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# The intensive care unit volume–mortality relationship, is bigger better? An integrative literature review

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ABSTRACT

*Objective:* To explore the association between patient volume in intensive care units (ICUs) and risk-adjusted mortality.
*Background:* Large multi-speciality ICUs are emerging in response to increasing demand for critical care. Consolidation of resources through regionalisation of services aims to contain costs and optimise demand management and operational synergies. Higher patient volumes in ICU have been associated with improved outcomes. Limited evidence exists, however, to suggest an optimal volume of patients in terms of risk-adjusted mortality.
*Review method:* Retrospective integrative literature review.
*Data sources:* EMBASE, PubMed and Cumulative Index to Nursing and Allied Health Literature electronic databases.
*Inclusion criteria:* Primary studies of risk adjusted mortality in adult ICU patients published between 1995 and 2012.
*Exclusion criteria:* Studies of admissions following elective procedures.
*Results:* Twenty quantitative observational studies were included in this review. Studies were primarily retrospective with three conducted prospectively. Nine studied mechanically ventilated patients, six included all admissions to ICU, three reported on patients with sepsis and one study each on patients post cardiac arrest and those receiving renal replacement therapy. A significant association was evident in sixteen studies suggesting a lower risk of adjusted mortality in higher-volume units. The association was not consistent across all diagnosis. A non-linear relationship observed in two studies noted no mortality benefit occurring above a volume threshold of 450 cases annually per diagnostic category and above 711 cases not specific to a diagnostic group.
*Conclusion:* Patient mortality may be improved in large capacity ICUs. However, the association is not consistent across all diagnostic groups. Risk adjusted mortality is increased in low volume ICUs. There appears to be a high volume threshold at which point the risk adjusted mortality benefit is also lost suggesting a window of optimal ICU organisational performance exists between low and high volumes. Further prospective research is recommended into clinical outcomes in high volume ICUs to explore association between organisational efficiency and quality of care.


## Introduction

Internationally the demand for intensive care is growing and the resources required are significant.[1] Growth in demand, driven by increased patient acuity, multiple comorbidities, population ageing and increasing therapeutic complexity, leads to escalating costs.[2,3] In Australia, for example, during 2009/2010 there were 124,991 admissions to ICU accounting for 391,600 bed days.[4] At a cost of $4000 (AUD) per ICU day the estimated annual

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expenditure was $1.56 billion.[5] Annual growth in demand compounds costs. In Australia from 2004 to 2010 demand for intensive care increased four per cent annually while in comparison the United States demand increased on average by ten per cent annually between 2000 and 2010.[4,6]

Organisational transformation in ICU is required to improve bed utilisation. Simply increasing bed capacity is not sustainable in terms of both economic and workforce requirements.[7] A key demand management strategy is networking between hospitals for the referral of critically ill patients to access definitive care.[8,9] Regionalisation, or consolidation of services into large capacity ICUs for a defined clinical network or geographic area, is being progressively adopted in many countries to concentrate resources and clinical expertise.[3,10] Small low complexity ICUs are increasingly being transferred and consolidated within regional or tertiary referral ICUs. As a result the available resources and expertise are better utilised, adequate patient volumes and improved access to definitive critical care is achieved.[11]

In hospitals with multiple ICUs, traditionally organised as segregated clinical units operating in isolation, services are increasingly being consolidated into large capacity multi-specialty ICUs referred to as an ICU 'hot-floor'.[12] The principal advantages include concentration of resources, a larger and more flexible ICU bed capacity, standardisation of clinical practice, efficiencies through economy of scale and enhanced operational synergies across critical care subspecialities.[13,14] Predictions of future service provision suggest that ICUs will comprise a much larger proportion of acute hospital beds, increasing from three to five per cent currently to between twenty and thirty per cent of beds.[3]

The association between large capacity high patient volume ICUs and mortality, however, is not well understood and the evidence to date is inconsistent across diagnostic groups. Early studies, conducted across a range of countries in the US, UK and Europe, suggested that critically ill patients have better outcomes in high volume ICUs with a reasonable occupancy rate.[15–18] In 1999 it was observed that larger units reduced average costs through increased economies of scale and also improved patient outcomes by increasing average volumes of activity by clinicians.[19] It was pointed out, however, that there can be no general presumption that larger units produce better outcomes for patients and results of early studies may have suffered from confounding due to heterogeneity of the ICU population.[20]

A recent systematic review of thirteen studies to 2010 concluded that outcomes of specific subsets of ICU patients are better in high volume ICUs.[21] Meta-analysis was not possible due to the heterogeneity of the ICU population and variation in the volume definitions adopted by investigators. The findings conflicted with some earlier studies and were later refuted in a study of mechanically ventilated patients.[22] The studies highlighted the inconsistent association that exists between ICU volume and patient mortality. Conflicting study outcomes, non-linearity of the association observed in some studies, and new studies recently conducted in Finland, United Kingdom, Australia and the United States warrant further contemporary review of the available literature.

## Aim

The aim of this integrative literature review was to report on the association between patient volume and risk adjusted mortality in adult ICUs, explore the non-linearity of association and seeks to identify an optimal volume–mortality threshold.

## Design

The integrative review strategy included a range of research designs and methods in experimental, non-experimental, qualitative and quantitative studies. This broad perspective enriches the understanding of outcomes measurement through the application of a systematic synthesis to draw conclusions.[23]

## Search methods

Electronic databases EMBASE, PubMed and CINAHL were searched using key words: intensive care, critical care, volume, outcome, quality and mortality. Three defined concepts were intersected using Boolean operators: Concept A – terms related to intensive care ('intensive care unit' OR 'ICU' OR 'critical care'); Concept B – terms related to the size of the ICU in regard to workload ('volume' OR 'activity'); and Concept C – terms related to quality of care ('outcome' OR 'mortality' OR 'quality'). Mortality was the specific outcome of interest and 'quality' was included to capture those publications where quality of care was the descriptor of the dependant variable. These concepts were then combined using the Boolean term 'AND' to capture relevant studies.

Previous reviews of the volume–mortality association found limited primary studies undertaken in ICU. Therefore the search was intentionally broad and included all available studies published in English from 1995 to 2012. All study types were considered including cross sectional, cohort studies, case–control and randomised control trials. Reference lists from retained publications were manually searched and additional studies identified.

Inclusion criteria required that studies were: (1) conducted in ICU; (2) involved only adult ICU patients; (3) studied patient mortality against volume; and (4) included risk adjustment of the patient population to control for potential confounding. Studies were excluded if not available in English, consisted of a review or editorial or studied paediatric and/or neonatal populations. Elective procedural sub-populations were also excluded due to pre-operative anaesthetic screening for suitability to undergo surgery and post-operative admission to ICU.

## Data abstraction

A data abstraction template was used by the principal investigator to record text and empirical results that related to key concepts of interest in this review. Two associate investigators independently verified the results summarised in Table 1.

## Synthesis

Exploration of key concepts, and interdependencies, related to patient volume, volume definitions, ICU case-mix, risk adjustment and risk adjusted mortality was undertaken. Methodological quality and statistical significance was then assessed to determine validity and generalisability of study results in Table 1.

## Quality appraisal

The integrative review methodology employed here does not support the application of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) for quality appraisal.[24] The lack of a standard definition for volume also prevents the use of PRISMA in this review.[25,26] Study methodology was therefore appraised using the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines.[27] STROBE encompasses twenty-two criteria to specifically appraise reports on observational and cross-sectional studies.

**Table 1**
Study characteristics.

| Study | Design | Patient population | Study sample | No. ICUs | Risk adjusted | Volume definition | Outcome | Stat | 95% CI/SD | Signific. |
|---|---|---|---|---|---|---|---|---|---|---|
| Vaara et al. (2012), Finland[41] | Retrospective observational mutlicentre | ICU patients receiving RRT | 1558 | 23 | Pt. demographics, diagnostics, TISS, SAPSII, readmission, ICU type, level, size | Annual case volume of RRT patients per ICU | Hospital mortality:<br>Small vs. large ICU<br>Low vs. high volume<br>Med. vs. high volume | <br>OR 2.061<br>OR 1.594<br>OR 1.377 | <br>1.50–2.84<br>1.15–2.21<br>1.03–1.84 | <br>$p < 0.001$<br>$p < 0.005$<br>$p < 0.030$ |
| Shahin and Harrison (2012), UK[26] | Retrospective observational mutlicentre | Patients with severe sepsis | 30,727 | 170 | Pt. demographics, diagnostics, APACHE II, readmissions, ICU type, level, size | No. admissions with severe sepsis per unit per year | Hospital mortality:<br>Non-ventilated<br>Mechanically ventilated | <br>OR 0.91<br>OR 0.92<br>OR 0.92 | <br>0.77–1.06<br>0.79–1.07<br>0.79–1.08 | <br>$p = 0.48$<br>n/s<br>n/s |
| Moran and Solomon (2012), Australia[33] | Retrospective observational mutlicentre | All ICU admissions | 208,810 | 136 | Pt. demographics, diagnostics, APACHE III, admission status readmissions, mortality, ICU type, level, size | Annualised patient volume per ICU | Hospital mortality per volume decile. Results comparing first decile with last significant | OR 1.26 | 1.060–1.50 | $p = 0.009$ |
| Cooke et al. (2012), US[34] | Retrospective observational mutlicentre | All ventilated non-surgical patients | 5131 | 119 | Pt. demographics, diagnostics, VA prognositc score, APACHE III, ICU type, level, size | No. admissions with mechanical ventilation (1 year) | 30-day mortality, 50-patient increase in volume associated with a 2% decrease in odds of mortality | OR 0.98 | 0.87–1.10 | n/s |
| Gopal et al. (2011), UK[22] | Retrospective observational mutlicentre | All ventilated patients | 17,132 | 14 | Pt. demographics, diagnostics, LOS, APACHE III, admission status, ICU type, level, size | Mean no. ventilated patients per ICU | Mortality folowing 24 h or more ventilation | OR 1.11 | 0.91–1.35 | $p = 0.297$<br>n/s |
| Reinikainen et al. (2010), Finland[37] | Retrospective observational mutlicentre | Patients with severe sepsis | 452 | 24 | Pt. demographics, diagnostics, TISS, SAPSII, mortality, ICU type, level, size | No. ICU beds | ICU, hospital and 1 year mortality | OR 2.36 (inverse) | 1.19–4.68 | $p = 0.014$ |
| Darmon et al. (2010), France[35] | Retrospective observational mutlicentre | All ventilated patients | 179,197 | 294 | Pt. demographics, diagnostics, SAPSII, admission source, mortality, LOS | No. ventilated patients annually per hospital | Hospital mortality | OR 0.998 | 0.998–0.999 | $p = 0.0001$ |
| Metnitz et al. (2009), Austria[32] | Prospective observational mutlicentre | All ICU admissions | 83,259 | 169 | Pt. demographics, diagnostics, TISS28, SAPSII, mortality, LOS, ICU activity | Admissions per bed and diagnoses per bed annually | Hospital mortality | OR 0.97 | 0.96–0.98 | <0.05 |
| Carr et al. (2009), US[40] | Retrospective observational mutlicentre | Post cardiac arrest admit to ICU | 4764 | 39 | Pt. demographics, diagnostics, APACHEIII, admission source, LOS, mortality, ICU type, level, activity | Cardiac arrest admissions annually | Hospital mortality:<br><20<br>20–34<br>35–50<br>>50 | <br>OR 1.00<br>OR 0.78<br>OR 0.71<br>OR 0.62 | <br>Not stated<br>0.55–1.11<br>0.45–1.11<br>0.45–0.86 | <br>n/s<br>n/s<br>n/s<br><0.01 |

Table 1 (*Continued*)

| Study | Design | Patient population | Study sample | No. ICUs | Risk adjusted | Volume definition | Outcome | Stat | 95% CI/SD | Signific. |
|---|---|---|---|---|---|---|---|---|---|---|
| Kahn et al. (2008), US[8] | Retrospective observational mutlicentre | All ventilated medical patients | 180,976 | 1170 | Pt. demographics, diagnostics, Charlson morbidity index, LOS, mortality, ICU type, activity | Annual admissions per ICU (1 year) | In hospital mortality | OR 0.77 | Not stated | $p = 0.03$ |
| Lin et al. (2008), Taiwan[39] | Retrospective observational mutlicentre | Ventilated haematology patients | 87,479 | n/s | Pt. demographics, diagnostics, Charlson Index, LOS, mortality, ICU type, activity | Mean case load by ICU physician | Hospital mortality (low volume = decreased survival) | OR 0.49 | 0.45–0.53 | $p < 0.001$ |
| Lecuyer et al. (2008), US[38] | Retrospective observational mutlicentre | Ventilated haematology patients | 1753 | 28 | Pt. demographics, diagnostics, SAPSII, LOS, mortality, ICU type, activity | Annual number of haematology patients per unit | ICU mortality | OR 0.98 | 0.97–0.99 | $p = 0.002$ |
| Peelen et al. (2007), Netherlands[18] | Retrospective observational mutlicentre | Patients with severe sepsis | 4605 | 28 | Pt. demographics, diagnostics, APACHE II, SAPSII, SIRS, readmissions, mortality | Annual number of patients with sepsis | ICU and hospital mortality | OR 0.997 | 0.955–1.0 | <0.05 |
| Needham et al. (2006), Canada[43] | Retrospective observational mutlicentre | All ventilated admissions | 20,219 | 126 | Pt. demographics, diagnostics, Charlson Index, admission source, mortality, ICU type, activity | Mean number of ventilation epsiodes per hospital | 30-Day mortality: | | | |
| | | | | | | | Medical patients | OR 0.94 | 0.90–0.99 | <0.05 |
| | | | | | | | Surgical patients | OR 1.01 | 0.92–1.11 | n/s |
| Kahn et al. (2006), US[17] | Prospective observational mutlicentre | All ventilated medical ICU admissions | 20,241 | 83 | Pt. demographics, diagnostic, APACHEIII, readmission, mortality, ICU/hospital type, size, activity | Total hospital patients annually | ICU and hospital mortality | OR 0.66 | 0.52–0.83 | <0.05 |
| Glance et al. (2006), US[16] | Retrospective observational mutlicentre | All ICU admissions | 70,757 | 92 | Pt. demographics, diagnostic, SAPSII, readmission, mortality, ICU type, size, activity | All patient admitted annually | Hospital mortality: | | | |
| | | | | | | | All patients | n/s | Not stated | n/s |
| | | | | | | | Severely ill | OR 0.77 | Not stated | <0.05 |
| Durairaj et al. (2005), US[15] | Retrospective observational mutlicentre | Medical ICU admissions | 43,635 | 44 | Pt. demographics, diagnostics, APACHEIII, admission source, LOS, mortality, ICU type, activity | Low, medium and high volume ICUs | Hospital mortality: | | | |
| | | | | | | | All patients | | | n/s |
| | | | | | | | GI patients | HR 0.68 | 0.54–0.85 | <0.05 |
| | | | | | | | Respiratory patients | HR 0.77 | 0.59–0.99 | <0.05 |
| Iapichino et al. (2004), Europe[30] | Prospective observational mutlicentre | All ICU admissions | 12,615 | 89 | Pt. demographics, diagnostics, SAPSII, admission source, LOS, mortality, ICU type, activity | No. of patients per bed per year | Hospital mortality | OR 0.97 | 0.95–0.99 | <0.05 |
| Jones and Rowan (1995), UK[31] | Retrospective observational mutlicentre | All ICU admissions | 8796 | 26 | Pt. demographics, diagnostics, APACHEII, admission source, LOS, mortality, ICU type, activity | Total patients admitted per unit/total days for study period = average daily volume | Hospital mortality: | | | |
| | | | | | | | Non-surgical | OR −0.33 | −0.64 to −0.07 | n/s |
| | | | | | | | Surgical | OR −0.51 | −0.75 to −0.15 | n/s |

*Abbreviations*: Pt.: patient; RRT: renal replacement therapy; TISS: Therapeutic Intervention Scoring System; SAPS: Simplified Acute Physiology Score; LOS: length of stay; APACHE: Acute Physiology and Chronic Health Evaluation (score); CI: confidence interval; SD: standard deviation; OR: odds ratio; HR: Hazard Ratio; n/s: not significant.

## Results

### *Search outcome*

A total of 94 studies were retained from the initial search with 72 excluded following abstract review. Of the remaining 22 articles a further two studies were excluded due to one study being on the impact of ICU occupancy and the other a study of patient outcomes related to the intensity of care received in closed vs. open medical staffing models.[28,29] Twenty studies in total were retained as described in Fig. 1.

The studies reported on a combined total of 1,012,783 patients in 2843 ICUs from a broad range of countries including the United States, United Kingdom, France, Austria, Finland, Taiwan, Canada, The Netherlands and Australia. All were large observational quantitative multicentre studies conducted at a national or international level.

Three studies were prospective and the remaining seventeen were retrospective cross sectional cohort studies. Five studies were conducted on all consecutive ICU admissions,[16,30–33] seven studied solely ventilated patients,[8,17,22,34–36] three studied patients with severe sepsis[18,26,37] and two studied critically ill haematology patients.[38,39] Also included was one study each on all medical patients, patients post cardiac arrest and patients receiving renal replacement therapy as summarised in Table 1.[15,40,41]

### *Study quality*

In summary, all studies were multicentre with large sample sizes conducted at a national or international level across a broad range of countries. Electronic clinical registries and administrative databases were used with the study design, setting, participant eligibility criteria and variables measured clearly defined.

A majority of studies were retrospective observational studies inferring that there may be a risk of potential confounding and the inclusion of consecutive ICU admissions in a majority of the studies may have introduced recruitment bias. However, while sample size calculations were not described, potential study limitations were countered by large samples sizes ranging from 452 to 208,810 patients, multicentre design, matching of ICU service levels and the application of risk adjustment control measures. Variation in volume definition, time that mortality was measured, patient heterogeneity and differing study methods prevented a formal meta-analysis from being undertaken.

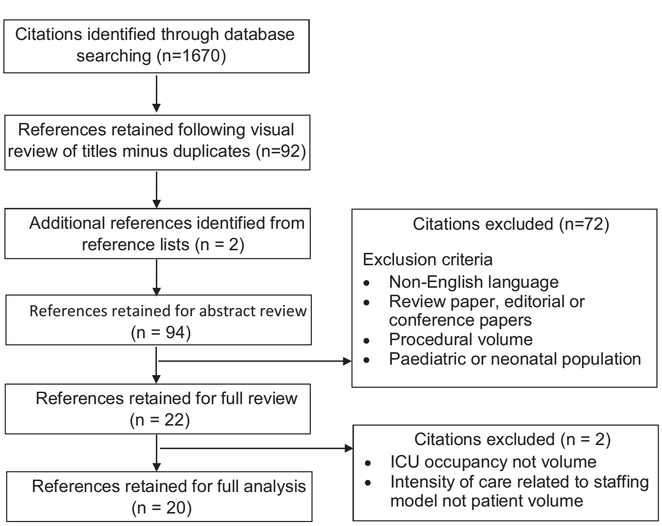


**Fig. 1.** Flow diagram of study selection strategy.

Patient heterogeneity requires control for severity of illness, diagnosis, age and gender to ensure reported mortality outcomes account for the risk profile of different patient cohorts to minimise confounding and increase generalisability of results.[42] All studies applied risk adjustment to the study population then used multiple logistic regression models to generate adjusted mortality in relation to volume. All studies stratified patients according to demographic characteristics, diagnosis and admission source, including readmission to ICU to further control for sample variation. At the organisational level ICUs were stratified in relation to academic affiliation, service level and complexity, size (number of beds), activity, and in a majority of studies rural vs. metropolitan locations.

Three studies estimated the intensity of the care being provided using the Therapeutic Intervention Scoring System (TISS28) to improve comparators. The Simplified Acute Physiology Score (SAPSII) was used in eight studies, Acute Physiology and Chronic Health Evaluation (APACHE) II and III in eight studies, and the Charlson Morbidity Index in four studies to control for severity of illness and estimate probability of mortality.

Results reported both unadjusted estimates and confounder adjusted estimates with precision of the estimate indicated with confidence intervals. Study limitations were reported and the generalisability of results was clearly established.

### *Mortality outcome*

The definition of mortality as the primary outcome measure varied considerably encompassing mortality occurring in ICU, hospital mortality, 30-day mortality and mortality at one year. Despite the different mortality definitions used, sixteen of the twenty studies reported a significant association, though not uniformly, across all patient sub-groups. High risk, complex and mechanically ventilated patients demonstrated the greatest mortality benefit in high volume ICUs.

A majority of the studies revealed the odds of death to be less than one for higher volume ICUs and an inverse association between volume and mortality for smaller volumes. One study reported a significant mortality risk reduction in all medical ventilated patients of 3.4% ($p = 0.04$) and another reported that high-volume hospitals had lower mortality, relative to low-volume hospitals, among sicker patients (APACHE III score > 57) in the respiratory cohort (Hazard Ratio, 0.77; 95% CI 0.59–0.99) and the GI cohort (Hazard Ratio, 0.67; 95% CI 0.53–0.85).[15,36]

Adjusted mortality rates remained lower in higher volume centres in three studies of all consecutive severely ill ICU admissions undertaken by Glance et al. (OR 0.77, 95% CI not stated, $p < 0.05$), Iapichino et al. (OR 0.97, 95% CI 0.95–0.99: $p < 0.05$) and Metnitz et al. (OR 0.97, 95% CI 0.96–0.98: $p < 0.05$).[16,30,32]

Reduced mortality was repeatedly demonstrated in high volume centres for ventilated medical patients.[8,17,35,36,43] These results were refuted, however, in a more recent Australian study of 208,810 ventilated patients which found no progressive decline in mortality across an annual volume range from 12 to 932 patients.[33] The mortality odds ratio was however significantly higher between the last volume decile (801–932 patients) in the series (OR 1.26, 95% CI 1.06–1.50; $p = 0.009$) and the first volume decile (12–101 patients) (OR 1.053, 95% CI 0.94–1.179; $p = 0.374$).[33]

An association between high patient volumes and mortality was reported for haematology patients in two studies with reduced mortality odds ratios (OR 0.98, 95% CI 0.97–0.99; $p = 0.002$) and (OR 0.49, 95% CI 0.45–0.53; $p < 0.001$).[38,39] Patients with severe sepsis were also found to benefit in two studies demonstrating decreased mortality with increased volume (OR 0.997, 95% CI 0.955–1.0; $p < 0.05$) and inversely with increased mortality associated with decreased volume (OR 2.36, 95% CI 1.19–4.68; $p = 0.014$).[18,37] While one study found a mortality benefit where there was greater than fifty post cardiac arrest admissions to ICU annually (OR 0.62, 95% CI 0.45–0.86; $p < 0.01$).[40] Higher mortality was also observed in patients on continuous renal replacement therapy in low volume ICUs (OR 1.594, 95% CI 1.15–2.21; $p < 0.005$).[41]

Results were mixed across patient sub-groups within individual studies. While medical ICU admissions, for example, were observed to have reduced mortality (OR 0.94, 95% CI 0.90–0.99; $p < 0.05$) surgical admissions did not demonstrate a significant reduction in mortality (OR 1.01, 95% CI 0.92–1.11).[43] Increased severity of illness was a typical characteristic of patient sub-groups with reduced mortality and higher patient volumes.

Lastly, there were four studies which initially observed a significant association between volume and mortality across all patients admitted to ICU.[22,26,31,34] Following risk adjustment, however, the association was no longer significant. This may have been attributable to patient heterogeneity and the use of administrative datasets.

## Discussion

Since the late 1970s measuring and understanding the association between volume and patient outcomes in the delivery of health services has been the focus of much research. An early seminal study undertaken in 1979 concluded that higher volumes of procedures should be pursued through regionalisation of services into high volume services.[44] Progressively this principle has been adopted within the ICU environment, resulting in the consolidation of services to achieve a critical mass of patients to improve quality of care, efficiency and ultimately reduce associated service costs.[3,12]

Large consolidated ICUs with high patient volumes typically manage the most complex and severely ill patients. In these ICUs mortality may be reduced by volume in some patient sub-groups.[12] While mortality is the primary outcome of interest it is worth noting that secondary exposures have also been found to have an inverse association with mortality including the presence of intensive care specialists and nurse to patient ratios in the ICU.[17,18,32]

Interpreting the association is complicated by various definitions of volume used including annual volume per ICU, average annual volume, average daily volume, annual volume per bed, diagnostic volume and average case load by physician. Despite this lack of consistency significant volume–mortality associations were found across the range of volume definitions applied in the studies. The validity of associations observed across studies with different volume definitions is supported by a study undertaken in 2009 of 246,051 patients in 268 hospitals over a thirteen-year period which concluded that volume–outcome analysis is similar regardless of how volume is defined.[45]

It was evident from this review that critically ill patients are best managed in ICUs where the most complex, high risk and severely ill patients are concentrated for treatment. This observation is based on the higher severity of illness observed in high volume ICUs and lower mortality.[15,16,30,33] The assumption that high risk ventilated and/or complex patients are best managed in high volume ICUs underpins the requirement for consolidated larger ICUs with sophisticated infrastructure, technology, clinical support services and expertise.[16,17,38] This is reflected in the criteria used to stratify and classify the level of an ICU according to internal resources, infrastructure, organisational model and the level, and availability, of support services such as medical imaging and pathology to support the management of complex critically ill patients.[46,47]

One factor that may explain improved patient outcomes is the impact on the caseload of medical staff. In a large retrospective study involving over 87,000 ICU patients suffering from pneumonia, the mortality of patients managed by high volume ICU physicians was found to be half that observed in low volume ICU physicians (OR 0.49; 95% CI 0.45–053; $p < 0.001$).[39] This is attributed to increased physician experience, enhanced clinical training and the adoption of evidence based standardised clinical practice in an environment with concentrated resources and systematised organisational processes.[8,48]

The association between low volume ICUs and worsening mortality may reflect smaller ICUs not having the same level of access to sophisticated technologies and expertise thereby compounding mortality rates.[16] Smaller ICUs have also been shown, in general, to have a longer average length of stay per patient when compared to high volume ICUs.[37] Baseline staffing levels and infrastructure are required for safe delivery of care. Based on the cost of an average ICU bed day it might be concluded that low volume ICUs are less cost effective than high volume ICUs when considering patient throughput.

While this review found a statistically significant association between higher volume ICUs and improved mortality, in some patient sub-groups, it is important to consider all organisational characteristics of the ICU when interpreting study outcomes. In particular, the presence of a High Dependency Unit (HDU) was significantly associated with higher mortality within a hospital (OR 1.261; 95% CI 0.990–1.680; $p = 0.006$).[18] An HDU provides a step down service for ICU and caters for critically ill patients with lower complexity and risk that do not require a 1 patient to 1 nurse ratio.[54] While there is no explanation for this association it could be due to a higher level of patient severity requiring transitional care in a HDU or due to the emergence of non-invasive ventilation allowing more complex critically ill patients to be managed in non-ICU areas such as HDU.

Higher risk adjusted mortality has been observed in ICUs with medical cover provided by intensive care medical trainees (OR 1.43; $p = 0.000$).[16] While no explanation is forthcoming it could be proposed that intensive care medical trainees work in university accredited tertiary ICUs which attract more complex patients through clinical referral networks. This may infer that a critical mass of severely ill and complex patients is required to support intensive care medical training programmes.

Increased mortality was also observed to be associated with high occupancy (OR 1.324; 95% CI 1.133–1.548; $p < 0.05$).[30] While this appears to counter the high volume-low mortality theory, it instead relates to the intensity of care, or number of beds in an ICU occupied by patients, at any one time impacting on staffing, resources and infrastructure. High volume rather refers to the number of consecutive patients through an ICU bed over a defined period.

Of note is the prospective study of 83,259 consecutive admissions across 169 ICUs which concluded there is a significant association between ICU volume and risk adjusted mortality (OR 0.96, 95% CI 0.956–0.979; $p < 0.05$). Specifically the study found that higher volume was associated with reduced mortality and higher patient to nurse ratio was associated with higher mortality.[32]

A non-linear 'U' shaped correlation has also been observed indicating there may be a low and high volume threshold suggesting a window of optimal organisational performance.[26,32,33] While risk-adjusted mortality may decrease in patients within the same diagnostic category as volume increases, it has also been observed that after a certain annual volume is reached ($n = 450$ cases) there is no further mortality benefit.[32] This non-linearity was also observed in a study of 30,727 patients across all patient sub-groups in 170 ICUs in the United Kingdom, however, no upper volume threshold was specified.[26] An Australian study identified a high volume threshold of 711 patients (OR 0.84; 95% CI, 0.76–0.92) after which no improvements in mortality were observed.[33] While there may be no benefit to mortality observed above a certain volume threshold there may be secondary detrimental effects associated with organisational fatigue.[32] In particular increased medical and nursing workload has been reported repeatedly to be associated with worse outcomes.[32,49,50] Explanations for this include less time for each patient, fewer hygienic measures, more infections, and increased adverse events as care processes break down.

Regionalisation of ICU services is resulting in the emergence of large capacity multi-specialty hot-floor ICUs with typically high patient volumes.[48,27] The high volume threshold suggested in some studies highlights the need to closely consider structural factors of these organisations particularly around staffing models to manage workload. Though under pressure to contain costs, nurse to patient ratios remain relatively constant in ICU. There is, however, a risk that patient to senior ICU Doctor ratios in ICU may not keep pace with growth in capacity and patient volume, and is further compounded by the increasing complexity of critically ill patients.[51–53]

## Conclusion

It is evident that there is an association between the volume of patient sub-groups treated in ICU and risk adjusted mortality. Studies suggest patients with higher severity of illness benefit most. A lack of consistent findings across different patient types suggests other factors need to be considered in addition to volume, in particular structural characteristics of the organisation such as staffing models.

The relationship between volume and mortality is not entirely linear with low and high thresholds observed at which the volume mortality relationship reverses. This observation is central to understanding the impact of alternative ICU organisational models on patient outcomes and infers that bigger ICUs may be better but only to a volume threshold. Prospective studies are required to explore this phenomenon further to inform future health policy and capital planning for new and redeveloped intensive care services.

## Limitations

This review was limited by varying definitions of volume and the timeframes applied to patient mortality measures, however, it was possible to describe the volume–mortality association that exists in ICUs with different levels of clinical activity. A further limitation was related to a majority of studies being retrospective thereby limiting the ability to control for confounding in the ICU population which has a high heterogeneity. Furthermore the pooling of different ICU patient sub-groups studied may confound results.

## Authors' contributions

Brett Abbenbroek initiated the conception and design of the study, and prepared the first draft version of the document. Christine M. Duffield and Doug Elliott reviewed the design, analysis and interpretation of the data, and approved the final version of the document.

## Conflict of interest

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