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Incidence of acute kidney injury in patients on invasive mechanical ventilation: A prospective observational study

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Abstract
Background: Invasive mechanical ventilation (IMV) is life-saving in critically ill patients but may reduce renal perfusion and contribute to acute kidney injury (AKI). Local data on how often AKI develops in ventilated patients are limited.
Methods: This prospective observational study enrolled adults aged 20–80 years on IMV in the intensive care units (ICUs) of a tertiary teaching hospital in Tamil Nadu, India, over 18 months. Patients with chronic kidney disease, pregnancy, systolic blood pressure <90 mmHg or inotropic support before ventilation were excluded. Serum creatinine, urea and electrolytes were measured at baseline and every 24 hours, and urine output was recorded hourly. Patients were followed for up to 7 days or until liberation from the ventilator. AKI was defined by the serum creatinine criteria of the Acute Kidney Injury Network (AKIN); the primary outcome was a rise in creatinine of more than 0.3 mg/dL from baseline within 48 hours, and secondary outcomes were reduced urine output and electrolyte disturbance.
Results: Of 86 patients screened, 78 were analysed (45 men, 57.7%; 33 women, 42.3%). AKI developed in 34 patients (43.6%), all of whom also had reduced urine output; 44 patients (56.4%) did not develop AKI. Head injury (46.2%), hypertension (38.5%), diabetes mellitus (35.9%) and respiratory disorders (33.3%) were the recorded risk factors. Mild hypokalaemia occurred in 19 patients (24.4%; 9 with AKI), mild hyperkalaemia in 2 (both with AKI), moderate hyperkalaemia in 1 (no AKI) and mild hypernatraemia in 2 (no AKI). Two patients with AKI required continuous renal replacement therapy. Overall, 57 patients (73.1%) were extubated, 19 (24.4%) died and 2 (2.6%) left against medical advice.
Conclusions: Nearly 44% of patients on IMV developed AKI, recognised by a rising serum creatinine with falling urine output. Daily monitoring of creatinine, urine output and electrolytes should be routine in ventilated patients so that AKI is identified early.

Keywords: Acute kidney injury, Mechanical ventilation, serum creatinine, urine output; AKIN criteria and intensive care

Introduction

The kidneys receive roughly a quarter of the cardiac output, which makes them particularly sensitive to falls in blood flow such as those that accompany positive-pressure ventilation [1]. Acute kidney injury (AKI) is an abrupt loss of kidney function that causes retention of waste products, electrolyte disturbance and changes in volume status; because even small changes carry a higher risk of morbidity and mortality, the term AKI has largely replaced acute renal failure [2]. Serum creatinine is the most widely used marker, but it rises 48 to 72 hours after the injury and is unreliable in critically ill patients who are not in a steady state, so urine output is an important complementary marker [2].

Mechanical ventilation is often essential, yet it is itself associated with AKI through three interacting pathways: the effect of positive intrathoracic pressure on systemic and renal haemodynamics, the effect of arterial blood gas changes, and the systemic release of inflammatory mediators (biotrauma) [1]. Raised intrathoracic pressure increases renal venous pressure and lowers renal blood flow, activating the renin–angiotensin–aldosterone system and vasopressin release, which reduces glomerular filtration rate, causes sodium and water retention and lowers urine output [1]. Reported incidences of AKI in ventilated patients vary with case mix and definition, from about 29% in a cohort of 2,783 ventilated adults [citation to be added] to 45% among patients on invasive ventilation [3] and 65% in ventilated COVID-19 pneumonia [4]. AKI in this setting has been linked to longer ventilation and ICU stay and higher mortality [3]. Data from Indian ICUs are comparatively scarce.

This study assessed the incidence of AKI in adults on invasive mechanical ventilatory support in a tertiary care hospital. The primary objective was a rise in serum creatinine of more than 0.3 mg/dL from baseline within 48 hours. Secondary objectives were reduced urine output within 48 hours and changes in serum electrolytes.

Materials and Methods

Study design, setting, and ethics

This prospective observational study was conducted over 18 months in the intensive care units of SRM Medical College Hospital and Research Centre, Potheri, Kattankulathur, Tamil Nadu, India. The Institutional Ethics Committee approved the study on 25 March 2022 (8253/IEC/2022), and written informed consent was obtained from each participant or legally authorised representative before enrolment.

Participants

Adults aged 20–80 years receiving IMV, including those with controlled diabetes mellitus, controlled hypertension, respiratory disorder or acute respiratory distress syndrome, or head injury, were eligible. Patients who declined consent, those with chronic kidney disease (CKD), pregnant women, and those with systolic blood pressure <90 mmHg or on inotropic support before invasive ventilation were excluded. Of 86 patients screened, 8 were excluded (2 left against medical advice, 2 underwent tracheostomy, 1 had CKD, 1 had systolic blood pressure <90 mmHg and 2 were on inotropes before ventilation), leaving 78 for analysis.

Outcomes and data collection

At ICU admission, demographic details, diagnosis, weight and height were recorded, and baseline urea, creatinine and serum electrolytes (sodium, potassium, chloride, bicarbonate) were drawn. Renal function tests and electrolytes were repeated every 24 hours while the patient remained on the ventilator. Urine output was measured hourly and summed over 24 hours; if it fell below 0.5 mL/kg/hour, renal function tests were repeated at that time. Ventilator mode and ventilator days were recorded daily. Each patient was followed for up to 7 days or until weaned from the ventilator, and the day on which AKI appeared was noted.

AKI was identified and classified using the serum creatinine criteria of the Acute Kidney Injury Network (AKIN) [2]. The primary outcome was a rise in serum creatinine of more than 0.3 mg/dL from baseline within 48 hours. Secondary outcomes were a reduction in urine output of more than 10% below the baseline value within 48 hours and electrolyte disturbance. Hyperkalaemia was graded as mild (5.5–6.0 mmol/L), moderate (6.0–6.5 mmol/L) or severe (>6.5 mmol/L), and hypokalaemia as mild (3.0–3.5 mmol/L), moderate (2.5–3.0 mmol/L) or severe (<2.5 mmol/L). In-hospital outcome (extubated, died, or discharged against medical advice) was also recorded.

Sample size and statistical analysis

Using $n = Z^2PQ/d^2$ with Z = 1.96, an expected proportion P = 55.6% taken from a reference study of ventilated ICU patients [1], Q = 44.4% and d = 11.12 (20% of P), the required sample size was 76.7, rounded to 77; 78 patients were recruited. Data are presented as frequencies, percentages, and mean ± standard deviation, and were analysed with SPSS version 21 for Windows.

Results: Participant characteristics

The analysis included 78 patients, of whom 34 developed AKI and 44 did not. There were 45 men (57.7%) and 33 women (42.3%); mean age was 49.34 ± 24.04 years in men and 49.67 ± 15.55 years in women. The largest age group was 50–60 years (17 patients, 21.8%). Head injury was the commonest recorded condition (46.2%), followed by hypertension (38.5%), diabetes mellitus (35.9%) and respiratory disorders (33.3%); some patients had more than one (Table -1).

Table 1: Participant characteristics and risk factors (N = 78)

Characteristic	N	%
Male sex	45	57.7
Female sex	33	42.3
Age 20–40 years	25	32.1
Age 40–60 years	29	37.2
Age 60–80 years	24	30.8
Head injury	36	46.2
Hypertension (controlled)	30	38.5
Diabetes mellitus (controlled)	28	35.9
Respiratory disorder / ARDS	26	33.3

Mean age ± SD: men 49.34 ± 24.04 years; women 49.67 ± 15.55 years. Risk factor categories are not mutually exclusive, so percentages do not sum to 100. ARDS, acute respiratory distress syndrome.

Incidence of AKI, serum creatinine and urine output

AKI developed in 34 of 78 patients (43.6%) during follow-up. All 34 had a rise in serum creatinine from baseline and all 34 also had reduced urine output within 7 days of ventilation; none of the 44 patients without AKI had a sustained rise in creatinine or fall in urine output. Two patients with AKI had a serum creatinine more than three times baseline with serum potassium above 6 mmol/L and were treated with continuous renal replacement therapy (CRRT) (Table 2).

Table 2: Incidence of AKI and associated changes (N = 78)

Outcome	N	%
AKI (AKIN serum creatinine criteria)	34	43.6
No AKI	44	56.4
Raised serum creatinine	34	43.6
Reduced urine output	34	43.6
CRRT required	2	2.6

The 34 patients with raised serum creatinine and the 34 with reduced urine output were the same patients who met the definition of AKI. CRRT, continuous renal replacement therapy.

Electrolyte disturbances

Mild hypokalaemia was the commonest disturbance (19 patients, 24.4%), occurring in 9 patients with AKI and 10 without; no patient had moderate or severe hypokalaemia. Mild hyperkalaemia occurred in 2 patients (2.6%), both with AKI, and moderate hyperkalaemia in 1 patient (1.3%) without AKI. Mild hypernatraemia occurred in 2 patients (2.6%), neither of whom developed AKI (Table -3).

Table 3: Electrolyte disturbances in relation to AKI (N = 78)

Disturbance	Grade	n (%)	With AKI	Without AKI
Hypokalaemia	Mild	19 (24.4)	9	10
Hypokalaemia	Moderate or severe	0	0	0
Hyperkalaemia	Mild	2 (2.6)	2	0
Hyperkalaemia	Moderate	1 (1.3)	0	1
Hyperkalaemia	Severe	0	0	0
Hypernatraemia	Mild	2 (2.6)	0	2

Percentages are of all 78 patients.

Outcomes
Of the 78 patients, 57 (73.1%) were extubated, 19 (24.4%) died in the ICU and 2 (2.6%) were extubated and then left against medical advice (Table 4).

Table 4: In-hospital outcome of patients on invasive mechanical ventilation (N = 78)

Outcome	N	%
Extubated	57	73.1
Died	19	24.4
Left against medical advice	2	2.6

Patients who left against medical advice did so after extubation, under physician supervision.

Discussion
In this prospective study, 43.6% of adults on invasive mechanical ventilation developed ArKI, and in every case the creatinine rise was accompanied by reduced urine output. The incidence is close to the 45% reported among patients on invasive ventilation [3] and to the 40.1% reported in critically ill COVID-19 patients in the Catalonian AKICOV study [5], lower than the 65% reported in a single centre cohort of ventilated COVID-19 pneumonia [4], and higher than the 28.8% reported in 2,783 ventilated adults [citation to be added]. Differences in definition (AKIN, RIFLE or KDIGO), timing of baseline creatinine and severity of illness limit direct comparison.

Interpretation in the context of existing evidence
Positive intrathoracic pressure raises venous pressures, reduces renal blood flow and glomerular filtration, and activates the renin–angiotensin–aldosterone system and vasopressin release, leading to sodium and water retention and reduced urine output [1]. Higher positive end-expiratory pressure was associated with a progressively greater incidence of AKI in ventilated COVID-19 patients [6], and in ARDS older age, illness severity, diabetes and acidosis were associated with AKI, whereas peak airway pressure and heart failure were associated with its severity [7]. Ventilator pressures were not analysed in our study, so their contribution cannot be quantified.
Head injury was the commonest background condition in our cohort. Neurocritical care patients face many renal insults, and sepsis was the leading cause of AKI in a large neurocritical care series [8] bleeding with anaemia may also impair renal oxygen delivery [5]. We did not test whether any recorded condition independently predicted AKI, so their role here is descriptive. Electrolyte disturbances were mostly mild. Hypokalaemia was the commonest but occurred about equally with and without AKI, whereas hyperkalaemia was uncommon. Hyperkalaemia is reported more often than hypokalaemia in established AKI, particularly in patients needing CRRT, and early CRRT can help control potassium [9] this is consistent with the two patients in our series who needed CRRT with potassium above 6 mmol/L. Dysnatraemia has also been associated with AKI [citation to be added], but only two of our patients were hypernatraemic and neither developed AKI.
Urine output is a sensitive and readily available marker. Close urine-output monitoring improved AKI detection in a large ICU cohort [10], and patients meeting both urine-output and creatinine criteria are at highest risk of death or dialysis [11, 12]. Combining both markers, as in this study, therefore addresses the delayed rise of creatinine. Mortality in our cohort was 24.4%; AKI during invasive ventilation has been associated with longer ventilation, longer ICU stay and higher ICU mortality [3], and mortality rises with RIFLE class [13]. We did not compare mortality between patients with and without AKI.

Strengths and limitations
Strengths include the prospective design, daily biochemical and urine-output surveillance, standard AKIN classification, and exclusion of CKD and pre-ventilation shock. Limitations include the single-centre observational design with a modest sample, no non-ventilated comparison group, and therefore no causal inference. Reduced urine output was defined as a fall of more than 10% from baseline, which is less stringent than the standard AKIN criterion, and because every patient with AKI met both criteria the two markers were not independent. Follow-up was limited to a maximum of 7 days in hospital. Ventilator settings, sepsis, nephrotoxic drug exposure and illness-severity scores were not analysed, and no multivariable analysis was performed.

Conclusion
Among 78 adults on invasive mechanical ventilation, 34 (43.6%) developed AKI, always with reduced urine output, and in-hospital mortality was 24.4%. Daily monitoring of serum creatinine, urine output and electrolytes should be routine in ventilated patients to allow early recognition of AKI. Larger multicentre studies that record ventilator settings and compare outcomes between patients with and without AKI are needed.

Declarations
Ethics approval and consent to participate: The Institutional Ethics Committee of SRM Medical College Hospital and Research Centre approved the study (8253/IEC/2022, 25 March 2022). Written informed consent was obtained from all participants or their legally authorised representatives before enrolment.

Consent for publication: Not applicable. The manuscript does not contain any individual person's identifiable data, images or videos.

Data availability: The datasets generated and analysed during the current study are not publicly available because they contain patient-level clinical information, but they are available from the corresponding author on reasonable request.

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laboratory data acquisition, data interpretation and critical revision of the manuscript. All authors read and approved the final manuscript.

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