Assessing delivery of mechanical ventilation: risks and benefits of large databases

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Invasive mechanical ventilation is a key component of critical care medicine. Resource-intensive and expensive, it is an essential intervention to support many patients through critical illness. Examining and estimating system-wide capacity for mechanical ventilation, whether the system in question is a country, a region, or a group of hospitals, is often accomplished using population-level data. These data may be used to assess whether capabilities match current or projected needs, and may be used to evaluate differences in use and outcomes across a system or systems [1–3].

Specific uses for population-level data
Population-level data are often used to better understand the epidemiology and outcomes of mechanical ventilation. Such data have demonstrated that patients requiring mechanical ventilation span a wide age range, are highly comorbid, and account for an outsized percentage of overall hospital costs [4]. Studies across hospitals have shown substantial variation in use of mechanical ventilation and demonstrated the possibility of a volume–outcome relationship, with lower mortality at hospitals with higher rates of use [5, 6]. Population-level data have also been used to understand temporal trends in use of mechanical ventilation. Over time, use of mechanical ventilation has increased and the treated population has changed, with patients having a higher severity of illness [1, 7]. Furthermore, in the United States, the use of tracheostomy also increased (until 2008), with a concomitant increase in the use of post-acute care facilities [7, 8]. Recognition of these trends was important, as they informed the need to move beyond in-hospital endpoints to follow patients post discharge to fully understand mechanical ventilation outcomes. Moreover, tracking of these trends can facilitate planning of post-acute care services to meet heightened demand.

Population-level data may be particularly useful for examining long-term outcomes requiring longitudinal follow-up. Studies using population-level data have documented an increased risk of long-term mortality, a transient increase in risk of psychiatric diagnoses and psychoactive medication prescriptions, and an increased need for subsequent healthcare utilization after episodes of prolonged mechanical ventilation [9–11]. Furthermore, outcome-focused studies have been used to identify patient populations where use of mechanical ventilation may be of limited benefit. A national study from Taiwan of patients with cancer who underwent prolonged mechanical ventilation demonstrated that 1-year mortality was 85.7%, and that patients with liver, lung or metastatic cancer had the worst survival [12]. In the United States, a study of nursing home residents with advanced dementia showed that use of mechanical ventilation increased over time in this population without an associated improvement in survival [13]; moreover, this trend of increasing use for patients with dementia was confirmed in a separate study using Canadian data, suggesting that such practices were not isolated to the US [2]. These studies, and others like them, have served to better inform the risk–benefit ratio for mechanical ventilation by clarifying what the long-term risks are, as well as what the benefit (in terms of survival) is likely to be.

Considerations when using large databases to study mechanical ventilation
The information that can be learned about mechanical ventilation from any specific population-level database depends on two main factors. The first is the ability to identify mechanical ventilation accurately in the
data (Table 1). The second is the specifics of the clinical details collected that may allow for a more nuanced assessment of mechanical ventilation. In a hierarchy of potential information, at the bottom is the ability to identify whether mechanical ventilation was used at all during hospitalization; at the top is the ability to identify details of ventilator settings and measurements, such as compliance and driving pressures (Fig. 1). With some

| Data source | Definition of mechanical ventilation | Comparison standard | Sensitivity | Specificity | Positive predictive value | Negative predictive value | Accuracy |
|-------------|--------------------------------------|---------------------|-------------|------------|--------------------------|--------------------------|----------|
| Quan et al. [14] | Hospital discharge data from three hospitals in Calgary | ICD-9 codes (96.7x) | Chart review | 87.0 | 99.7 | 93.0 | 99.5 | 0.9 |
| Garland et al. [15] | Canadian Discharge Abstract Database | CCI codes (GZ.31. CA-ND, 1.GZ.31. CR-ND) | Prospectively collected clinical database (Winnipeg ICU database) | 91.5 | 94.4 | 94.8 | 90.9 | 0.93 |
| Blichert-Hansen et al. [16] | Danish National Patient Registry | Danish procedure codes | Chart review | – | – | 100 | – | – |
| Wunsch et al. [17] | Medicare data | ICD-9 codes (96.7x) | Prospectively collected clinical database (APACHE Outcomes) | 58.4 | 96.0 | 89.6 | 79.7 | – |
| Kerlin et al. [18] | Electronic health records from two US health systems | ICD-9 codes (96.7x) | Chart review, validated electronic algorithm | 38.0, 46.0 | 99.6, 99.6 | – | – | 0.73, 0.69 |

*ICD-9* International Classification of Disease, 9th edition, *CCI* Canadian Classification of Health Interventions

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**Fig. 1** Schematic of information in databases including information on mechanical ventilation.
exceptions, large databases tend to include information that falls towards the bottom of this hierarchy. In particular, these databases often lack the clinical variables required to ascertain patient severity of illness, hindering the ability to adjust for differences in casemix. As the available detail increases, the cohort sample size often decreases, resulting in a loss of population coverage for databases with these most detailed components.

Some countries, such as the United Kingdom and Australia, have the ability to track essentially all use of mechanical ventilation at hospitals, linked with detailed clinical data that allow for a rich assessment of casemix and outcomes (although even these databases do not contain the detailed physiology and mechanical ventilation settings described above). In the United States, population-level data are often collected for administrative purposes. Consequently, mechanical ventilation is often identifiable solely through International Classification of Diseases (ICD)-9 and -10 codes which, at their best, only indicate its use at some point during hospitalization and the broad duration of time (less than or more than 96 h). Moreover, when the validity of these procedure codes have been examined, they had high specificity (>95%) but low sensitivity (42–58%), with substantial variability in sensitivity across different US hospitals [17, 18].

The patients in a cohort defined by these ICD codes are, therefore, very likely to have received mechanical ventilation. However, due to the low sensitivity, many patients who also received mechanical ventilation are likely to have been excluded. Knowledge of these performance characteristics is necessary to appropriately interpret population-level data, as understanding (and potentially quantifying) how misclassification may impact results will ensure robust conclusions from the data. Even taking these considerations into account, population-averaged data are of limited utility to guide clinical decisions for individual patients. While these data may inform discussion of potential outcomes, the likelihood of a particular outcome occurring for a given patient is often poorly predicted, even when using high-quality clinical data [19].

Despite its shortcomings, population-level data have greatly furthered our understanding of how mechanical ventilation is used and associated outcomes for patients. With growing facility with artificial intelligence techniques that can process and enrich extremely large amounts of data, there is the potential to gain more nuanced insights from large population-level datasets that also include more detailed clinical information [20]. It is incumbent on us to continue to assess such real-world evidence to improve our understanding of how to best provide life-sustaining therapies, such as mechanical ventilation.

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**Compliance with ethical standards**

**Conflict of interest**

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