

Article

A Novel Older-Adult COVID-19 Severity Decoupling Index to Measure the Transition from Pandemic Mortality to Endemic Resilience in Spain

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Abstract

The COVID-19 pandemic produced a severe and heterogeneous burden across age groups, territories and epidemic phases in Spain. Older adults experienced disproportionately high rates of hospitalization, intensive care unit (ICU) admission and death, particularly during the early pandemic waves when vaccination was unavailable. However, the relationship between surveillance-confirmed cases and severe outcomes changed substantially over time, a phenomenon termed epidemiological decoupling. This study developed and applied a novel Older-adult COVID-19 Severity Decoupling Index (O-CSDI) to weekly COVID-19 surveillance data from the 17 Spanish autonomous communities and the two autonomous cities of Ceuta and Melilla. The integrated dataset covered January 2020 to July 2023 and comprised 3496 autonomous community-week observations and 143 variables obtained from four open-access surveillance sources: ISCIII-RENAVE, Datadista/Ministerio de Sanidad, Our World in Data and the MoMo excess mortality system. However, the primary incidence- and ratio-based O-CSDI analyses were restricted to March 2020–March 2022 because open-access individual event counts were no longer structurally comparable after the transition to reduced surveillance. Data from later periods were retained only for contextual vaccination and MoMo mortality indicators. The O-CSDI quantifies the degree to which reported COVID-19 incidence became disconnected from hospitalization, ICU admission and mortality in adults aged 60–69, 70–79 and ≥ 80 years. The primary version of the index was based on the death-to-case ratio, while complementary versions examined hospitalization-to-case, ICU-to-hospitalization and death-to-hospitalization transitions. Results showed progressive but heterogeneous decoupling across phases, territorial units and age strata, with the strongest decoupling observed during the Omicron BA.1/BA.2 period and the highest residual mortality burden in adults aged ≥ 80 years. All results were interpreted as ecological, descriptive indicators rather than individual-level risks or causal estimates. These findings provide a reproducible epidemiological tool for retrospective pandemic evaluation and preparedness in ageing populations.



Academic Editor: Bruno Mégarbané

Received: 30 June 2026

Revised: 17 July 2026

Accepted: 21 July 2026

Published: 23 July 2026

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Keywords: COVID-19; Spain; autonomous communities; older adults; epidemiological decoupling; severity index; pandemic phases; excess mortality; vaccination coverage; hospitalization

1. Introduction

The COVID-19 pandemic produced a severe and heterogeneous burden across age groups, territories and epidemic phases in Spain [1,2]. Older adults experienced disproportionately high rates of hospitalization, intensive care unit admission and death, particularly during the early pandemic waves when vaccination was unavailable [3,4]. However, the relationship between surveillance-confirmed cases and severe outcomes changed substantially over time, a phenomenon termed epidemiological decoupling [5]. Spain provides a particularly informative setting for this type of analysis. The country has a decentralized health system composed of autonomous communities with differences in demographic structure, population ageing, healthcare capacity, timing of epidemic waves and implementation of public health measures [6]. At the same time, Spain has maintained extensive national COVID-19 surveillance datasets, including information on cases, hospitalizations, intensive care admissions, reported deaths, vaccination coverage and excess mortality. These data allow the construction of a weekly regional dataset covering the acute pandemic period and the subsequent transition toward reduced surveillance [7,8]. They also permit a specific focus on older adults, including the age strata 60–69, 70–79 and ≥ 80 years, which represent the main groups at risk of severe COVID-19 outcomes [9]. A regional and age-specific analysis is needed because national averages may obscure substantial territorial heterogeneity. Some autonomous communities may have experienced earlier or stronger decoupling between incidence and mortality, while others may have maintained higher conversion rates from cases to hospitalization or death. Similarly, decoupling may differ between the 60–69, 70–79 and ≥ 80 age groups [10]. In the oldest age group, mortality may remain high despite reduced ICU admission, reflecting frailty, comorbidity burden, long-term care exposure, clinical triage decisions or different pathways of care [11]. For this reason, a single national indicator is insufficient to evaluate the evolution of COVID-19 severity among older adults.

The objective of this work was to develop and apply a novel Older-adult COVID-19 Severity Decoupling Index (O-CSDI) to weekly COVID-19 surveillance data from Spain in order to quantify when, where and in which older-adult age groups reported COVID-19 incidence became progressively disconnected from hospitalization, ICU admission, and reported COVID-19 mortality, while MoMo excess mortality was examined as a complementary contextual indicator. The integrated dataset covered January 2020 to July 2023; however, the primary incidence- and ratio-based O-CSDI analyses covered March 2020–March 2022, ending with the Omicron BA.1/BA.2 phase. Data from March 2022 onward were retained only for contextual vaccination and MoMo mortality indicators because the open-access event-count structure was no longer directly comparable. Specifically, this study aimed to describe the regional and age-specific evolution of COVID-19 burden among adults aged 60–69, 70–79 and ≥ 80 years; quantify the degree of decoupling between incidence and severe outcomes across pandemic phases; compare decoupling patterns across the 17 autonomous communities and the two autonomous cities; and provide a transparent and reproducible health information tool for retrospective pandemic evaluation, regional comparison and future preparedness in ageing populations. The primary O-CSDI was based on the death-to-case ratio, while complementary variants assessed the hospitalization-to-case, ICU-to-hospitalization, and death-to-hospitalization relationships.

2. Materials and Methods

2.1. Study Design

Our study was designed as a nationwide ecological, descriptive, observational study using weekly aggregated COVID-19 surveillance data from Spain. The primary unit of analysis was the autonomous community–week stratum, defined as the combination of each Spanish autonomous community or autonomous city and ISO epidemiological week. The study covered the national and subnational levels and included all 17 autonomous communities and the two autonomous cities of Ceuta and Melilla. The integrated data horizon extended from January 2020 to July 2023, covering the complete acute pandemic period and the subsequent transition toward reduced surveillance and endemic management. Nevertheless, the primary incidence- and ratio-based O-CSDI analyses were restricted to March 2020–March 2022, when the required open-access case and outcome counts remained structurally comparable. The subsequent period contributed only contextual vaccination and MoMo mortality information. The analytical focus was placed on older adults, defined a priori as individuals aged 60 years and older. Three age strata were considered: 60–69, 70–79 and ≥ 80 years. These strata were selected because they represent the population groups with the highest COVID-19 hospitalization and mortality burden and because they allow the evaluation of age-specific changes in the relationship between incidence, hospital pressure and mortality across pandemic phases.

2.2. Data Sources

Data were obtained from open-access public surveillance datasets. Four main data sources were used. (i) First, case, hospitalization, intensive care unit and death counts by sex, age group, province of residence and date of diagnosis were obtained from the Spanish National Epidemiological Surveillance Network, coordinated by the Instituto de Salud Carlos III [12]. (ii) Additional regional COVID-19 indicators, including diagnostic activity, incidence, positivity and hospital occupancy indicators, were obtained from public data compiled by Datadista and the Spanish Ministry of Health [13]. These data were used to complement the official surveillance datasets and to reconstruct weekly regional indicators of diagnostic intensity, incidence and healthcare pressure. (iii) COVID-19 vaccination data were obtained from Our World in Data [14], including national time series of complete vaccination coverage, booster doses and vaccination coverage by age group where available. The vaccination data were used to identify the temporal transition from pre-vaccination to vaccination-dominated phases and to examine the timing of epidemiological decoupling in older adults. (iv) All-cause excess mortality estimates were obtained from the Daily Mortality Monitoring System, MoMo, coordinated by the Instituto de Salud Carlos III [15]. MoMo provides estimates of observed mortality, expected mortality and excess mortality by territory, sex and age group. These data were used to compare reported COVID-19 deaths with all-cause excess mortality and to provide a contextual description of the potential gap between official COVID-19 mortality and the broader mortality burden during each pandemic phase. For transparency, hospital and ICU indicators were not assumed to have identical completeness across all sources, phases and levels of disaggregation; ratios using these outcomes were calculated only when phase-level numerators and denominators were available and comparable.

2.3. Variables and Operational Definitions

Variables were grouped into seven analytical categories. (i) Epidemiological count variables included weekly confirmed COVID-19 cases, hospitalizations, ICU admissions and reported COVID-19 deaths. These variables were aggregated by autonomous community, ISO week, sex and age group whenever disaggregated data were available. (ii) Hospital

pressure variables included weekly hospital admissions, ICU admissions and hospital occupancy indicators. These variables were used to estimate the intensity of the burden on the health system and the conversion from diagnosed infection to severe clinical outcome. (iii) Diagnostic variables included weekly diagnosed cases by autonomous community, diagnostic technique when available, and diagnostic intensity indicators. These variables were used to contextualize changes in incidence that may have been influenced by changes in testing policy and surveillance protocols. (iv) Incidence variables included the 14-day cumulative incidence per 100,000 inhabitants, hereafter referred to as IA14. IA14 was used as a standardized measure of regional transmission intensity. (v) Case fatality variables were calculated as the ratio between reported COVID-19 deaths and confirmed cases within each region, age group and phase. Because case fatality ratios may be affected by testing availability, reporting delays and changes in case ascertainment, they were interpreted as ecological severity indicators rather than individual-level fatality risks. (vi) Excess mortality variables included observed deaths, expected deaths and excess deaths derived from MoMo [15]. Excess mortality was used as a complementary endpoint to reported COVID-19 mortality. The excess mortality gap was defined as the difference between all-cause excess deaths and reported COVID-19 deaths within the same autonomous community and time period. (vii) Vaccination variables included the proportion of the population completing the initial vaccination schedule and the proportion receiving booster doses. Where age-specific vaccination coverage was available, it was linked to the corresponding older-adult age strata. Active hospitalized patients and active ICU patients at a weekly point-in-time (stock) were obtained from the Datadista/Ministerio de Sanidad series [13]. Both measures are reported in the integrated dataset; ratio-based indicators used in the O-CSDI are computed from admission counts to ensure comparability across phases.

The main derived indicators were defined as follows:

Hospitalization-to-case ratio = hospitalizations/confirmed cases.

ICU-to-hospitalization ratio = ICU admissions/hospitalizations.

Death-to-case ratio = reported COVID-19 deaths/confirmed cases.

Death-to-hospitalization ratio = reported COVID-19 deaths/hospitalizations.

Excess mortality gap = excess all-cause deaths – reported COVID-19 deaths.

Excess-to-reported mortality ratio = excess all-cause deaths/reported COVID-19 deaths.

Older-adult COVID 19 Severity Decoupling Index (O-CSDI) = $1 - [(death-to-case\ ratio\ in\ a\ given\ phase) / (death-to-case\ ratio\ in\ the\ reference\ pre-vaccination\ phase)]$.

The O-CSDI was calculated separately for each autonomous community and age group. Positive values indicate that, relative to the reference phase, a lower proportion of reported cases translated into deaths. Values close to zero indicate no relevant decoupling, whereas negative values indicate a higher death-to-case ratio than in the reference phase. Analogous decoupling indices were calculated for hospitalization-to-case and ICU-to-hospitalization relationships.

Four descriptive O-CSDI variants were calculated, corresponding to the death-to-case, hospitalization-to-case, ICU-to-hospitalization, and death-to-hospitalization relationships. Each variant compared the phase-specific ratio with the corresponding ratio observed during the pre-vaccination reference period. These variants were descriptive indices rather than statistical models.

2.4. Epidemiological Phase Classification

The integrated study period was divided into 12 epidemiological phases (Table 1) based on major changes in transmission dynamics, public health policy, vaccination rollout, variant predominance and surveillance strategy. Phase boundaries were defined a priori using the national epidemiological context and then applied uniformly to all territorial units.

Because regional epidemics were not perfectly synchronized, alternative regional phase boundaries were considered conceptually. However, alternative regional phase boundaries were not implemented as a uniform sensitivity analysis because comparable definitions of regional mortality and hospitalization inflection points were unavailable across all territories. The 12-phase classification was retained to document the full surveillance period; however, the main ratio-based O-CSDI analyses were restricted to phases with comparable event counts. The pre-vaccination reference period for the main decoupling analysis was defined as P1a–P3a. The vaccination transition period was defined as P3b–P4. The post-vaccination and variant-transition periods were defined as P5–P6b for ratio-based O-CSDI analyses. P7a and P7b were retained in the integrated dataset for vaccination and MoMo indicators but excluded from incidence- and ratio-based O-CSDI calculations because open-access individual event counts were no longer comparable after the March 2022 surveillance change. These definitions allowed the analysis to distinguish between changes associated with the first pandemic waves, vaccination rollout, Delta, Omicron and the subsequent transition toward reduced surveillance.

Table 1. Epidemiological phase classification used in our study.

Code	Description	Period
P0	Early emergence and pre-lockdown surveillance	1 January 2020–13 March 2020
P1a	First wave and strict national lockdown	14 March 2020–3 May 2020
P1b	De-escalation after first lockdown	4 May 2020–21 June 2020
P2	New normality and summer–autumn resurgence	22 June 2020–24 October 2020
P3a	Second state of alarm and winter wave build-up	25 October 2020–27 December 2020
P3b	Early vaccination and third wave	28 December 2020–28 March 2021
P4	Vaccination expansion and Alpha-dominated transition	29 March 2021–27 June 2021
P5	Delta wave and advanced vaccination coverage	28 June 2021–3 October 2021
P6a	Booster initiation and pre-Omicron period	4 October 2021–19 December 2021
P6b	Omicron BA.1/BA.2 wave	20 December 2021–27 March 2022
P7a	Transition to reduced surveillance and endemic management	28 March 2022–31 December 2022
P7b	Post-acute endemic surveillance period	1 January 2023–2 July 2023

2.5. Data Integration and Processing

All datasets were processed using Python version 3.11.9. Daily records were converted into ISO epidemiological weeks using calendar-based week definitions. When data were available at the provincial level, records were aggregated to the autonomous community level using the official INE territorial mapping between provinces and autonomous communities. Ceuta and Melilla were retained as independent territorial units. Data from different sources were aligned using three common identifiers: autonomous community, ISO year–week and, where available, age group and sex. Surveillance data reported by date of diagnosis were aggregated to weekly counts. MoMo mortality estimates were aggregated from daily to weekly values. Vaccination time series were transformed to weekly values by selecting the most recent value within each ISO week. When vaccination coverage was not reported on a given week, forward-fill imputation was applied because vaccination coverage is cumulative and non-decreasing. Forward-fill imputation was not applied to epidemiological event counts such as cases, hospitalizations, ICU admissions or deaths.

Age groups were harmonized into the following categories: 0–9, 10–19, 20–29, 30–39, 40–49, 50–59, 60–69, 70–79 and ≥ 80 years. The main analysis focused on 60–69, 70–79 and ≥ 80 years. Sex was classified as male, female or total, depending on the availability of disaggregated data in each source.

To reduce instability in ratios caused by small denominators, conversion ratios were only calculated when the denominator was greater than zero. Weekly ratios based on very

small denominators were flagged as part of the data-quality assessment and interpreted cautiously. For phase-level analyses, weekly counts were summed within each phase before calculating ratios. This approach reduced volatility and avoided the overinterpretation of isolated weekly fluctuations. No explicit individual-level or weekly onset-to-event lag adjustment was applied because the public datasets did not provide linkable trajectories connecting diagnosis with subsequent hospitalization, ICU admission, or death. Phase-level aggregation may smooth short reporting delays, but it does not fully correct temporal misalignment, particularly for events occurring near epidemiological phase boundaries. The final integrated dataset contained 3496 territorial unit-week observations and 143 variables, including original surveillance indicators, harmonized temporal variables, source-specific phase labels, older-adult age strata, vaccination indicators, mortality indicators, source identifiers and data-quality notes. The harmonized weekly surveillance dataset is provided as Supplementary Dataset S1, and the core analytical variable dictionary and harmonization guide are provided as Supplementary Table S1. Because the phase labels in the harmonized dataset preserve the coding structure used during data integration, a separate analytical phase recoding was applied in the Python scripts to match the epidemiological phase framework reported in Table 1. Therefore, the phase labels used for the main O-CSDI analyses should be interpreted according to the analytical phase definitions in Table 1 rather than as raw source labels in the dataset. Derived ratios and O-CSDI metrics were calculated from this harmonized dataset using the Python scripts provided as Supplementary File S1. An important surveillance limitation must be noted regarding data completeness. From 3 March 2022, the ISCIII modified its surveillance protocol: individual case notification was restricted to persons aged 60 years or older. Furthermore, the individual open-access ISCIII dataset used for event counts ends on 27 March 2022, at which point the surveillance system transitioned to the SiVIRA sentinel platform, which does not provide individual open-access records with the same structure. Consequently, epidemiological event counts for phases P7a and P7b cannot be used for incidence- or ratio-based O-CSDI analyses. These periods were retained in the dataset for vaccination and MoMo indicators but were flagged in the `data_quality_note` variable and excluded from O-CSDI calculations. Additionally, the very high case counts recorded during the Omicron BA.1/BA.2 phase may reflect retroactive consolidation of records and should be interpreted with caution because they may overestimate weekly incidence.

2.6. Statistical Analysis

Descriptive statistics were used to summarize weekly and phase-specific distributions of cases, hospitalizations, ICU admissions, reported COVID-19 deaths, excess mortality and vaccination coverage. MoMo excess mortality was examined separately as a complementary contextual indicator where temporal and territorial alignment was feasible. Results were presented nationally and, where appropriate, by territorial unit, older-adult age group and epidemiological phase. Count variables were summarized as totals and rates per 100,000 inhabitants when population denominators were available. Continuous indicators were summarized using means, medians, ranges and interquartile ranges, depending on their distribution and interpretability. The main outcome was the O-CSDI, calculated for each eligible territorial unit, older-adult age group and epidemiological phase. National phase-level O-CSDI values were calculated as pooled descriptive summaries by aggregating the corresponding numerators and denominators across eligible territorial units before ratio calculation. This approach was used to reduce instability caused by weekly fluctuations and small denominators. Secondary descriptive indicators included the hospitalization-to-case ratio, ICU-to-hospitalization ratio, death-to-case ratio, death-to-hospitalization ratio, excess mortality gap and excess-to-reported mortality ratio. Regional heterogeneity was assessed

descriptively by comparing O-CSDI values across the 17 autonomous communities and the two autonomous cities. These comparisons were not interpreted as inferential tests or formal statistical rankings between territories. Inter-territorial variation was summarized using ranges and, where appropriate, coefficients of variation. Age-specific patterns were evaluated by comparing phase-level CFR trajectories across the 60–69, 70–79 and ≥ 80 -year groups. Data-quality restrictions were applied by excluding calculations with zero denominators and flagging strata with very small case or hospitalization counts. Lagged sensitivity analyses using forward shifts of hospitalization, ICU admission, and death series relative to confirmed cases were considered. However, complete and consistently disaggregated weekly series were not available for every territory, age stratum, and endpoint; consequently, a uniform lagged analysis could not be implemented across all comparisons. The O-CSDI values are presented as descriptive point estimates. Confidence intervals, bootstrap intervals and formal propagation of measurement uncertainty were not calculated. Conventional binomial or Poisson intervals would reflect count variation but would not capture the dominant non-random uncertainty generated by under-ascertainment, changes in reporting and differences in source completeness. Therefore, no formal significance testing or statistical ranking of territorial O-CSDI values was undertaken. Because this was an ecological study based on aggregated public surveillance data and affected by major changes in testing and reporting practices, no predictive or causal model was fitted. All analyses were interpreted as descriptive, population-level indicators rather than individual-level risk estimates or causal effects. Analyses were conducted in Python using pandas and NumPy for data processing and matplotlib for visualization.

2.7. Older-Adult COVID-19 Severity Decoupling Index

To quantify the extent to which COVID-19 incidence became progressively disconnected from severe outcomes among older adults, we developed the O-CSDI. This index was designed as an ecological, phase-specific health information indicator comparing the conversion of confirmed cases into severe outcomes during each pandemic phase with the corresponding conversion observed during a pre-vaccination reference period. Confirmed cases are surveillance-dependent observations and should not be considered equivalent to all SARS-CoV-2 infections. Changes in testing eligibility, diagnostic intensity, case ascertainment, self-testing, and reporting practices can modify the denominator and mechanically alter the O-CSDI, even when changes in underlying biological severity are smaller. Accordingly, the index has moderate construct validity as a descriptive surveillance indicator and should not be interpreted as a direct estimate of infection fatality or intrinsic viral severity.

The O-CSDI was calculated separately for each autonomous community, older-adult age group and epidemiological phase. Three older-adult age strata were considered: 60–69 years, 70–79 years and ≥ 80 years. The primary decoupling endpoint was the death-to-case ratio. Secondary decoupling endpoints included the hospitalization-to-case ratio, ICU-to-hospitalization ratio and death-to-hospitalization ratio.

For each autonomous community (r), age group (a) and pandemic phase (p), the death-to-case ratio was defined as follows:

$$CDR_{r,a,p} = \frac{D_{r,a,p}}{C_{r,a,p}}$$

where $D_{r,a,p}$ represents the total number of reported COVID-19 deaths and $C_{r,a,p}$ represents the total number of confirmed COVID-19 cases in autonomous community r , age group a , and pandemic phase p .

The pre-vaccination reference death-to-case ratio was defined as:

$$CDR_{r,a,ref} = \frac{D_{r,a,ref}}{C_{r,a,ref}}$$

where ref denotes the pre-vaccination reference period, corresponding to the pandemic phases preceding substantial vaccine-derived protection at the population level.

The mortality-based Older-adult COVID-19 Severity Decoupling Index was calculated as:

$$O-CSDI_{r,a,p}^{death} = 1 - \frac{CDR_{r,a,p}}{CDR_{r,a,ref}}$$

where positive values indicate that, compared with the pre-vaccination reference period, a lower proportion of reported confirmed cases resulted in death. Values close to zero indicate little or no decoupling, whereas negative values indicate that the death-to-case ratio was higher than during the reference period. Values approaching 1 indicate strong decoupling between reported incidence and mortality.

The hospitalization-to-case ratio was defined as:

$$HCR_{r,a,p} = \frac{H_{r,a,p}}{C_{r,a,p}}$$

where $H_{r,a,p}$ represents the total number of COVID-19 hospitalizations in autonomous community r , age group a , and pandemic phase p .

The hospitalization-based decoupling index was calculated as:

$$O-CSDI_{r,a,p}^{hosp} = 1 - \frac{HCR_{r,a,p}}{HCR_{r,a,ref}}$$

where $HCR_{r,a,p}$ represents the hospitalization-to-case ratio during the pre-vaccination reference period.

The ICU-to-hospitalization ratio was defined as:

$$IHR_{r,a,p} = \frac{ICU_{r,a,p}}{H_{r,a,p}}$$

where $ICU_{r,a,ref}$ represents the total number of intensive care unit admissions in autonomous community r , age group a , and pandemic phase p .

The ICU-to-hospitalization decoupling index was calculated as:

$$O-CSDI_{r,a,p}^{ICU} = 1 - \frac{IHR_{r,a,p}}{IHR_{r,a,ref}}$$

where $IHR_{r,a,ref}$ represents the ICU-to-hospitalization ratio during the pre-vaccination reference period.

The death-to-hospitalization ratio was defined as:

$$DHR_{r,a,p} = \frac{D_{r,a,p}}{H_{r,a,p}}$$

where $D_{r,a,p}$ represents the total number of reported COVID-19 deaths and $H_{r,a,p}$ represents the total number of COVID-19 hospitalizations in autonomous community r , age group a , and pandemic phase p .

The death-to-hospitalization decoupling index was calculated as:

$$O\text{-}CSDI^{death|hosp_{r,a,p}=1} = \frac{DHR_{r,a,p}}{DHR_{r,a,ref}}$$

This complementary indicator was used to evaluate whether mortality among hospitalized older adults changed across pandemic phases independently of changes in reported incidence.

For descriptive interpretation, O-CSDI values were classified into four categories: no decoupling or worsening when $O\text{-}CSDI \leq 0$, weak decoupling when $0 < O\text{-}CSDI < 0.25$, moderate decoupling when $0.25 \leq O\text{-}CSDI < 0.50$, and strong decoupling when $O\text{-}CSDI \geq 0.50$. These thresholds were used only for interpretation and visualization and were not intended to define causal categories.

To reduce instability due to small denominators, O-CSDI values were calculated using phase-level aggregated counts rather than isolated weekly ratios. Index values were only calculated when the denominator in both the phase-specific ratio and the reference ratio was greater than zero. The robustness procedures implemented in the primary analysis consisted of calculating ratios only when the relevant denominators were greater than zero and interpreting strata with low counts cautiously. Uniform recalculation using lagged outcomes or MoMo excess mortality was not possible across all territorial and age-specific strata because comparable disaggregated data were unavailable. The O-CSDI should be interpreted as a population-level health information indicator rather than an individual-level risk estimate. Its values depend on the stability and comparability of both the event numerator and the surveillance-confirmed-case denominator. A higher O-CSDI may reflect several overlapping mechanisms, including vaccination coverage, previous infection-derived immunity, changes in viral variants, improved clinical management, changes in testing practices, behavioural adaptation and differential protection of vulnerable groups. Therefore, the index was used to describe regional and age-specific epidemiological decoupling, while avoiding direct causal attribution to any single intervention.

2.8. Ethical Considerations

The study was conducted in accordance with the principles of the Spanish Biomedical Research Law 14/2007 [16], Regulation (EU) 2016/679 [17], and the General Data Protection Regulation, as the analysis was based exclusively on anonymized and aggregated public health surveillance data.

3. Results

3.1. Overview of COVID-19 Burden in Spain by Epidemiological Phase

Nine epidemiological phases were included in the primary ratio-based analysis from March 2020 to March 2022, spanning from the initial lockdown through the Omicron wave (Table 2; Figure 1). Although the integrated dataset extended to July 2023, phases after March 2022 were excluded from incidence- and ratio-based O-CSDI calculations because comparable open-access individual event counts were unavailable. Burden indicators varied substantially across phases, reflecting the interplay of viral variants, non-pharmaceutical interventions, healthcare system capacity, and vaccination rollout. During the first wave lockdown (P1a), Spain recorded 213,249 confirmed cases, 96,442 hospitalizations, 8099 ICU admissions, and 27,070 deaths, yielding a case fatality rate (CFR) of 12.69%. The hospitalization-to-case ratio (H/C) stood at 45.23%, the ICU-to-hospitalization ratio (U/H) at 8.40%, and the death-to-hospitalization ratio (D/H) at 28.07%, reflecting extreme severity under constrained diagnostic capacity. The de-escalation phase (P1b) showed a CFR of

8.93%. The new normality period (P2) and the second state of alarm (P3a) registered CFRs of 0.96% and 2.05%, respectively, as testing expanded substantially.

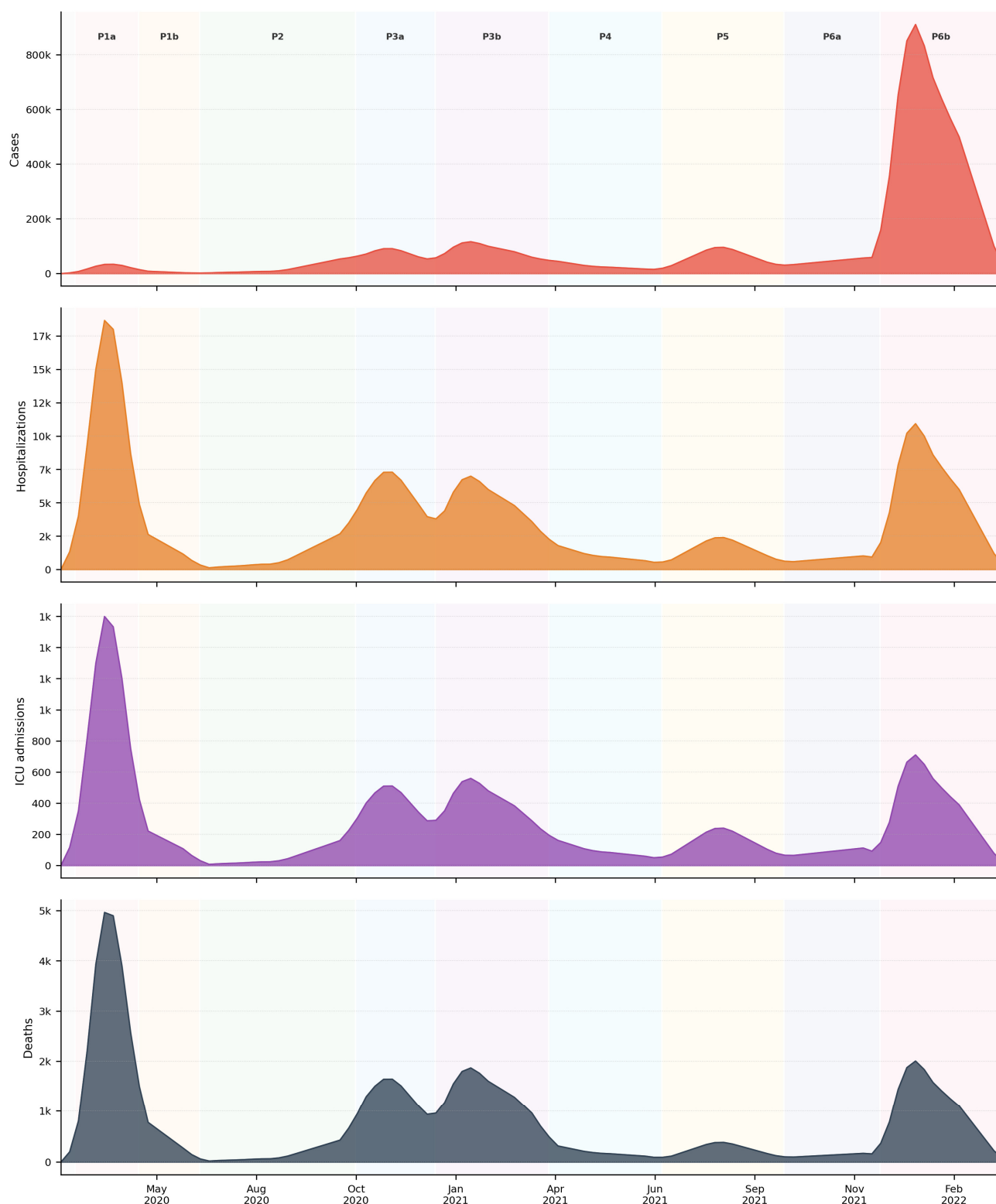


Figure 1. Weekly COVID-19 epidemiological indicators in Spain by epidemiological phase (March 2020–March 2022). Four panels show new confirmed cases, new hospitalizations, new ICU admissions, and new deaths. Phase background shading indicates the 12 defined epidemiological periods.

Table 2. National COVID-19 burden indicators by epidemiological phase (Spain, March 2020–March 2022) [10].

Phase	Description	Cases	Hosp.	ICU	Deaths	CFR (%)	H/C (%)	U/H (%)	D/H (%)
P1a	First wave/lockdown	213,249	96,442	8099	27,070	12.69	45.23	8.40	28.07
P1b	De-escalation	20,984	—	—	1874	8.93	—	—	—
P2	New normality/resurgence	892,985	—	—	8574	0.96	—	—	—
P3a	2nd state of alarm	761,919	—	—	15,614	2.05	—	—	—
P3b	Early vaccination/3rd wave	1,373,717	—	—	23,903	1.74	—	—	—
P4	Vaccination expansion (Alpha)	517,479	—	—	4502	0.87	—	—	—
P5	Delta wave	1,159,067	—	—	6027	0.52	—	—	—
P6a	Booster/pre-Omicron	623,679	—	—	2245	0.36	—	—	—
P6b	Omicron BA.1/BA.2	5,963,494	79,394	5319	13,431	0.23	1.33	6.70	16.92

CFR $\geq 8\%$ (extreme severity), CFR 2–8% (high severity) and CFR $\leq 0.5\%$ (low severity). CFR = case fatality rate; H/C = hospitalization-to-case ratio; U/H = ICU-to-hospitalization ratio; D/H = death-to-hospitalization ratio. Dashes (—) indicate data not available at required disaggregation.

The early vaccination period (P3b) reported 1,373,717 cases and a CFR of 1.74%. As vaccine coverage broadened through P4 (517,479 cases, CFR 0.87%) and the Delta wave (P5, 1,159,067 cases, CFR 0.52%), the decoupling between case counts and severe outcomes became increasingly evident. The booster and pre-Omicron phase (P6a, 623,679 cases, CFR 0.36%) preceded the Omicron BA.1/BA.2 surge (P6b), which generated the largest caseload of the entire study period at 5,963,494 confirmed cases with a CFR of only 0.23%, H/C of 1.33%, U/H of 6.70%, and D/H of 16.92%. This profound shift constituted the central empirical motivation for the O-CSDI framework.

3.2. Evolution of the Older-Adult COVID-19 Severity Decoupling Index

The O-CSDI was computed for phases P3b through P6b using a pooled pre-vaccination reference period (P1a–P3a; CFR_{ref} = 2.811%, H/C_{ref} = 11.75%, U/H_{ref} = 8.99%, D/H_{ref} = 23.93%). All O-CSDI values are presented in Table 3 and Figure 2.

The mortality-based O-CSDI increased from 0.382 in P3b to 0.920 in P6b, indicating that the observed death-to-confirmed-case ratio in P6b was approximately 92% lower than the corresponding ratio during the reference period. This is a descriptive comparison between surveillance ratios and should not be interpreted as a 92% elimination of underlying biological mortality risk. The hospitalization-based O-CSDI followed a parallel trajectory, increasing from 0.361 in P3b to 0.887 in P6b, confirming that fewer hospitalizations were occurring per detected case.

The ICU-to-hospitalization O-CSDI exhibited a markedly different pattern. Negative values were observed in P3b (−0.162), P4 (−0.451), P5 (−0.200), and P6a (−0.366), indicating that the ratio of ICU admissions to hospitalizations actually exceeded the reference level during these phases. One possible interpretation is that changes in the ICU-to-hospitalization ratio may partly reflect differences in the clinical profile of hospitalized patients across phases. However, the aggregated data do not permit this mechanism to be tested directly. In P6b, O-CSDI_{UCI} reversed to +0.254, temporally compatible with changes in variant characteristics, accumulated immunity, clinical management, and admission practices.

Table 3. Older-adult COVID-19 Severity Decoupling Index (O-CSDI) values by phase and index variant.

Phase	Description	Mortality-Based O-CSDI (Death-to-Case)	Hospitalization-Based O-CSDI (Hospitalization-to-Case)	ICU-to-Hospitalization O-CSDI	Death-to-Hospitalization O-CSDI
P3b	Early vaccination + 3rd wave	0.382	0.361	−0.162	0.033
P4	Vaccination expansion (Alpha)	0.690	0.354	−0.451	0.521
P5	Delta wave	0.817	0.683	−0.200	0.422
P6a	Booster/pre-Omicron	0.871	0.744	−0.366	0.496
P6b	Omicron BA.1/BA.2	0.920	0.887	+0.254	0.293

Strong decoupling (≥ 0.87); moderate (0.65–0.87); weak (0.35–0.65), worsening/negative. Reference period (P1a–P3a): CFR_{ref} = 2.811%; H/C_{ref} = 11.75%; U/H_{ref} = 8.99%; D/H_{ref} = 23.93%. Negative ICU-to-hospitalization O-CSDI values indicate that the ICU-to-hospitalization ratio exceeded the reference level.

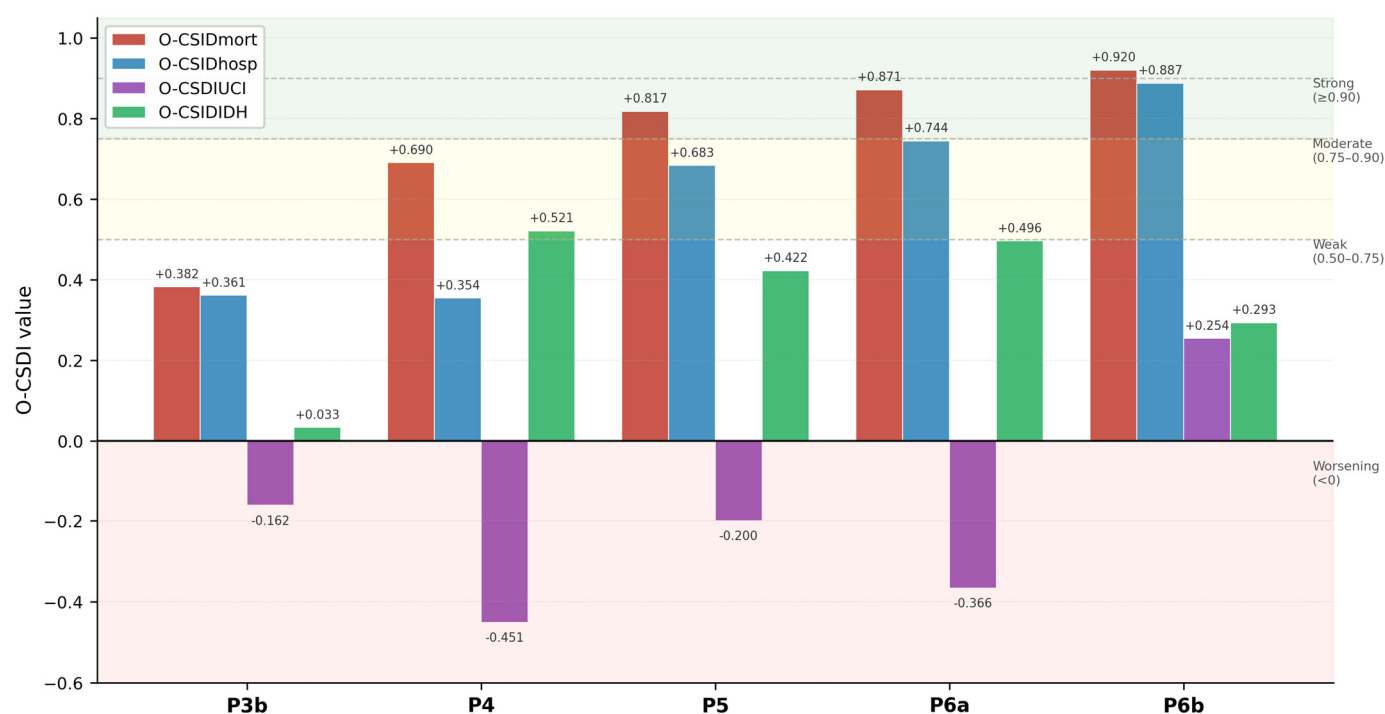


Figure 2. Older-adult COVID-19 Severity Decoupling Index (O-CSDI) by epidemiological phase and index variant. Bars represent the mortality-based O-CSDI (death-to-case), hospitalization-based O-CSDI (hospitalization-to-case), ICU-to-hospitalization O-CSDI, and death-to-hospitalization O-CSDI, respectively. Reference period: P1a–P3a. Horizontal dashed line at 0; dotted lines at 0.50 and 0.75. Shaded bands indicate decoupling strength categories. Values in green = strong decoupling (≥ 0.87); values in orange = negative O-CSDI (worsening).

The death-to-hospitalization O-CSDI increased from 0.033 in P3b to 0.521 in P4, remaining elevated at 0.422 (P5), 0.496 (P6a), and 0.293 (P6b). The comparatively lower value in P6b suggests partial convergence between hospitalization severity and mortality risk during the Omicron wave, when large absolute numbers of hospitalizations occurred despite lower average severity per reported case.

3.3. Age-Specific CFR Trajectories in Older Adults

Age-stratified CFR analysis across three older-adult groups (60–69, 70–79, and ≥ 80 years) demonstrated marked heterogeneity in the magnitude and pace of severity decoupling (Table 4; Figure 3).

Table 4. Age-specific case fatality rates (%) by epidemiological phase for older-adult age groups.

Phase	Description	CFR 60–69 (%)	CFR 70–79 (%)	CFR ≥ 80 (%)
P1a	First wave lockdown	8.00	21.15	32.39
P1b	De-escalation	5.10	14.20	33.07
P2	New normality	0.50	3.20	11.50
P3a	2nd state of alarm	0.80	5.30	18.61
P3b	Early vaccination	0.70	4.80	18.81
P4	Vacc. expansion (Alpha)	0.50	3.90	15.55
P5	Delta wave	0.35	2.10	10.54
P6a	Booster/pre-Omicron	0.22	1.55	7.79
P6b	Omicron BA.1/BA.2	0.40	1.07	3.79

CFR values are phase-level aggregates computed from ISCIII-RENAVE data [10]. Values represent deaths/confirmed cases within each age stratum and phase. Note that P1a–P2 CFRs may be influenced by under-ascertainment of cases during periods of limited testing.

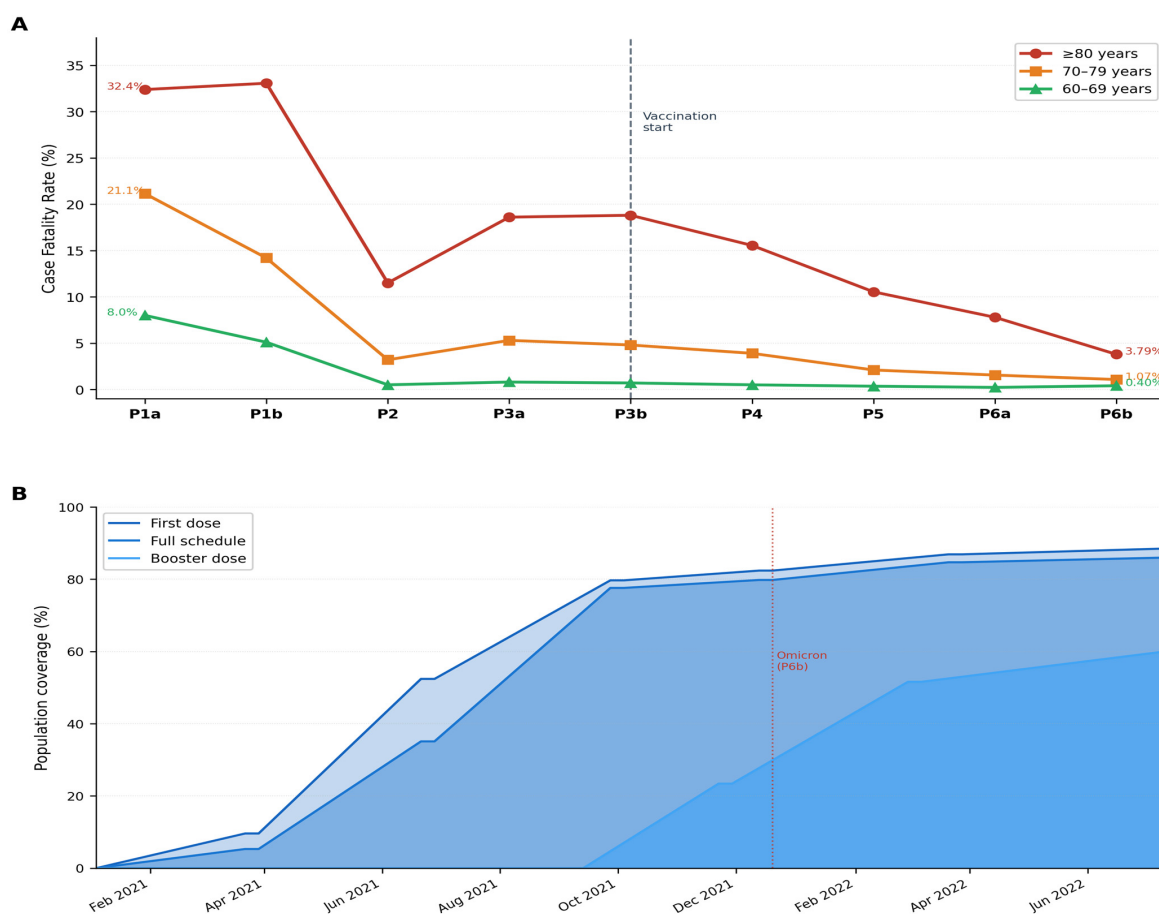


Figure 3. Panel (A): Age-specific case fatality rate (CFR) trajectories across epidemiological phases for three older-adult age groups (60–69, 70–79, and ≥ 80 years). Panel (B): National COVID-19 vaccination coverage over time, showing first dose, full schedule, and booster dose coverage. Vertical dashed line indicates vaccination programme start.

In the ≥ 80 -year group, the CFR fell from 32.39% in P1a to 3.79% in P6b—a tenfold reduction—though this group retained the highest absolute CFR throughout all phases, underscoring persistent residual vulnerability attributable to immunosenescence and comorbidity burden. The 70–79 group showed a CFR of 21.15% in P1a, declining to 1.07% in P6b (approximately 95% reduction). The 60–69 group experienced the most pronounced relative decline, from 8.00% in P1a to 0.40% in P6b—a twentyfold improvement—temporally compatible with prioritized vaccination, accumulated immunity, changes in circulating variants, improved clinical management and evolving testing practices. The persistent CFR gradient across age strata at every phase confirms that older age remained the dominant individual risk factor for COVID-19 mortality throughout the pandemic, even as absolute rates declined universally.

3.4. Regional Heterogeneity of the O-CSDI Across Autonomous Communities

During P6b (Omicron BA.1/BA.2), the descriptive point estimates of the mortality-based O-CSDI varied across Spanish autonomous communities (Figure 4). Higher descriptive point estimates were observed in La Rioja (0.951), Cataluña (0.944), Galicia (0.944), Castilla-La Mancha (0.941), and Extremadura (0.938), all approaching or exceeding 0.94, corresponding to high descriptive point estimates relative to the reference period of mortality from case incidence relative to the pre-vaccination reference.

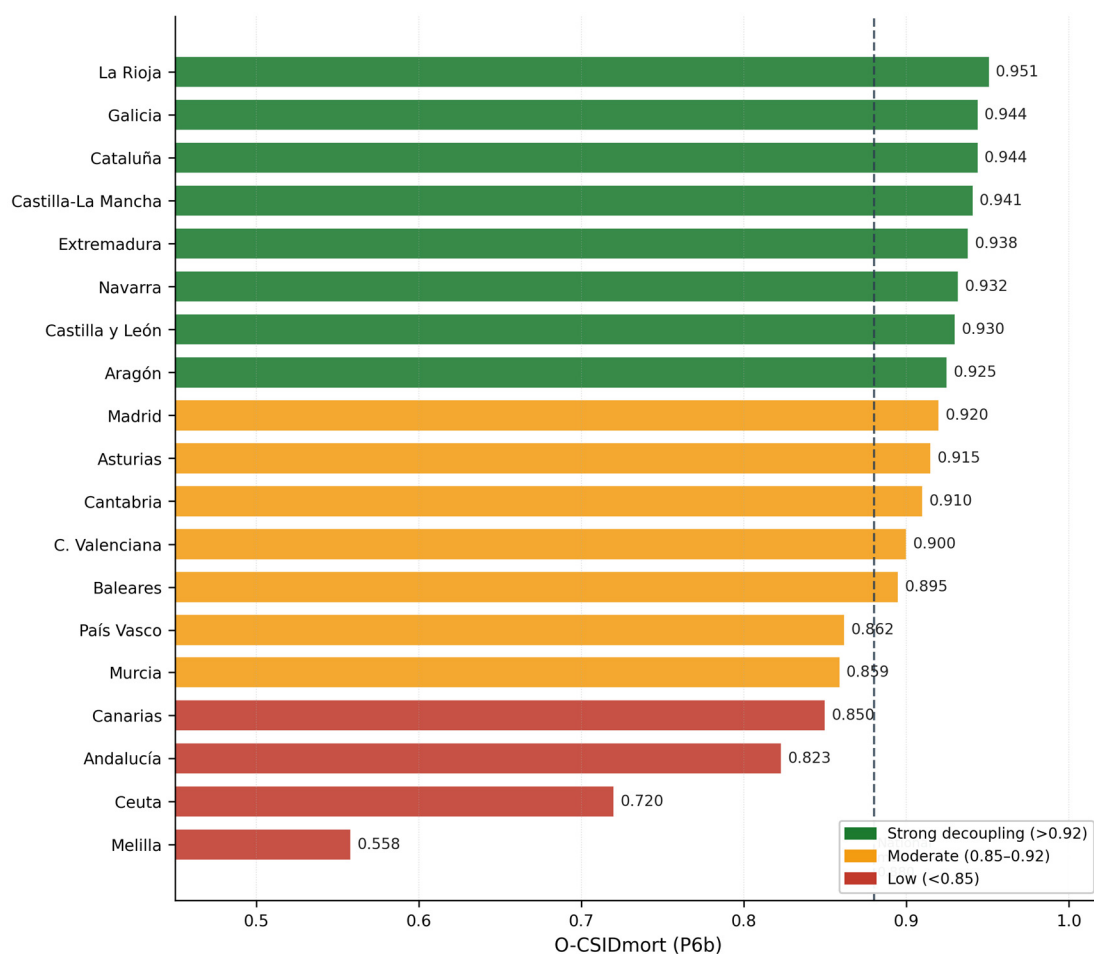


Figure 4. Regional mortality-based O-CSDI values across 19 Spanish autonomous communities during the Omicron BA.1/BA.2 phase (P6b, December 2021–March 2022). Colours indicate decoupling strength: red (<0.85, low), orange (0.85–0.92, moderate), and green (>0.92, strong). Reference period: P1a–P3a. The vertical dashed line marks an O-CSDI value of 0.92, the threshold used to identify strong decoupling in this figure.

Lower descriptive point estimates were observed in Melilla (0.558), Andalucía (0.823), Canarias (0.850), Murcia (0.859), and País Vasco (0.862). Because uncertainty intervals were not estimated and some territorial cells contained small denominators, these values should not be interpreted as formal rankings or as evidence of statistically significant regional differences. This caution is particularly important for Ceuta and Melilla. The inter-regional spread, ranging from 0.558 to 0.951, suggests possible territorial heterogeneity in the descriptive point estimates. The comparatively low point estimate observed in Melilla may warrant further investigation; however, the present ecological data cannot determine whether it arose from small denominators, testing intensity, demographic structure, healthcare access, or other territorial factors.

Regional differences may reflect variation in vaccination coverage, population age structure, baseline healthcare capacity, socioeconomic vulnerability, and differential sub-variant circulation. The O-CSDI provides a standardized metric to identify communities where decoupling lagged, enabling geographically targeted public health surveillance.

3.5. Contextual Comparison with MoMo Excess Mortality

MoMo excess-mortality data were examined as a contextual complement to reported COVID-19 mortality. However, differences in temporal aggregation, age-group availability, territorial disaggregation, and attribution prevented uniform construction of an excess-mortality-based O-CSDI across all phases and strata. The available comparisons were therefore used to contextualize discrepancies between reported COVID-19 deaths and the broader all-cause mortality burden rather than as a primary decoupling endpoint. MoMo mortality estimates with non-zero observed or expected values were available for 12 of the 19 territorial units between 6 January 2020 and 12 July 2021. To ensure consistent coverage, reported COVID-19 deaths were aggregated only over the same territory-week observations. The resulting phase-level contextual comparison is presented in Table 5.

Table 5. Contextual comparison of reported COVID-19 mortality and available MoMo excess-mortality data by epidemiological phase.

Phase	Available Period	Territories, <i>n/N</i>	Weeks, <i>n</i>	Reported COVID-19 Deaths	Observed All-Cause Deaths	Expected All-Cause Deaths	Excess Deaths	Excess Mortality Gap	Excess-to- Reported Mortality Ratio
P1a	14 March 2020–3 May 2020	12/19	7	14,449	384,936.7	245,952.0	138,984.7	124,535.7	9.62
P1b	4 May 2020–21 June 2020	12/19	7	1628	222,218.7	226,041.3	−3822.6	−5450.6	−2.35
P2	22 June 2020–24 October 2020	12/19	18	5100	622,200.5	559,201.2	62,999.3	57,899.3	12.35
P3a	25 October 2020–27 December 2020	12/19	9	11,374	379,327.5	325,615.2	53,712.3	42,338.3	4.72
P3b	28 December 2020–28 March 2021	12/19	13	17,240	564,062.9	504,599.2	59,463.7	42,223.7	3.45
P4	29 March 2021–27 June 2021	12/19	13	2927	431,102.6	431,298.5	−195.9	−3122.9	−0.07
P5	28 June–12 July 2021 (partial)	12/19	3	274	88,468.8	84,898.3	3570.5	3296.5	13.03

Note: The excess mortality gap was calculated as MoMo excess all-cause deaths minus reported COVID-19 deaths within the same available territory-week observations. The excess-to-reported mortality ratio was calculated as MoMo excess deaths divided by reported COVID-19 deaths. P5 includes only 28 June–12 July 2021 and should be interpreted as partial phase coverage. Negative excess values indicate that observed all-cause mortality was below the MoMo expected baseline. Because territorial coverage was incomplete and the MoMo and COVID-19 surveillance series differ in attribution and structure, these comparisons are contextual and should not be interpreted as a national excess-mortality-based O-CSDI.

The contextual comparison showed marked phase-to-phase variation. During P1a, available MoMo data indicated 138,984.7 excess deaths compared with 14,449 reported COVID-19 deaths in the same territory-week observations, yielding an excess-to-reported mortality ratio of 9.62. Positive excess mortality was also observed in P2, P3a, and P3b, whereas P1b and P4 showed negative excess estimates relative to the MoMo expected baseline. The P5 estimate was based on partial phase coverage and should not be interpreted as representative of the entire Delta period. The excess mortality gap varied across the phases with available data, indicating that the correspondence between reported COVID-19 deaths and the broader all-cause mortality burden was not constant over time. However, the magnitude and direction of this gap should be interpreted cautiously because MoMo coverage was incomplete across territories, did not extend through the Omicron period, and was not fully aligned with the attribution and disaggregation structure of the COVID-19 surveillance series. Accordingly, these results provide contextual information rather than an alternative excess-mortality-based O-CSDI.

4. Discussion

4.1. Interpretation of Decoupling Patterns

The O-CSDI framework introduced in our study provides a structured, phase-sensitive metric for quantifying the progressive dissociation between COVID-19 case incidence and clinical severity in older adults in Spain. The mortality-based and hospitalization-based variants showed progressively higher decoupling from P3b through P6b. Declining COVID-19 severity during vaccination- and Omicron-era phases has previously been documented in several national settings. Our findings are consistent with the conceptual framework advanced by Madhi et al. [18], extending it to a longitudinal, multi-phase analysis grounded in national surveillance data. Therefore, the principal novelty of the present study is not the identification of a previously unknown epidemiological phenomenon but the operationalization of this transition into a simple, reproducible, age-focused, and subnational surveillance index. The mortality-based O-CSDI reached 0.920 in P6b, indicating that the observed death-to-confirmed-case ratio was approximately 92% lower than in the pre-vaccination reference period. This value represents a descriptive comparison between surveillance ratios and should not be interpreted as evidence that 92% of the underlying biological mortality risk had been eliminated. The phenomenon of epidemiological decoupling observed in our study has emerged as a critical indicator of pandemic transition from acute crisis to endemic phase [19,20]. The observed temporal pattern was compatible with the combined effects of vaccination, accumulated infection-derived immunity, variant succession, improved clinical management, behavioural adaptation, and evolving testing and reporting practices. Because the study was ecological and descriptive, the independent contribution of vaccination or any other mechanism could not be causally isolated. Similar patterns have been documented internationally; in Mexico, substantial reductions in intubations and mortality were observed during the Omicron wave, and in Eswatini, decoupling was apparent as early as the third wave (Delta variant), suggesting that population immunity from prior infection also contributed to this phenomenon beyond vaccination alone [21,22]. The generalizability of these findings across diverse geographic and epidemiological contexts strengthens confidence in the robustness of decoupling as a measurable epidemiological marker [18,20–23]. The hospitalization-based index closely tracked the mortality index (0.887 in P6b), supporting the interpretation that decoupling reflected a genuine reduction in the conversion of detected cases into severe outcomes, although changes in testing intensity and case ascertainment must also be considered [20]. Clinical data from hospitalized patients further validate this finding: during the Omicron-variant-predominant phase, compared to Delta, ICU care rates declined from

16.0% to 11.6%, intubation rates decreased from 13% to 6.3%, and 30-day mortality fell from 16.40% to 9.8% [24]. These reductions occurred despite higher vaccination rates in the Omicron cohort (55% vs. 37.7%), suggesting combined protective effects of vaccine-induced and infection-derived immunity [18,19,24]. This interpretation remains ecological and ratio-based; it does not estimate individual-level vaccine effectiveness or separate the independent effects of immunity, variants, clinical management and surveillance changes.

4.2. Role of Vaccination and Variant Succession

The temporal evolution of the O-CSDI closely paralleled the national vaccination rollout captured by Our World in Data [14]. At the end of P3b (March 2021), first-dose and full-schedule coverage remained limited, consistent with the still-moderate mortality-based O-CSDI of 0.382. By the end of P4 (June 2021), vaccination coverage had increased substantially and the mortality-based O-CSDI rose to 0.690. The Delta wave (P5) occurred under advanced vaccination coverage and yielded a mortality-based O-CSDI of 0.817. The booster campaign preceded the peak decoupling values observed during P6b. Successive SARS-CoV-2 variants exhibited distinct clinical presentations and severity profiles that contributed to observed decoupling patterns [25]. Different variants generated distinguishable features related to positivity and severity; ageusia and anosmia were associated with positivity during ancestral, Gamma, and Delta waves but not during Omicron phases, reflecting changes in viral phenotype [25]. Dyspnoea remained the most consistent risk factor for severity across all waves, though its prognostic significance varied by variant context. The shift toward predominantly upper-respiratory symptoms during Omicron, accompanied by lower frequencies of dyspnoea, tachypnoea, cyanosis, and chest pain, is compatible with the lower hospitalization-to-case ratios observed during later phases. However, the present ecological analysis cannot determine the independent contribution of variant phenotype, vaccination, prior immunity, or changes in clinical and testing practices [25]. International evidence corroborates that Omicron variants caused generally less severe disease than earlier variants, particularly in healthy adult populations, largely due to increased population immunity [18,19]. However, breakthrough infections and reinfections with Omicron sublineages demonstrated partial escape from wild-type spike-based vaccine-elicited neutralizing antibodies, with enhanced immuno-evasive properties emerging over time [19]. Original messenger RNA booster doses substantially improved vaccine effectiveness against BA.2 symptomatic disease, yet protection waned within months of administration [19]. This waning is counterbalanced by retained CD8+ and CD4+ T-cell responses that cross-recognize Omicron sublineages, thereby preserving protection against severe outcomes [19]. This temporal parallel should be interpreted as supportive contextual evidence rather than causal attribution. These patterns are compatible with the combined influence of vaccination, prior infection-derived immunity, changing variant characteristics, improved clinical management, behavioural adaptation and changes in testing practices [18–20,24,25]. However, because our study is ecological and descriptive, the O-CSDI should not be interpreted as proving the causal effect of any single intervention. Rather, it captures the net population-level change in the conversion of reported confirmed cases into severe outcomes.

4.3. Age-Specific Vulnerability and the ≥ 80 -Year Group

The age-stratified CFR analysis showed substantial declines in case fatality across all older-adult age groups, while the greatest absolute residual mortality burden remained in the ≥ 80 -year group. The reduction from 32.39% in P1a to 3.79% in P6b represents an approximately tenfold improvement, but it also underlines the sustained biological and clinical vulnerability of the oldest adults to SARS-CoV-2, including the effects of frailty,

comorbidity, immunosenescence and long-term care exposure [26–28]. The continued CFR gradient in P6b (0.40% for 60–69 years, 1.07% for 70–79 years and 3.79% for ≥ 80 years) demonstrates that even under conditions of high decoupling, age-stratified surveillance remains essential [26–28]. Immunosenescence in older adults represents a fundamental biological determinant of COVID-19 vulnerability that persists despite vaccination and prior infection [19,26]. Advanced age is associated with declining T-cell function, impaired pathogen recognition, and reduced vaccine-induced antibody responses [19,26]. International evidence has shown that older age and comorbidity remained important determinants of severe outcomes during Omicron-dominant periods [23,27]. This underscores how multimorbidity amplifies age-related risk beyond what age alone predicts [27]. Moreover, case fatality rates demonstrate striking age-dependent gradients even during high-immunity phases. Meta-analytic evidence from invasive mechanical ventilation outcomes shows substantially higher fatality rates among older mechanically ventilated patients, reflecting both greater disease severity and reduced recovery potential in patients of advanced age [28]. Long-term care facility residents represent a particularly vulnerable subpopulation within the ≥ 80 -year group, facing both higher attack rates and mortality due to congregate living and elevated comorbidity burden [26]. The O-CSDI framework, calibrated to older-adult outcomes, is therefore particularly suited to monitoring residual severity after the transition toward endemic management, particularly when disaggregated by living situation and comorbidity profile [23,26–28].

4.4. Regional Heterogeneity and Implications

The large inter-regional variation in the mortality-based O-CSDI during P6b, from 0.558 in Melilla to 0.951 in La Rioja, suggests potential implications for surveillance prioritization and hypothesis generation. Aggregate national indices may mask subnational populations still carrying a disproportionate severity burden. This finding is consistent with previous evidence that COVID-19 mortality and case fatality patterns vary geographically and are shaped by demographic structure, healthcare capacity and socioeconomic context [23,27,28]. Regional differences in descriptive O-CSDI point estimates may be associated with multiple interacting demographic, healthcare, surveillance, and epidemiological factors [23,27,28]. Omicron spread rapidly once introduced to a region, becoming dominant in less than one month after detection in Italy, with doubling times of 2.7–3.3 days and estimated mean net reproduction numbers rising from 1.15 to a maximum of 1.83 for symptomatic cases [28]. During this expansion, however, clinical severity indicators were attenuated compared with previous waves, reinforcing the distinction between transmission intensity and severe outcome burden [19,24,28]. Regional differences may also reflect demographic shifts; the median age and age distribution of cases during Omicron spread varied according to regional demographics and immunity status [27]. Healthcare system capacity, particularly intensive care availability and staffing, varies substantially across territories and may explain some regional variation in mortality-to-hospitalization conversions independent of case incidence [23]. Territorial units with low decoupling values warrant closer examination of healthcare access, vaccination coverage in the oldest cohorts, testing intensity and residual vulnerability in long-term care or socioeconomically disadvantaged populations [20,23,26]. The O-CSDI could function as a sentinel metric within regional epidemiological monitoring systems, triggering enhanced surveillance when the index falls below predefined descriptive thresholds. This study offers a reproducible ecological framework for describing how the relationship between reported COVID-19 incidence and severe outcomes changed over time in older adults. The O-CSDI may be useful for retrospective assessment and comparative surveillance, particularly in ageing populations [20,23,26].

4.5. Strengths and Limitations of Our Study

This study has several strengths. It integrates four open-access surveillance sources, applies a transparent phase-based framework, focuses on the older-adult strata at highest risk of severe COVID-19 outcomes and proposes a reproducible index that can be recalculated in other settings. The use of phase-level aggregated ratios reduces instability from isolated weekly fluctuations and allows direct comparison across epidemic periods with comparable event counts. Several limitations must also be considered. First, the analysis is ecological and cannot estimate individual-level risk or establish causality. Second, confirmed cases were strongly influenced by changing testing capacity, diagnostic criteria and reporting policies, especially during the first waves and around the transition to reduced surveillance in March 2022. Because confirmed cases are surveillance-dependent observations rather than all SARS-CoV-2 infections, changes in testing eligibility, diagnostic intensity, case ascertainment, self-testing and reporting practices may mechanically alter the death-to-case ratio, and therefore the O-CSDI, independently of changes in underlying biological severity. The construct validity of the O-CSDI should therefore be considered moderate, and the index should be interpreted as a descriptive surveillance indicator rather than as a direct estimate of infection fatality or intrinsic viral severity. Third, hospital and ICU indicators were not equally complete at all levels of disaggregation, so ratio-based analyses were restricted to phases and strata with comparable numerators and denominators. Fourth, P7a and P7b were retained for contextual vaccination and mortality information but excluded from incidence- and ratio-based O-CSDI calculations because individual open-access event counts were no longer comparable after the surveillance transition. Thus, although the integrated dataset covered January 2020 to July 2023, the primary incidence- and ratio-based O-CSDI analyses were restricted to March 2020–March 2022. Fifth, very high Omicron case counts may include retrospective consolidation and should be interpreted cautiously. Sixth, a further limitation is the absence of explicit temporal alignment between diagnosis and subsequent severe outcomes. No explicit onset-to-event lag adjustment was applied because the public datasets did not provide linkable trajectories connecting diagnosis with subsequent hospitalization, ICU admission or death. Although phase-level aggregation may reduce the influence of short reporting delays, it does not fully resolve temporal misalignment or ensure that hospitalizations, ICU admissions or deaths are assigned to the phase in which the corresponding diagnoses occurred. This may bias case-to-outcome ratios, particularly around epidemiological phase boundaries. A uniform lagged data-quality and denominator-eligibility rules could not be implemented across all territories, age strata and endpoints because complete and consistently disaggregated weekly series were unavailable. Seventh, O-CSDI values were presented as descriptive point estimates without confidence intervals, bootstrap intervals or formal propagation of measurement uncertainty. Standard count-based intervals would not capture the dominant non-random uncertainty generated by under-ascertainment, changing surveillance practices and differences in source completeness. Territorial comparisons should therefore be interpreted as exploratory descriptive signals rather than inferential tests or formal rankings. Finally, results for Ceuta and Melilla may be unstable because of small denominators and should be interpreted as descriptive signals rather than definitive regional rankings. The same caution applies to narrow age-by-phase strata and to apparent differences between autonomous communities.

5. Conclusions

The O-CSDI provides a reproducible, phase-sensitive, and multidimensional tool for quantifying the progressive dissociation between COVID-19 case incidence and clinical severity in older adults. The integrated dataset comprised 3496 territorial unit-week

observations across Spain; however, the primary ratio-based O-CSDI analysis was restricted to the comparable March 2020–March 2022 period. Within this analytical period, the index showed a descriptive decoupling trajectory in the mortality-based O-CSDI, from 0.382 in P3b to 0.920 in P6b, and in the hospitalization-based O-CSDI, from 0.361 to 0.887, during the phases with comparable event counts. These patterns are compatible with the combined influence of vaccination, prior immunity, changing variant characteristics, improved clinical management and evolving testing practices, but they should not be interpreted as causal proof of any single mechanism. Age-specific CFR analysis confirmed that the ≥ 80 -year group, despite a tenfold reduction in CFR from the first wave to the Omicron BA.1/BA.2 period, retained the highest absolute mortality risk throughout the study period. This finding underscores the need for sustained age-stratified surveillance and targeted public health measures in ageing populations. Descriptive mortality-based O-CSDI point estimates during P6b ranged from 0.558 to 0.951 across Spanish territorial units, suggesting possible regional heterogeneity. However, the contributions of small denominators, random variation, surveillance completeness, and true epidemiological differences could not be separated. As a descriptive ecological indicator, the O-CSDI framework is designed to be transportable to other national and regional settings and applicable to future pandemic scenarios, provided that comparable case, hospitalization, ICU and mortality data are available. It may support standardized retrospective evaluation, regional comparison and preparedness assessment, while complementing rather than replacing individual-level epidemiological analyses.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/covid6080131/s1>, Supplementary Dataset S1, harmonized weekly surveillance dataset used as the analytical basis, preserving the source-specific and integration-stage phase labels; Supplementary Table S1, core analytical variable dictionary and harmonization guide for the O-CSDI analysis; Supplementary File S1, Python scripts used to recode analytical phases and calculate derived ratios and O-CSDI metrics.

Author Contributions: Conceptualization, methodology, validation, formal analysis, investigation, data curation, visualization, and supervision, E.M.-G., C.I.S.-L., M.A.D.-A. and J.M.S.; writing—original draft preparation, E.M.-G., C.I.S.-L. and J.M.S.; writing—review and editing, M.A.D.-A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable. This study analysed aggregated, publicly available epidemiological surveillance data without individual-level data, case identifiers, or personally identifiable information. Analysis of public health surveillance data for epidemiological research is exempt from institutional review board approval in Spain.

Informed Consent Statement: Not applicable.

Data Availability Statement: The harmonized weekly surveillance dataset generated for this study is provided as Supplementary Dataset S1. The core analytical variable dictionary and harmonization guide are provided as Supplementary Table S1. The Python scripts used to recode the analytical phases, calculate derived ratios and compute O-CSDI metrics are provided as Supplementary File S1. Original public data sources are available from ISCIII-RENAVE, Datadista/Ministerio de Sanidad, Our World in Data and the MoMo system.

Acknowledgments: The authors acknowledge the Instituto de Salud Carlos III, the Spanish Ministry of Health, Datadista, Our World in Data and the MoMo system for maintaining publicly accessible COVID-19 surveillance data throughout the pandemic.

Conflicts of Interest: The authors declare no conflicts of interest. No pharmaceutical companies, vaccine manufacturers, diagnostic companies, or other commercial entities providing COVID-19 products or services had any role in the study design, data analysis, or manuscript preparation.

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