DIGITAL-2023-CLOUD-AI-04-ICU-DATA

INDICATE

Deliverable D6.3

MVP Quality Benchmarking

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Cover Page

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1.0	22-05-2026	Gregor Lichtner	Incorporate reviewer feedback

[1]PU = Public; SEN = Sensitive, limited under the conditions of the Grant Agreement; CO = Confidential, only for members of the Consortium.
[2]R= Document/Report; DEC = Website; DEM = demonstrator; DATA = federated datasets

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1 Introduction

Deliverable D6.3, “Minimal viable product (MVP) Quality Benchmarking”, documents the MVP implementation of the **quality benchmarking dashboard for intensive care medicine**. The deliverable is part of Work Package 6 and contributes to the clinical demonstration activities of the INDICATE project by translating the project’s federated data infrastructure into a concrete use case for multicentre care quality benchmarking.

The overall aim of the MVP is to enable participating intensive care units (ICUs) to calculate predefined clinical quality indicators in a standardized manner, submit aggregated, non-identifiable results to the INDICATE Hub, and compare their local performance on these quality indicators with European benchmark data from other participating ICUs. The system follows a federated approach: clinical data remain at the data provider site, individual quality indicators are computed locally, and only aggregated, non-identifiable outputs are exchanged.

1.1 Background and purpose

Quality indicators are widely used to assess and improve the quality of care in intensive care medicine [1]. They can support internal quality management, enable comparisons between institutions, and help identify areas where care processes may be improved. However, quality indicator implementation is often limited by heterogeneous interpretation of narrative indicator definitions, differences in local data availability and coding practices, and the continued reliance on manual or semi-manual data collection [2].

The quality benchmarking use case is designed to address these limitations by combining three elements: harmonized local data representation using the OMOP Common Data Model (CDM), comprehensive machine-interpretable quality indicator definitions using Clinical Quality Language (CQL), and the use of the INDICATE federated technical infrastructure for exchange of aggregated benchmarking results.

This approach supports a uniform and transparent operationalization of intensive quality indicators across sites and reduces ambiguity in local interpretation. The distributed analysis architecture allows participating institutions to execute the indicator logic locally and share only aggregated, non-identifiable results for cross-site comparison. Overall, the project provides the methodological foundation for reproducible, scalable, and privacy-preserving calculation of intensive care quality indicators across European hospitals within the INDICATE project.

1.2 Scope of the MVP

The MVP comprises the components required to perform a federated benchmarking workflow for participating ICUs. At the data-provider site, this includes access to a local OMOP CDM database, local execution of the CQL-based quality indicator definitions, local storage of detailed patient-level indicator results and aggregated ICU-level benchmarking output, a data-exchange component for manual review and submission of aggregated results prior to transmission, and a local dashboard component for displaying benchmarking outputs. The INDICATE Hub provides the service and database components required to receive, store, and distribute aggregated, non-identifiable benchmark data from participating sites.

The MVP focuses on a predefined set of nine intensive care quality indicators across ventilation, weaning, feeding, glucose control, thromboembolic prevention, infection rate, pain/sedation/delirium, advance care planning, and mobilization. Together, these indicators cover central aspects of ICU care processes and provide the basis for the first version of the benchmarking dashboard within INDICATE.

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2 Quality Benchmarking System

2.1 Overview

The Quality Benchmarking System is the primary output of Deliverable D6.3. It provides an MVP implementation of a federated benchmarking workflow in which participating intensive care units calculate predefined quality indicators locally, submit aggregated and non-identifiable results to the INDICATE Hub, and use a dashboard to compare their local results with benchmark data from other participating sites (Figure 1).

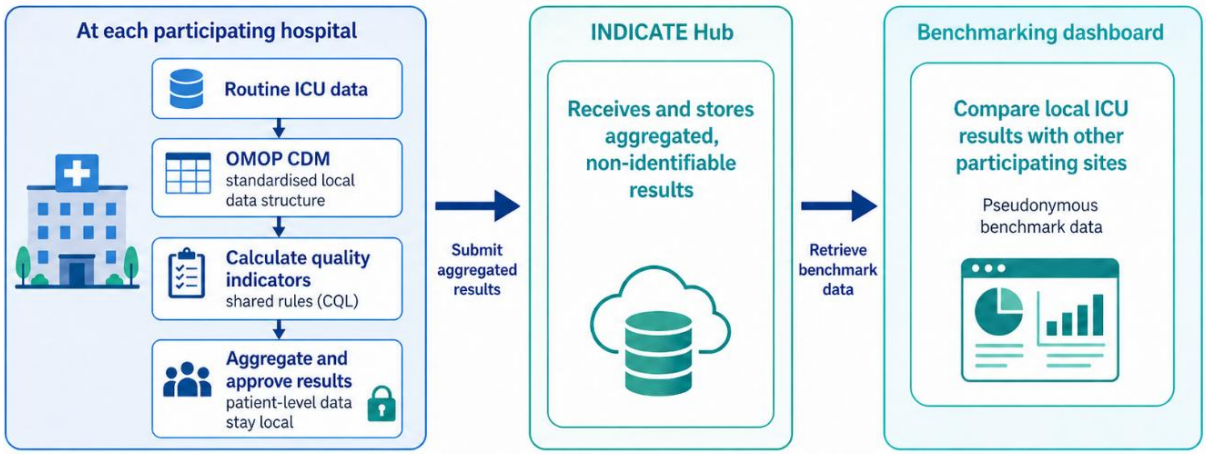

Figure 1: Overview of the Quality Benchmarking System. *At each participating hospital, routine ICU data are locally transformed to the standardized OMOP Common Data Model and used to calculate quality indicators as part of a continuous benchmarking process. After provider-side review and explicit approval through the local submission interface, aggregated, non-identifiable results are submitted to the INDICATE Hub. These results can be retrieved via the benchmarking dashboard to enable ongoing comparison with pseudonymous results from other participating sites.*

At each participating hospital, the starting point is the **local patient database**. This database contains routine ICU data that have been transformed into the OMOP Common Data Model according to the INDICATE Data Dictionary.

The **quality indicators** are formalized in Clinical Quality Language (CQL), a domain-specific programming language for expressing clinical logic, such as eligibility criteria, calculation rules, time windows, and exclusions [3]. Here, we have used CQL to translate the clinical quality indicator (QI) definitions into executable rules that can be applied consistently across hospitals. The CQL definitions are executed locally at the data providers using the CQLonOMOP software, developed independently of INDICATE [4]. For each eligible patient, time interval, and quality indicator, CQLonOMOP calculates detailed local results, which are stored locally at the data provider site and are not shared centrally.

For benchmarking, **local results are aggregated across patients and reporting periods**, such as days, weeks, or months. These aggregated values form the dataset that may be shared with the INDICATE Hub. Before upload, configurable **privacy thresholds** are checked, such as a minimum number of eligible patients per QI and time frame. The threshold is applied separately for each QI and aggregation level. Therefore, if the threshold is not met for a weekly interval, the corresponding weekly result is not eligible for submission or display, while the same data may still contribute to monthly or yearly aggregates if the threshold is reached at those levels. Only aggregated results that pass the applicable threshold are eligible for upload, and transfer requires

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explicit **provider-side review and approval** through the local submission interface. Further automation of this approval step may be considered in later project phases, depending on governance requirements and local policies of participating institutions.

Approved aggregated results are then transferred to the **INDICATE Hub** together with a **pseudonymous provider** identifier. This pseudonym is generated and known only by the data provider itself. The mapping between the real institutional identity and the pseudonymous identifier is not stored centrally and is not known to other data providers. The Hub therefore receives, stores, and distributes aggregated benchmarking data without identifying the contributing institutions.

The **dashboard application** retrieves aggregated results from the INDICATE Hub for all participating data providers (Figure 2). At the benchmarking level, results are only shared by the INDICATE Hub if at least three data providers contribute data for the same QI and time frame. The dashboard then presents these results as a pseudonymous comparison across providers, for example by ordering the provider-specific QI values from lowest to highest. Each provider can identify its own result because it knows its own pseudonym, but it cannot identify the other providers. This allows the local ICU to see where its result lies in relation to the other participating sites, while preserving local control over patient data and institutional confidentiality.

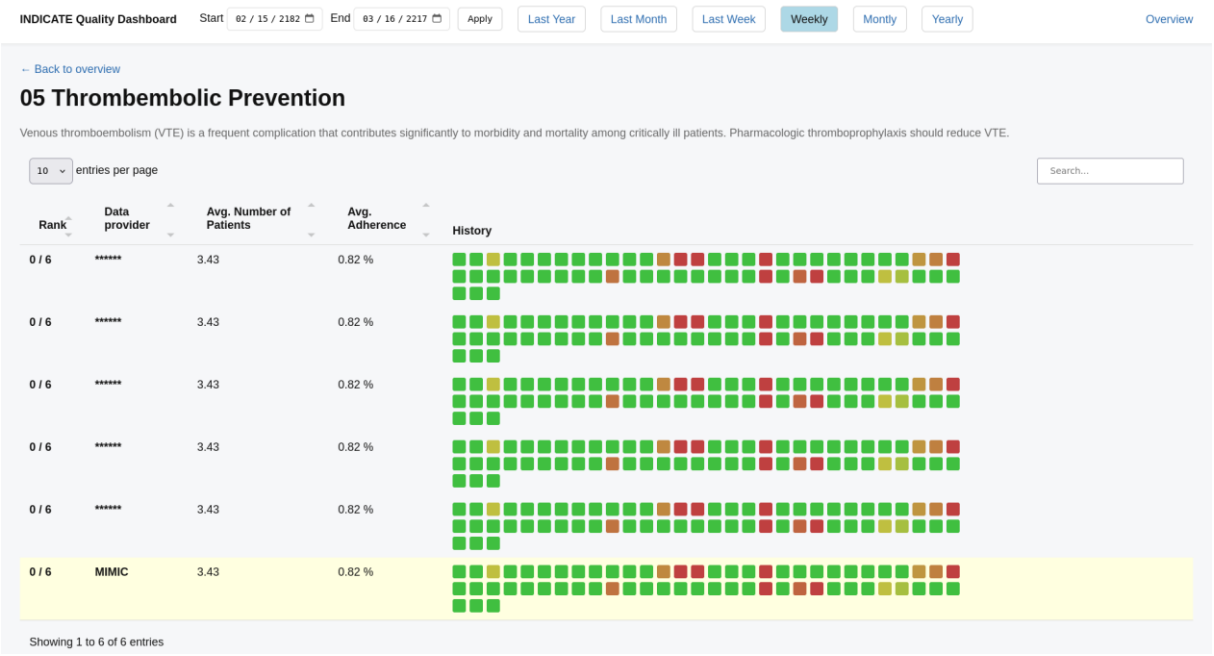

Figure 2: Quality Benchmarking Dashboard. *The dashboard displays pseudonymous provider-level benchmark results for the selected quality indicator and reporting period. The local provider is highlighted and can identify its own result, while other providers remain pseudonymous. The table shows rank, average number of eligible patients, average adherence, and a time-resolved history of indicator values for the thromboembolic prevention quality indicator. In the history column, each colored square represents one aggregation interval according to the selected aggregation level; for example, when weekly aggregation is selected, each square represents one week. The color encodes the adherence or rate for the respective provider and indicator in that interval, providing a compact visual summary of temporal variation across providers. As no real multi-provider benchmark dataset was available at the time of MVP documentation, the figure uses duplicated illustrative data for several pseudonymous providers. The figure therefore demonstrates the dashboard layout and intended comparison functionality, but not the full visual interpretability of a multi-provider benchmark.*

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2.2 Intended users and usage scenario

The intended users of the MVP quality benchmarking system are the participating INDICATE data providers, including local implementation teams, ICU clinicians and quality management staff involved in intensive care quality assessment.

The primary **operational users** are local data provider teams responsible for preparing OMOP-mapped data, configuring the local deployment, executing QI calculations, and submitting results to the INDICATE Hub. They require technical documentation and support for the client application setup, database connectivity, CQL execution, data submission, and dashboard deployment.

The primary **clinical users** are ICU professionals and quality managers who use the dashboard to interpret quality indicator results. For these users, the system is intended to present benchmarking outputs in an understandable and clinically meaningful way. The dashboard allows them to view local indicator performance over selected reporting periods and compare it with benchmark data derived from other participating sites. This supports local quality assessment and can help identify areas where clinical processes may warrant further review.

A **typical usage scenario** is as follows. A participating hospital prepares the required routine intensive care data in a local OMOP CDM database. The local CQLonOMOP component periodically evaluates the predefined quality indicators on the local data. The resulting patient-level and time-interval-level results remain at the institution and are aggregated locally. Authorized personnel review the aggregated results and approve submission. The local data-exchange component then sends the approved aggregated, non-identifiable results to the INDICATE Hub. When the local dashboard is opened, it retrieves aggregated benchmark data from the Hub and displays the local site's results in comparison with the pseudonymized results of other participating providers.

2.3 Relationship to Deliverable D4.2

The quality benchmarking system builds on D4.2, which provides the INDICATE Hub structure in the Azure-based project environment. In D6.3, this Hub infrastructure is used as the central component for exchanging aggregated benchmarking results between participating data providers.

The D4.2 Hub provides the shared infrastructure layer for the central data-exchange service and the storage of aggregated, non-identifiable quality indicator results. It supports the core functions required by the benchmarking use case: authenticated and encrypted communication with data-provider components, reception of approved aggregated results, central persistence of benchmark data, and distribution of aggregated results back to participating providers for dashboard visualization.

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3 Quality Indicators Methodology

The MVP quality benchmarking system uses a predefined set of intensive care quality indicators that are implemented in a standardized and machine-interpretable manner. The quality indicators were identified through a literature review of commonly used quality indicators in European intensive care and selected by a team of intensive care physicians to cover a broad range of clinical scenarios.

The indicators are defined at two complementary levels. First, clinicians have created human-readable quality indicator definitions that specify the clinical rationale, target population, numerator, denominator, exclusions, expected value, and guidance. These are accessible in the `indicate-qi-definitions` GitHub repository[1]. Second, based on the human-readable specification, medical computer scientists have operationalized the quality indicator logic in Clinical Quality Language (CQL)[2]. These computer-executable quality indicators can be executed on the patient data locally at the individual data providers using the CQLonOMOP component, developed independently of the INDICATE project by our team [4].

3.1 Implemented quality indicators

The MVP implements nine quality indicators covering processes and outcomes of intensive care medicine. Most indicators are process indicators expressed as ratios, where higher values indicate better fulfilment. The infection-rate indicator (QI 6) is an outcome indicator expressed as an incidence, where lower values indicate better performance, The unit of analysis is indicator-specific. For most indicators, results are computed for complete 24-hour periods defined from start of the morning shift (default 06:00) to end of night shift (default 05:59) of the following day. Some indicators additionally use 8-hour shift-based subintervals within the 24-hour period. The following table gives an overview of the quality indicators:

No.	Quality indicator	Clinical focus	Unit of analysis	Expected direction
1	Lung-protective ventilation in ARDS	Protective ventilation settings in intubated mechanically ventilated ARDS patients	24-hour ventilation period	Higher is better
2	Weaning from mechanical ventilation	Daily spontaneous breathing trial or equivalent progression toward liberation from ventilation	24-hour ventilation period	Higher is better
3	Early enteral nutrition and calorie target met	Adequate calorie intake relative to individualized daily calorie target	24-hour ICU day	Higher is better
4	Maintaining appropriate glucose levels	Regular glucose monitoring and successful response to deranged glucose values	8-hour shift	Higher is better

[1] https://github.com/umg-minai/indicate-qi-definitions
[2] https://github.com/umg-minai/cql-indicate-qi

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5	Prevention of venous thromboembolism	Pharmacologic thromboprophylaxis during ICU stay	24-hour ICU day	Higher is better
6	Infection rate: pneumonia and catheter-related infections	Ventilator-associated pneumonia and catheter-related bloodstream infection	Incidence per 1,000 device days	Lower is better
7	Pain, sedation and delirium	Regular assessment of pain, sedation, and delirium	8-hour shift	Higher is better
8	Advance care plan	Documentation of advance care planning and decision authority	ICU stay / patient	Higher is better
9	Early mobilisation	Daily mobilisation during daytime ICU care	ICU day, 06:00–22:00	Higher is better

The definitions used in the MVP are summarized in the following table. Note that the source of truth for the human-readable quality indicator definitions is the version-controlled `indicate-qi-definitions` repository.

Indicator	Definition used for benchmarking
QI 1: Lung-protective ventilation in ARDS	The initial population includes adult ICU patients who are intubated, mechanically ventilated in a volume-driven or pressure-driven ventilation mode, and diagnosed with ARDS during the observation period. ARDS severity is derived from the PaO_2/FiO_2 ratio and PEEP. For each observation, the indicator is fulfilled if all lung-protective criteria are met: PEEP is at least the recommended value according to the simplified ARDSnet PEEP table, tidal volume is between 4 and 8 mL/kg ideal body weight, plateau pressure is ≤30 cmH_2O, and driving pressure is ≤14 cmH_2O. In pressure-controlled ventilation, inspiratory pressure may be used as a substitute if plateau pressure is not recorded. (GitHub)
QI 2: Weaning from mechanical ventilation	The initial population includes adult ICU patients who are intubated and mechanically ventilated for at least 48 hours. The denominator consists of complete 24-hour periods starting after the first 24 hours of mechanical ventilation; incomplete final periods are excluded. The numerator is fulfilled if, within the respective 24-hour period, there is a documented spontaneous breathing trial, extubation, or absence of mechanical ventilation for at least five minutes. (GitHub)
QI 3: Early enteral nutrition and calorie target met	The initial population includes adult ICU patients during the observation period. The indicator evaluates whether calorie intake in each complete clinical day (defined from start of morning shift to end of night shift; configurable), starting from the

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	second complete day, is within ±10% of the individualized daily calorie target. The calorie target is based on available energy-requirement documentation, carbon dioxide production, or weight-/BMI-based formulas and is adjusted using insulin requirements and phosphate measurements. Periods with contraindication to enteral feeding and incomplete first or last periods are excluded. (GitHub)
QI 4: Maintaining appropriate glucose levels	The initial population includes adult ICU patients during the observation period. The indicator is evaluated for complete 8-hour shifts. Glucose control is successful if at least one glucose measurement is available in the shift, measurements are performed regularly with no interval exceeding 10 hours except for the first measurement, and all glucose values are either within the acceptable range of 3.3–10.0 mmol/L or followed within two hours by a control measurement showing normalization or at least 20% movement toward the acceptable range. (GitHub)
QI 5: Prevention of venous thromboembolism	The initial population includes adult ICU patients during the observation period. For each complete 24-hour period starting 24 hours after ICU admission, the numerator is fulfilled if at least one pharmacologic anticoagulant from the predefined anticoagulant concept sets is administered. The first 24 hours and incomplete final 24-hour periods are excluded. (GitHub)
QI 6: Infection rate: pneumonia and catheter-related infections	The initial population includes adult ICU patients with an ICU stay longer than 24 hours. The indicator combines the incidence of ventilator-associated pneumonia and catheter-related bloodstream infection. Ventilator-associated pneumonia is counted per 1,000 invasive-ventilation days, and catheter-related bloodstream infections are counted per 1,000 central-venous-catheter days. The combined infection-rate endpoint is the sum of both incidence rates. A lower incidence indicates better performance. (GitHub)
QI 7: Pain, sedation and delirium	The initial population includes adult ICU patients during the observation period. The indicator is evaluated for complete 8-hour shifts. A shift is fulfilled if pain, sedation, and delirium assessments are all documented at least once and are performed regularly, with no interval exceeding 10 hours except for the first assessment. Accepted instruments include, among others, BPS/NRS/VAS for pain, RASS/Ramsay for sedation, and CAM-ICU, 3D-CAM, 4AT, DOS, DRS, Nu-DESC, DDS, or ICDSC for delirium. The indicator evaluates whether the assessments were performed, not the clinical score values themselves. (GitHub)
QI 8: Advance care plan	The initial population includes adult ICU patients who have been on the ICU for more than 72 hours. The numerator is fulfilled if, at least once during the first 72 hours, an advance care plan is

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	agreed, consultation with the patient is documented, and decision authority is documented. (GitHub)
QI 9: Early mobilisation	The initial population includes adult ICU patients with an ICU stay of at least 48 hours. The denominator consists of daytime periods from 06:00 to 22:00, excluding incomplete periods and periods with an explicit order not to mobilize. The numerator is fulfilled if mobilisation is documented at least once during the daytime period. (GitHub)

3.2 Data definitions and calculation logic

The quality indicators are calculated directly from OMOP CDM data. The required data elements vary by indicator and include demographic data, ICU stay information, diagnoses, procedures, observations, measurements, device-related information, and medication data. Only the data elements required for the selected quality indicators are used by the CQLonOMOP engine. For a list of concepts used see the INDICATE Data Dictionary (project: Quality Benchmarking Dashboard)[3] or the Data Provider Information document.

The primary analysis consists of local execution of the standardized QI definitions and derivation of aggregated site-level results for benchmarking. Detailed results are first computed at patient and time-interval level. Specifically, one numeric value per quality indicator, eligible patient, and day is calculated. The numeric value is between 0-100% for most indicators, indicating the fulfilment of that indicator, but may have a different interpretation depending on the indicator (e.g. infections per 1,000 device days). These patient-level quality indicators are then aggregated locally across patients and across longer reporting periods such as days, weeks, or months, depending on the reporting configuration.

[3] https://indicate-eu.github.io/data-dictionary/#/projects?id=5&tab=variables

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4 Technical Architecture and Data Flow

The Quality Benchmarking System follows a federated architecture in which routine clinical data never leave the participating hospitals. The system is designed to enable cross-site benchmarking without transferring patient-level data to a central repository. Instead, each data provider prepares the required intensive care data locally, executes the standardized quality indicator logic within its own environment, reviews the resulting aggregated outputs, and submits only approved, aggregated and non-identifiable benchmarking data to the central INDICATE Hub.

4.1 Overall architecture

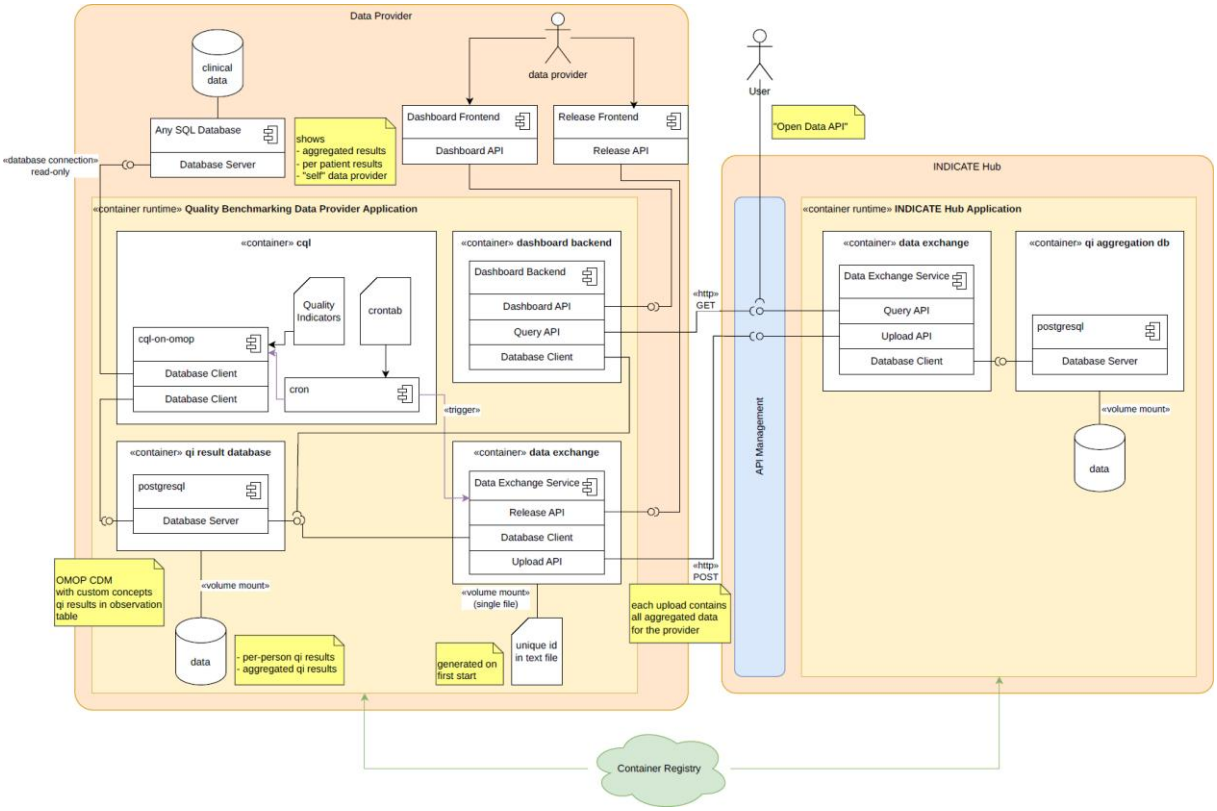

Figure 3: Federated benchmarking architecture. *At each data provider, routine clinical data are held locally in an OMOP CDM database. The data provider components (left) execute CQL-based quality indicator logic using the CQLonOMOP engine, store patient-level and aggregated indicator results in a local result database, and provide local dashboard and data release interfaces. Approved aggregated results are submitted through the local data exchange service to the central INDICATE Hub via secured APIs. The Hub receives uploads and the INDICATE Hub components store aggregated QI results in a central PostgreSQL database, and expose them for querying by authorised dashboard users. Patient-level data remain within the data provider environment; only approved aggregated results are transferred centrally. Containerized components are deployed from the shared container registry.*

Figure 3 illustrates the technical architecture for the quality benchmarking dashboard use case. Crucially, the architecture consists of two separate domains which are connected by a communication channel: on the left-hand side the data provider (of which there are multiple despite the diagram depicting only one example) and on the right-hand side the INDICATE Hub. The domains perform different tasks, are the responsibilities of different stakeholders and contain different technical components.

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The **data provider** makes available clinical data in the form of an OMOP CDM v5.4-formatted database (top left). This database is not part of the software or infrastructure provided by INDICATE. The remainder of the components hosted by each data provider are the following containers:

1. **cql:** A CQL engine which periodically reads clinical data from the database, evaluates the quality indicators and writes patient-level results into a separate result database.
2. **qi result database:** A database for detailed as well as aggregated quality indicator results specific to the data provider.
3. **data exchange + release frontend**: A service for reviewing and submitting aggregated quality indicator result data to the INDICATE Hub.
4. **dashboard backend + dashboard frontend:** A dashboard service for receiving aggregated result data for all data providers from the INDICATE Hub and displaying the actual quality benchmarking dashboard as a web-application.

The **INDICATE Hub** (of which there is only one, central instance) is operated by the INDICATE project (Deliverable D4.2) and consists of two components:

1. **data exchange**: A service for receiving and distributing aggregated, non-identifiable quality indicator results.
2. **qi aggregation db:** A database for aggregated, non-identifiable quality indicator results of all data providers.

The INDICATE Hub is hosted in an Azure-based environment which handles naming, authentication, observability, encryption/secure transmission, accountability and similar aspects for the data exchange service (API Management in the diagram).

4.2 Data submission mechanisms

Submission of the aggregated quality indicator results to the central INDICATE hub is based on local generation and controlled release of aggregated benchmarking results. The system is designed so that data providers can review the aggregated outputs before submission Figure 3). No patient-level data are submitted to the central infrastructure (Figure 4). Authorized personnel at the data-provider site inspect the aggregated quality indicator results and approve their submission to the INDICATE Hub. This manual approval step ensures that the participating institution remains in control of which aggregated data are released.

In the MVP, the approval step is implemented as a provider-side release decision for already aggregated QI results. It is not intended to replace local data quality management or to provide central semantic validation of the clinical plausibility of the submitted values. Content-level assessment of whether results should be released, for example because local source data are incomplete, implausible, or affected by mapping problems, remains the responsibility of the participating data provider. If such issues are identified during local review, the provider can withhold approval, correct the underlying local data or mapping where appropriate, rerun the calculation, and only then submit updated aggregated results.

The MVP provides the technical mechanism for provider-side review and approval before submission, but it does not prescribe a fixed weekly clinical review cadence or a permanent requirement for weekly clinician approval. The operational frequency of review and submission, as well as the assignment of responsible local roles, remains subject to data providers. Further automation of this approval step may be considered in later project phases, depending on governance requirements and local policies of participating institutions.

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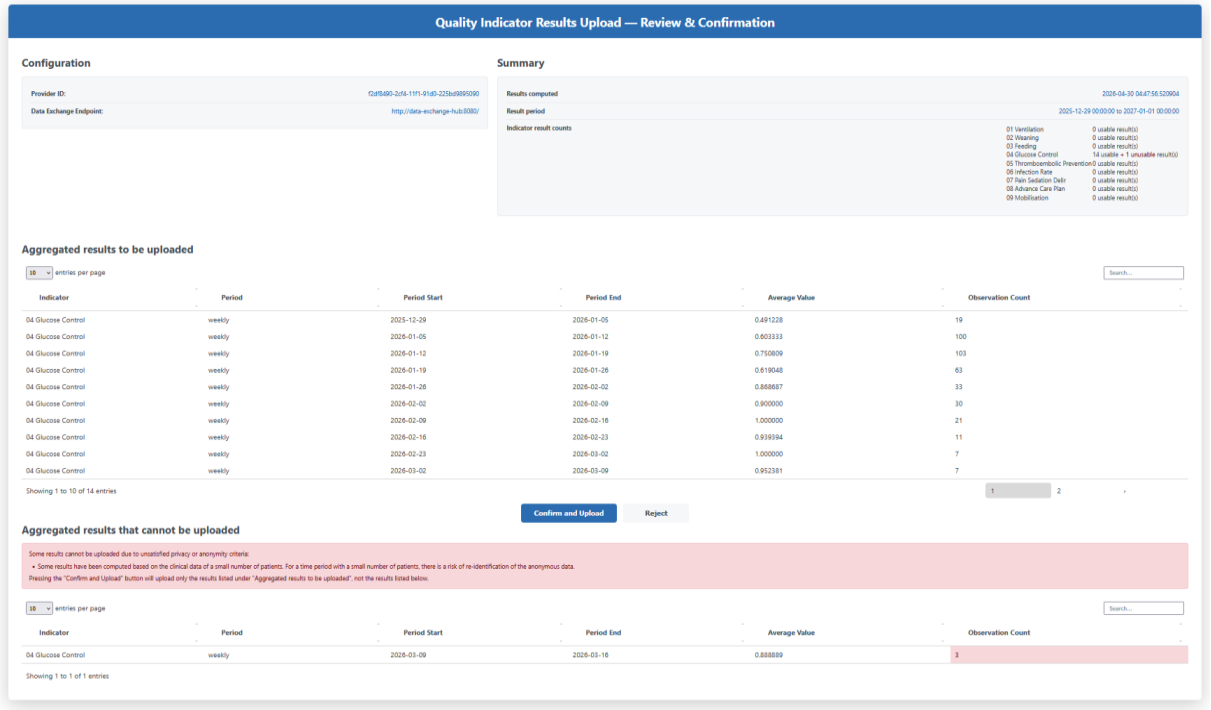

Figure 4: Local review and approval dashboard for result upload at the data provider site. *The dashboard is used by the participating data provider to review aggregated quality indicator results before submission to the INDICATE Hub. It displays configuration details (provider ID and data exchange endpoint), a summary of the computation and reporting period, counts of usable and unusable results per indicator, and a tabular overview of the aggregated results to be uploaded. Based on this review, the user can either confirm and upload the results or reject the upload.*

4.3 Access, enrollment, and privacy safeguards

The quality benchmarking system is designed as a restricted-access system for enrolled INDICATE data providers. Access to the central INDICATE Hub is limited to authorized provider-side software components, while access to the local dashboard is controlled by the respective participating institution according to its local policies and technical environment. Data providers are enrolled by setting up the required local OMOP CDM v5.4 database, deploying the local benchmarking components, configuring secure communication with the Azure-based INDICATE Hub, and testing local QI execution, aggregation, review, submission, and dashboard retrieval.

Access instructions are provided to enrolled data providers as part of the technical documentation. In brief, providers access the system by configuring and starting the local software components in their own infrastructure, registering the required certificate for authenticated communication with the INDICATE Hub, and verifying successful QI execution and data exchange. The local dashboard is then accessed through the locally deployed dashboard endpoint using a standard web browser. Access to this endpoint, including user authentication and network availability, is managed by the participating institution according to its local policies.

The system implements several privacy safeguards by design. Routine clinical data remain at the participating hospital and are neither transferred centrally nor stored in the provided use case components. Detailed patient-level and time-interval-level QI results are also stored only locally. For benchmarking, these results are aggregated across patients and reporting periods. Only aggregated results that pass a configurable minimum cell-size threshold, for example a minimum

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number of eligible patients per QI and time frame, are eligible for submission. In the MVP workflow, transfer additionally requires manual review and approval by authorized personnel.

Submitted results are linked to a locally generated pseudonymous provider identifier. The data provider knows its own pseudonym and can therefore recognize its own results in the dashboard. The INDICATE Hub and other data providers do not know the mapping between the pseudonym and the real institution. In addition, benchmark data are only shared by the Hub where a sufficient number of providers (i.e., 3) contribute data for the same QI and time frame, reducing the risk that individual institutional contributions can be inferred.

For API-based submission and retrieval, the authentication architecture is based on certificate-based OAuth 2.0 client authentication for non-interactive provider-side clients. Each provider generates a certificate locally, shares only the public certificate with INDICATE, and keeps the private key within its own environment. The architecture also includes mandatory provenance information, token validation at the Azure API Management layer, rate limiting, audit logging, and certificate lifecycle controls to support traceability and secure operation (see AP-AUTH-001_BenchmarkingAPI_AuthenticationProposal.docx and INDICATE_CertificateSetupGuide_DataProvider_v1.1.docx).

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5 User-Facing Functionality

5.1 Dashboard views and navigation

The user-facing component of the MVP quality benchmarking system is the benchmarking dashboard. Its primary view provides an overview of all implemented quality indicators for the selected reporting period (Figure 5). For each indicator, the overview table displays the number of contributing data providers, the average number of eligible patients, the average adherence or rate, the local provider's rank, and a time-resolved history of indicator values. This allows users to quickly identify indicators with relevant variation or potential need for local review.

At the top of the dashboard, users can define the observation period using start and end date fields or predefined shortcuts such as "Last Year", "Last Month", and "Last Week". Users can also select the aggregation level for the displayed results to weekly, monthly, or yearly aggregation. These controls allow the same benchmark data to be explored over different time horizons and levels of temporal granularity.

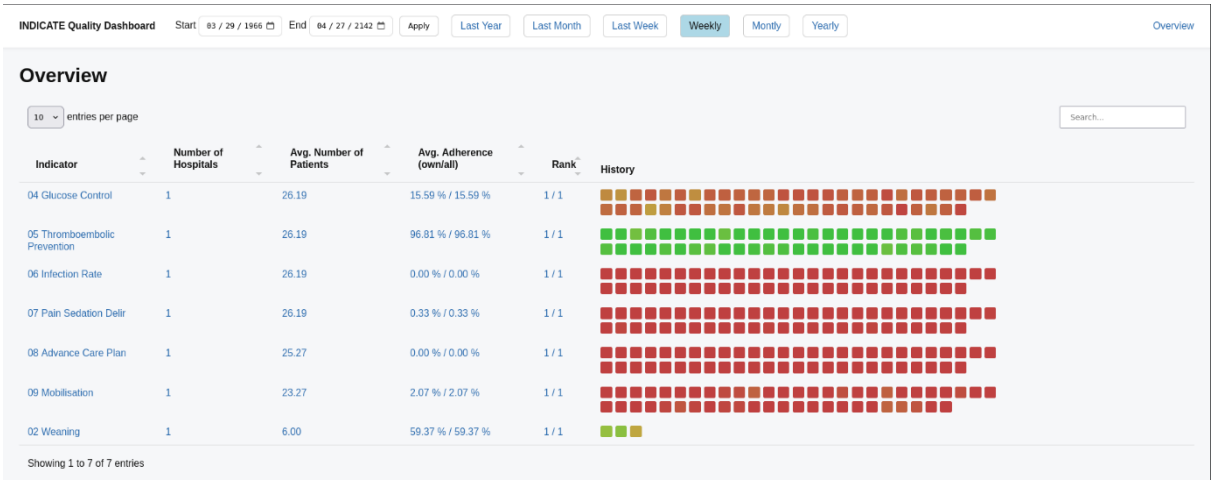

Figure 5: Dashboard overview of quality indicator results. *The primary dashboard view summarizes all implemented quality indicators for the selected observation period and aggregation level. For each indicator, the table shows the number of contributing providers, the average number of eligible patients, the average adherence or rate, the local provider's rank, and a time-resolved history of indicator values. In the history column, each colored square represents one aggregation interval within the selected observation period, allowing users to visually inspect temporal patterns, changes, or outlying intervals before opening the detailed indicator view.*

From the overview, users can navigate to an indicator-specific view by selecting a quality indicator. This detailed view displays pseudonymous provider-level benchmark results for the selected quality indicator and reporting period (Figure 2). The local provider is highlighted and can identify its own result, while all other providers remain pseudonymous. The table shows the provider-level rank, average number of eligible patients, average adherence, and a time-resolved history of indicator values. This enables participating ICUs to compare their own performance with the distribution of results from other participating providers while preserving provider confidentiality.

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5.2 Interpretation of benchmark results

The benchmarking dashboard is intended to support quality assessment and local quality improvement. The displayed results allow participating ICUs to compare their local quality indicator values with benchmark data from other participating sites. The benchmark should be interpreted as a structured comparison of standardized indicator outputs, not as a definitive ranking of clinical quality.

For most process indicators, higher values indicate better fulfilment of the indicator. Examples include the proportion of eligible ventilation observations meeting lung-protective criteria, the proportion of eligible weaning periods with spontaneous breathing trials or equivalent progression, or the proportion of 8-hour shifts with complete pain, sedation, and delirium assessment. For these indicators, values closer to the expected value indicate more complete adherence to the defined process. For the infection-rate indicator, lower values indicate better performance, because the outcome is expressed as incidence per 1,000 device days.

Benchmark results should be interpreted in light of several contextual factors:

Factor	Implication for interpretation
Case mix and clinical context	Differences in patient populations may influence indicator values even when care processes are similar.
Organisational structures and resource availability	Differences in staffing, equipment, local responsibilities, or institutional resources may influence indicator values independently of individual clinical decision-making.
Local workflows and implementation context	Variations in ICU workflows, documentation routines, and local implementation of care processes may affect measured indicator fulfilment.
Data availability and data quality	Missing or inconsistently mapped data may reduce apparent indicator fulfilment. Data quality issues within the source systems may remain.
Number of contributing providers	Benchmark stability increases as more providers contribute data.
Frequency of processing and transfer	Providers may differ in how often they update and submit results, affecting timeliness and completeness of benchmarks.

The dashboard should therefore be used as a screening and quality-management tool. Values that differ substantially from the benchmark should trigger local review, starting with data completeness, mapping quality, and only if that is ensured, consideration of organisational context, resource availability, local workflows, case mix, and clinical practice. Such differences should not automatically be interpreted as proof of superior or inferior care without further investigation.

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6 Participating Data Providers & Data

This section documents the current deployment status of the MVP quality benchmarking use case at the time of submission. It summarizes which parts of the federated workflow have been implemented and demonstrated, which data-provider-side components have been executed by participating institutions, and what evidence is available for the end-to-end workflow.

6.1 Current deployment status

At the time of submission, the MVP quality benchmarking system includes the local data-provider components, the central INDICATE Hub components, the underlying Azure infrastructure through which these central components are operated (based on deliverable D4.2), and the dashboard functionality required for the federated benchmarking workflow. The system is operational for enrolled data providers and supports computation of quality indicators, result aggregation, manual review of aggregated outputs, submission to the Hub, retrieval of benchmark data, and dashboard-based visualization.

The system has been tested by participating data providers at different levels of completeness. Three data providers have executed relevant local components of the benchmarking workflow in their own technical environments, including CQL-based QI evaluation, local storage of fine-grained adherence results, and preparation of aggregated results. In addition, one data provider provided end-to-end evidence for the local provider workflow, including video documentation of local component startup, the data submission review and approval interface, and the local dashboard application. Since only one provider dataset was available for dashboard demonstration at the time of submission, the dashboard could demonstrate local result visualization and data retrieval, but not yet a multi-provider ranking view.

The available video evidence comprises:

- Local startup of all technical components: [Video 1: Local component startup]
- Review & approval of aggregated results before submission: [Video 2: Review interface]
- Local dashboard application showing available results: [Video 3: Dashboard application]

6.2 Overview of contributing institutions

At the time of submission, the following data providers had participated in testing or demonstrating the MVP quality benchmarking workflow.

Provider	Country	Status	QIs covered	Data Period	Data Volume
Charité Berlin	Germany	Local execution	QI 1 (Ventilation) QI 4 (Glucose Control)	01/01/2019-30/04/2026 (minimal item set available & mapped to OMOP CDM)[4]	March 2026: 1617 ICU visits with 925441 rows of clinical data
UZ Gent	Belgium	Local execution	QI 4 (Glucose Control) QI 5 (Thromboembolic Prevention) QI 7 (Pain, Sedation, Delirium)	01/01/2024–31/12/2025	Not reported / local execution only
Erasmus MC	Netherlands	Local execution	Not reported / local execution only	Not reported / local execution only	Not reported / local execution only

[4] The OMOP transformation pipeline for the minimal item set is in place for the complete data period. Until final ethical and data protection approval of the Charité Data Protection Officer, a period of 1 month is used for demonstrating the MVP version. As soon as the approval is in place, all data will be made available.

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7 Documentation and Dissemination

7.1 Documentation and technical support

The primary documentation and support channels are the GitHub repositories in which the clinical definitions, executable logic, and technical components are maintained. Data providers are asked to report questions, problems, or requests for clarification through GitHub issues in the repository that corresponds to the affected component. Additional support is provided through written documentation (included in the supplementary materials) as well as recordings of data-provider support meetings.

Topic	Repository
Clinical QI definitions, numerator/denominator logic, clinical interpretation	https://github.com/umg-minai/indicate-qi-definitions
CQL implementation of the QI definitions	https://github.com/umg-minai/cql-indicate-qi
CQLonOMOP execution component	https://github.com/umg-minai/cql-on-omop
Container deployment, data exchange, dashboard, and component-specific issues	Respective INDICATE component repositories

This repository-based process ensures that clinical and technical issues are documented transparently, can be tracked over time, and can be resolved in the location where the relevant specification or implementation is maintained.

7.2 Dissemination

The main planned dissemination activity is a scientific publication describing the INDICATE quality benchmarking approach and its application in intensive care medicine. The planned publication will target a peer-reviewed journal in the field of intensive care medicine.

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8 Alignment with Grant Agreement Requirements

This section maps the implemented MVP quality benchmarking system to the relevant Grant Agreement requirements for Deliverable D6.3, the associated milestone, and Task T6.5.

Grant Agreement	Implemented functionality in D6.3	Evidence in this report
D6.3: MVP Quality Benchmarking	The deliverable provides the first operational version of the quality benchmarking system for intensive care medicine.	Sections 2–6 describe the system, architecture, data flow, indicators, dashboard functionality, and submitted data.
Using D4.2...	The quality benchmarking workflow uses the Azure-based INDICATE Hub structure from D4.2 as the central infrastructure for receiving, storing, and distributing aggregated benchmarking results.	Section 4.
...a federated quality benchmarking system will be set up...	Quality indicators are calculated locally at each data-provider site. Patient-level data remain local. Only aggregated, non-identifiable results are submitted centrally.	Sections 3 and 4.
... to allow ICUs across Europe to compare their performance to European benchmarks.	Participating data providers can retrieve benchmark data from the INDICATE Hub and view their local quality indicator results in comparison with pseudonymized results from other sites.	Sections 2 and 5.

8.1 Alignment with Task T6.5

Task T6.5 defines the broader quality benchmarking dashboard work. The MVP delivered in D6.3 addresses the elements of T6.5 that are required for the first operational benchmarking system.

Task T6.5 element	Alignment in D6.3 MVP	Status in MVP
T6.5.1 Identify clinically meaningful scenarios from scientific literature and clinical data	The MVP focuses on intensive care quality benchmarking using nine predefined clinical quality indicators covering ventilation, weaning, feeding, glucose control, thromboembolic prevention, infection rate, pain/sedation/delirium, advance care planning, and mobilisation.	Addressed for MVP indicator set.

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T6.5.2 Develop automated data-processing pipelines using machine-readable transactions based on ETL processes	The MVP uses locally mapped OMOP CDM data, CQL-based quality indicator definitions, and CQLonOMOP execution to calculate standardized indicator results at each site.	Addressed through local OMOP/CQL execution workflow.
T6.5.3 Create a user-facing dashboard application for automated data visualisation and comparison of benchmarks	The MVP includes a dashboard for displaying local aggregated quality indicator results and comparing them with benchmark data from other participating sites.	Addressed through benchmarking dashboard.
T6.5.4 Create APIs that allow integration of benchmark calculations into existing patient data management systems	The MVP includes data-exchange components and authentication architecture for secure provider-side submission.	Addressed.
T6.5.5 Establish a consistent, anonymous benchmarking dataset based on data disclosed through the federated infrastructure	The MVP establishes the Hub-side data model and services for a central aggregated benchmarking dataset. At submission, available evidence was limited to tested/demonstrated provider workflow.	Addressed for MVP contributors.
T6.5.6 Generate a repository of machine-readable guideline recommendations for disclosure through the knowledge platform, in addition to the dashboard	The MVP uses version-controlled repositories for clinical QI definitions and executable CQL implementations. The broader linkage to the WP5 knowledge platform is outside the core D6.3 MVP reporting scope.	Addressed.

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9 Limitations and Planned Next Steps

At submission, available benchmark outputs were demonstration outputs rather than stable European benchmark estimates. They demonstrate that cross-site benchmarking is technically and methodologically feasible, but should not yet be interpreted as stable or fully representative European reference values. Comparability may be affected by differences in ICU populations, observation periods, local data availability and mapping, documentation practices, the subset of indicators that can be calculated reliably at each site and differences in scheduling of indicator computation and result upload. The MVP benchmark is also not risk-adjusted and therefore does not account for differences in patient severity, ICU specialization, staffing, case mix, or other contextual factors. Benchmark results should therefore be interpreted as quality-management signals that may prompt local review, not as definitive performance rankings.

The current workflow includes provider-side review and, where applicable, manual or semi-automated submission of aggregated results. This is appropriate for the MVP stage and supports local control over released data. Future iterations should further streamline data exchange while preserving traceability, accountability, and data protection safeguards.

9.1 Expansion to further providers

A central next step is the expansion of the quality benchmarking system to further INDICATE data providers and additional European countries. Additional sites will be supported in deploying the local containerized components, validating database connectivity, testing CQL execution, reviewing local indicator results, and submitting aggregated outputs. Increasing the number of active contributors will improve the value of the benchmarking system in several ways: It will increase the stability of benchmark estimates, broaden the clinical and geographic coverage of the system, improve the basis for identifying variation in ICU care processes, and support more meaningful comparison across European intensive care settings. It will also provide more feedback on technical deployment, indicator logic and dashboard usability.

9.2 Further development of indicators

For the quality indicators, the next steps include continued refinement of clinical definitions and CQL implementations based on technical and clinical feedback of the participating data providers. Future work may include expanding the indicator set, improving the handling of indicator-specific edge cases, strengthening validation against local clinical expectations, and improving the consistency of required OMOP concepts and value sets across providers. Version-controlled repositories for the clinical QI definitions and CQL implementations will continue to be used to document and track changes.

9.3 Sustainability beyond the MVP

Sustainability beyond the MVP will require continued maintenance of the local data-provider components, the INDICATE Hub services, the CQL-on-OMOP execution component, the data-exchange workflow, and the dashboard. It will also require stable processes for clinical governance, versioning of QI definitions and CQL implementations, provider support, and onboarding of additional sites. Scientific dissemination will be supported through a planned peer-reviewed publication in the field of intensive care medicine, presenting the federated benchmarking method, technical workflow, benchmark results, and deployment experience across participating European ICUs.

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11 List of abbreviations

Abbreviation	Phrase
CDM	Common Data Model
CQL	Clinical Quality Language
OHDSI	Observational Health Data Sciences & Informatics
OMOP	Observational Medical Outcomes Partnership
QI	Quality Indicator
ICU	Intensive Care Unit
SQL	Structured Query Language
MVP	Minimum Viable Product

12 Supplements

12.1 Documents

- Data Provider Information (version from April 21, 2026)
  - Link: 01_data-provider-information.pdf
- Study Protocol (version 1.0 from March 23, 2026)
  - Link: 02_StudyProtocol_QualityBenchmarkingDashboard_v1.0.pdf
- Guide for ICU Clinicians (version 1.0 from April 27, 2026)
  - Link: 03_QualityBenchmarkingDashboard_GuideForICUClinicians_v1.0.pdf

12.2 Videos

- Local startup of all technical components
  - Link: docker-compose-startup.mp4
- Review & approval of aggregated results before submission
  - Link: results-review-upload-demo.mp4
- Local dashboard application showing available results
  - Link: dashboard-demo-charite-qi-04-glucose.mp4

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