al. 2021). Another study conducted in Hong Kong demonstrated that immunization is very cost-effective at high infection rates (Xiong et al. 2022).

Therefore, using a decision tree model, this study compared mass vaccination of the mRNA COVID-19 vaccine versus inactivated COVID-19 compared to a no vaccination scenario in order to identify the most cost-effective vaccine for preventing death in the Jordanian setting. This study's main goal was to ascertain which COVID-19 vaccine, from the perspective of the Jordanian provider, was more cost-effective—the mRNA or inactivated COVID-19 vaccine—when compared to the no-vaccination scenario in terms of reducing COVID-19-related mortality. As of right now, Jordan has not carried out any CEAs on COVID-19 vaccinations.

# Methods

The Consolidated Health Economic Evaluation Reporting Standards (CHEERS) were followed in the reporting of this study. The study used the viewpoint of the Jordanian Ministry of Health (MoH), a provider. The prices were shown in Jordanian Dinars (JOD) for 2021. Because of the one-year time horizon, costs and impacts were not discounted.

## Study location, population, and setting

The Hashemite Kingdom of Jordan served as the study site. The base population of Jordanian people who were 18 years of age or older in 2021 was used as the cohort for this economic analysis. Three hypothetical study settings were present: 1) mass vaccination campaign in which the study population received the mRNA COVID-19 vaccine at government facilities; 2) mass vaccination campaign in which the study population received the inactivated COVID-19 vaccine at government facilities; and 3) no mass vaccination campaign.

## Selection of the intervention, comparators, and outcome

The COVID-19 mRNA vaccine and the COVID-19 inactivated vaccine served as the study's interventions. However, no vaccination served as the comparator for each of these interventions. The mRNA vaccine served as the intervention and the inactivated vaccine as the comparator when comparing the two vaccination strategies together. This evaluation's primary finding was the number of deaths prevented by mass vaccination with mRNA and inactivated vaccines compared to a no-vaccination approach.

## Measurement and valuation of outcome

Infection, hospitalization, and death rates and percentages for the three strategies—mRNA, inactivated, and no vaccination—were taken from a study conducted in Bahrain (AlQahtani et al. 2022). Bahrain and Jordan have comparable sociodemographic data, and the data were gathered at the same time as this study, which is why it was selected. It is crucial to emphasize that these rates were gathered in Bahrain between January and July of 2021, a time when several COVID-19 viral variations were documented. The main form at first was Beta/B.1.351, which was followed by Delta/B.1.617.2 and Kappa/B.1.617.1. Nonetheless, 25% of COVID-19 cases were found to have the Delta variant over the final three months of data collection.

## Measurement and valuation of resources and costs

Both the COVID-19 treatment and the mass vaccination campaign employed the micro-costing approach. All expenses related to vaccine procurement, transportation, storage, administration, waste management, outpatient care, and inpatient treatment of patients with breakthrough infections were covered by the vaccination costs. The expenses associated with the no-vaccination approach covered both inpatient and outpatient care for COVID-19 patients.

Based on a review of the literature, observations, and conversations with MoH employees, the immunization campaign's cost sources were determined. Based on these observations, it was determined that the mass vaccination campaign comprised the following activities: providing training for staff, purchasing vaccines, paying for vaccine customs, vaccine wastage, consumables, staff in charge of main storage, staff participating in the mass vaccination campaign, incentives paid for campaign staff, campaign supervision, storing vaccines in refrigerators, supplying electricity to refrigerators, waste management, buying safety boxes for used vials and syringes, information technology support to preserve vaccinators' data, and transporting the vaccines to the vaccination centers.

Regarding the cost of treating COVID-19, labor and overhead expenses were collected from a published paper (Almohtaseb and Zawaneh 2020), while material resource microcosting was carried out. The Jordanian Ministry of Health's COVID-19 diagnostic and treatment protocol served as the basis for the identification of the material resources and the development of a clinical pathway (Fig. 1). The average expenses for a patient hospitalized in the intensive care unit (ICU) and general ward (GW) were calculated. The typical expenses of outpatient care for those who were placed in home quarantines were also calculated. Cost data from Prince Hamzeh and the MoH's pertinent departments was used wherever possible; however, in the event that it was not accessible, retail prices or proxy costs were used.

## Decision tree model

TreeAge software (TreeAge Pro Healthcare) R2.1 version 2022 was used in this study to create a decision-tree model (Fig. 1). Because the decision tree model can explicitly compare different methods based on their costs and results, it was chosen over the extended SEIR model. This is because the decision tree model focuses on economic endpoints rather than the intricate disease dynamics found in extended SEIR models. Decision trees have also been utilized in economic evaluation in a number of other researches, such as the one conducted by Jiang et al. (2022) or Shaker et al. (2021).

The differentiation between vaccinated and non-vaccinated individuals inside the decision tree model is the main focus of the investigation of heterogeneity in this economic evaluation. The model specifically examines how outcomes vary across these two broad vaccination groups, even if it does not account for variances based on age, sex, or other demographic factors.

The technique evaluates outcomes at each decision node, taking hospitalization status and final outcomes

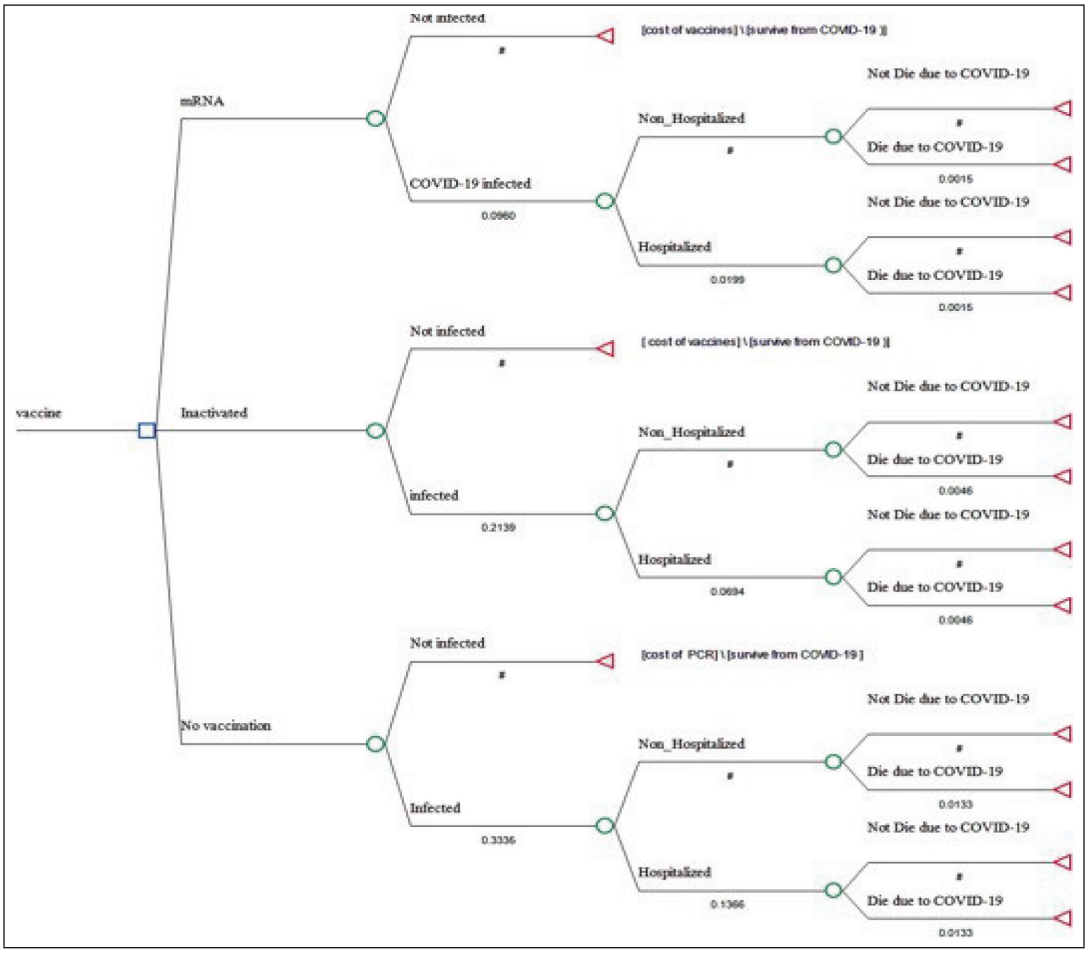


**Figure 1.** Decision tree model to compare mass vaccination using either mRNA or inactivated compared to no vaccination.

(living versus dead) into account in order to quantify variability. Any differences between the vaccinated and non-vaccinated populations are quantified using statistical analyses and subgroup-specific modeling.

At every decision node, results for subgroups are presented, highlighting the financial effects of vaccination status on medical expenses and results. Since the emphasis is on the wider effects of vaccination on health outcomes, no further modifications are performed for priority populations or particular demographic groupings.

## Model assumptions

A number of presumptions were made in order to create the decision tree. Initially, it was believed that everyone qualified for COVID-19 mRNA or inactivated vaccinations. Secondly, it was presumed that there were no immunization refusals. Third, there are no novel virus variations that could cause the vaccine to lose its potency or stop working altogether. Fourth, everyone could travel to immunization facilities. Fifth, patients had no possibility of relocating from one state to another. For example, there was no risk of hospitalization for non-hospitalized patients at home, and reinfection did not occur among infected individuals.

## Model parameters

The demographic cohort's transition probabilities were obtained from a Bahraini study that was published (AlQahtani et al. 2022) (Table 1).

**Table 1.** Transition probabilities.

| | mRNA vaccine | Inactivated virus vaccine | No vaccination |
|---|---|---|---|
| Probability of infection | 0.0960 | 0.2139 | 0.3335 |
| Probability of hospitalization | 0.0199 | 0.0694 | 0.1366 |
| Probability of death | 0.0015 | 0.0046 | 0.0133 |

## Model validation

The Validation Status of Health Economic Decision Models (AdViSHE) tool was used to make sure that the model's structured data was obtained. Experts also evaluated the model's underlying assumptions. To test internal validity, the model's response was examined by setting vaccine cost and effectiveness inputs to zero. Under this condition, the model produced zero costs and zero deaths, confirming its expected behavior.

## Scenario and sensitivity analysis

In the base case scenario, a one-way sensitivity analysis of the outcomes of the two vaccination strategies in comparison to no vaccination was carried out. Prices for vaccines were adjusted according to published prices, vaccine wastage costs were adjusted according to minimum and maximum vaccine prices, staff and supervision expenses were adjusted according to minimum and maximum salaries, and electricity and refrigerator costs were adjusted according to the presumption of how long a dose should be kept in a refrigerator (from one day to ninety days). Furthermore, because real-world data is scarce in the area and there is no proof of particular values, the probability parameters' values were varied at ± 50% of the base case values.

In the best-case scenario, the minimum vaccination costs and costs of hospitalization for all strategies were determined by LOS; only those with double infection probabilities underwent PCR testing; the cost of PCR testing was lowered by 50% from 20 JOD; and the probability parameters were 50% lower for both vaccines but 50% higher for no vaccination strategy.

In contrast, the worst-case scenario included the following: maximum vaccination costs, a PCR test for all, a cost of 20 JOD, probabilities of 50% more for both vaccines and 50% less for no vaccination, and hospitalization costs split into three groups: 30% of patients were admitted with a minimum length of stay, 30% with a maximum length of stay, and 40% with an average length of stay.

# Results

In the mass immunization campaign, the total cost of mRNA vaccination (including labor, material, and overhead costs) was 170,226,041.83 JOD, whereas the cost of the inactivated vaccine was 209,424,213.43 JOD. For both vaccinations, the largest factor was the cost of materials. The cost of the materials for the mRNA vaccine was 94.25% of the overall cost, whereas the cost of the inactivated vaccine was 95.36%. The remaining expenses for both vaccines' labor and overhead expenditures were comparable in size. According to published studies, the cost of the inactivated vaccine was 15.84 JOD per dose, whereas the cost of mRNA immunization in the mass vaccination campaign was 12.87 JOD per dose. The costliest component of the mass immunization utilizing the mRNA vaccine was the vaccine itself, accounting for 80.96% of the overall cost, followed by vaccine wastage (8.27%), medical staff expenses (2.81%), and vaccine customs duty (1.75%). Similar factors contributed the most to the costs of the mass vaccination using the inactivated vaccine: the cost of the vaccine (82.81% of the total cost), vaccine wastage (8.42%), medical personnel costs (2.81%), and vaccine customs tax (1.42%).

## Base case scenario

Mass vaccination was cost-effective for both mRNA and inactivated vaccines, saving 771,695,793.6417 JOD for mRNA and 467,538,806.0185 JOD for inactivated vaccines. Comparing mass immunization with the mRNA vaccine and the inactivated vaccine to no vaccination, the former reduced 28,372 deaths and the latter 22,819 deaths, respectively. Therefore, compared to the no-vaccination strategy, mass vaccination with the mRNA vaccine saved 27,199.20 JOD for each death prevented, while mass vaccination with the inactivated vaccine saved 20,489.01 JOD for each death prevented (Table 2).

**Table 2.** Costs, incremental costs, effects, and incremental effects of mRNA and inactivated strategies.

| Vaccination strategy | Costs (JOD) | Incremental costs (JOD) compared to no vaccination | Effect (number of deaths) | Incremental effect (number of deaths averted compared to no vaccination) |
|---|---|---|---|---|
| mRNA | 339,035,352.00 | -771,695,793.6417 | 952 | 28,372 |
| Inactivated | 643,192,339.62 | -467,538,806.0185 | 6,505 | 22,819 |
| No vaccination | 1,110,731,145.64 | | 29,324 | Not applicable |

## Sensitivity and scenario analysis

Regarding the ICER of mRNA, the tornado diagram demonstrates the results' robustness because, as Fig. 2 illustrates, the mRNA approach was still less expensive than not getting vaccinated.

The tornado diagram for the inactivated vaccination strategy revealed that the probability of infection for no vaccination strategy was the most influential parameter on the ICER. As it dropped to 0.16675 (-50% of the base case probability of infection for no vaccination strategy), the ICER of the inactivated vaccination strategy changed from a negative value (saving -20,489.01 JOD per death averted) to a positive value (2,662.09 JOD per death averted), as seen in Fig. 3.

### Best-case scenario

Both the mRNA and inactivated vaccines were more cost-saving than not getting vaccinated in the best-case scenario (ICERs 249,223.79 and 253,722.93 JOD saved per death averted, respectively), and Table 3 shows that the mRNA vaccine outperformed the inactivated vaccine (ICER 40,662.9025 JOD additional saved money per additional death averted).

### Worst case scenario

In the worst-case scenario, the mRNA vaccine was still cost-saving, with savings of 262,061,988.06 JOD and 5,189 deaths averted, compared to no vaccination, giving rise to an ICER of 50,503.05 JOD saved per death averted. While for the inactivated vaccine, it yields more costs (1,060,806,273.62 JOD) and 7,305 more deaths compared to no vaccination (Table 4).

## Discussion

The results of this study show that, in comparison to not getting vaccinated, a mass immunization campaign employing either mRNA or inactivated COVID-19 vaccines was cost-saving in avoiding COVID-19 mortalities. (ICERs -27,199.2032 and -20,489.0138, respectively), which was consistent with research done in Taiwan and Catalonia (López et al. 2021; Wang et al. 2021).

Furthermore, the mRNA vaccine proved more cost-effective than the inactivated vaccine in preventing deaths (ICER - 54,773.45 extra JOD per additional death averted). These results are in line with an Iranian study that assessed different COVID-19 vaccine types, such as mRNA and inactivated vaccines, and discovered that while both were more affordable than not getting vaccinated, mRNA vaccines had a lower ICER than inactivated vaccines (Vaezi and Meysamie 2021). Furthermore, a number of other studies have also reached similar conclusions to this one, including a global public health and economic impact study conducted in China and globally, CEA in Turkey and Spain (Hagens et al. 2021; Marco-Franco et al. 2021), and cost utility analysis (CUA) in Brazil (Hagens et al. 2021). These studies also found that vaccination is cost-effective, prevents cases, and averts death.

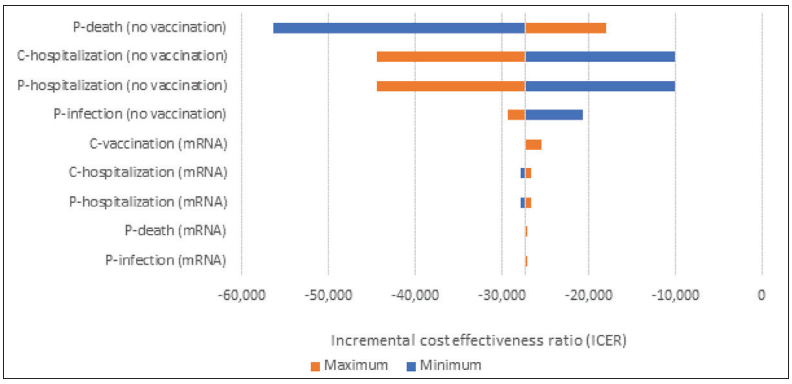


**Figure 2.** Tornado diagram of the ICER of mRNA vaccination strategy compared to no vaccination. Bar colors: blue indicates lower incremental cost-effectiveness ratio (ICER); orange indicates higher ICER. *P-* is probability, and *C-* is cost.

**Table 3.** Results of the best-case scenario sensitivity analysis.

| Strategy | Cost | Incremental Cost | Effect | Incremental Effect | ICER |
|---|---|---|---|---|---|
| Mrna | 176,795,848.4711 | -16,384,343,879.52 | 238 | -65,741 | -249,223.7940 |
| Inactivated | 233,246,067.2340 | -16,327,893,660.76 | 1,626 | -64,353 | -253,722.9359 |
| No vaccination | | | | | |
| mRNA vs. inactivated | 16,561,139,727.9962 | -56,450,218.76 | 65,979 | -1,388 | -40,662.90 |

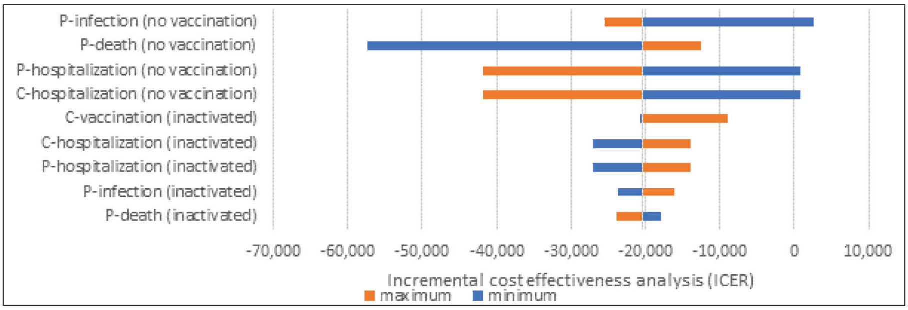


**Figure 3.** Tornado diagram of the ICER of the inactivated vaccination strategy compared to no vaccination.

**Table 4.** Result of worst-case scenario sensitivity analysis.

| Strategy | Cost | Incremental Cost | Effect | Incremental Effect | ICER |
|---|---|---|---|---|---|
| mRNA | 526,982,105.92 | -262,061,988.06 | 2,142 | -5,189 | -50,503.05 |
| No vaccination | 789,044,093.9938 | | 7,331 | | |
| Inactivated | 1,849,850,367.6167 | 1,060,806,273.62 | 14,636 | 7,305 | |
| mRNA vs inactivated | | -1,322,868,261.69 | | -12,494 | -105,878.26 |

In addition, given the COVID-19 vaccines' cost-effectiveness and cost-saving qualities, Siedner et al. (2022) suggested funding immunization programs in low- and middle-income countries (LMIC). The estimated ICERs showed that both vaccine methods were more cost-effective than not getting vaccinated. The negative values indicated the cost-saving of both vaccines' strategies compared to no vaccination, which was affected by the greater hospitalization costs, high infection risk, and death rate. In other words, when compared to not getting vaccinated, both vaccination regimens saved money and prevented death.

Although inactivated vaccinations are easier to store and deliver than mRNA vaccines (Jiang et al. 2022), the mRNA vaccine is more effective and less expensive than the inactivated vaccine, which is why the mRNA vaccine is now more widely used.

A number of important considerations led to the choice to employ a decision tree model for the CEA of COVID-19 vaccines in a mass immunization setting. First, a popular and proven technique in health economics for clearly, systematically, and transparently modeling decisions and consequences is the decision tree model. It enables us to evaluate the economic impact of COVID-19 immunization campaigns by comparing various approaches, such as vaccination vs. no vaccination, according to their costs and health outcomes. Furthermore, scenarios with discrete, mutually exclusive outcomes—like death, hospitalization, or recovery—that are pertinent to our examination of mass vaccination strategies are especially well-suited for decision trees.

They also offer a simple way to include different costs and probabilities for every possible event, which facilitates sensitivity analysis and helps determine the best economical course of action in many scenarios. Furthermore, this method has been used in a number of published researches to assess the cost-effectiveness of COVID-19 vaccinations in several contexts. Jiang et al. (2022), for instance, evaluated the cost-effectiveness of inactivated COVID-19 vaccinations using a decision tree model. Shaker et al. (2021) and other research have also utilized decision trees to study the economic effects of vaccination in the context of pandemic response. These researches gave us a solid foundation on which to build our own analysis using this approach.

## Conclusion

339,035,352.00 JOD, 643,192,339.62 JOD, and 1,110,731,145.64 JOD were the total expenses related to the mRNA vaccination strategy, inactivated vaccination strategy, and no vaccination strategy, respectively. These strategies were estimated to have caused 952, 6,505, and 29,324 deaths, respectively. With an ICER of -27,199.20 JOD per death prevented, the mRNA method was a dominant strategy compared to the inactivated strategy, which had an ICER of -20,489.01 JOD per death prevented compared to no vaccination. Additionally, the ICER was 54,773.45 JOD saved for every additional mortality prevented when comparing the mRNA vaccine to the inactivated vaccination strategy.

According to Jordanian providers, mRNA vaccinations are more cost-effective than inactivated vaccines at preventing COVID-19-related mortality.

## Acknowledgments

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## Additional information

### Conflict of interest

The authors have declared that no competing interests exist.

### Ethical statements

The authors declared that no clinical trials were used in the present study.

The authors declared that no experiments on humans or human tissues were performed for the present study.

Informed consent from the humans, donors or donors' representatives: ethical approval was obtained from university putra malaysia, ministry of health jordan, and prince Hamza hospital

The authors declared that no experiments on animals were performed for the present study.

The authors declared that no commercially available immortalised human and animal cell lines were used in the present study.

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## Author contributions

Conceptualization: Qusai Abdulraheem AbuQamar and Aidalina Mahmud, writing, preparation, and drafting the original manuscript: Qusai Abdulraheem AbuQamar, supervision: Aidalina Mahmud and Saba Madae'en, and review and editing of the manuscript: Aidalina Mahmud, Saba Madae'en, Norliza Ahmad, Lim Poh Ying, Azimatun Noor Aizuddin.

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## Data availability

All of the data that support the findings of this study are available in the main text.

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