Online Appendix

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SUPPLEMENTARY TABLES AND FIGURES

Appendix Table 1

Data available from The Critical Health Resources Information System (CHRIS)

Baseline data about each ICU extracted from CHRIS
Type of ICU (tertiary, metropolitan, rural/regional, private, paediatric)
Number of 'business as usual' physical ICU beds
Number of 'business as usual' open available staffed ICU beds
Data entered twice daily at 8 am and 8 pm, extracted from CHRIS
Total number of physical ICU beds available
Total number of open available staffed ICU beds
Total number of ICU patients (e.g. 1:1 nursing, ventilated)
Total number of High Dependency Unit patients
Total number of patients with COVID-19 within the ICU
Total number of patients with COVID-19 who are on a ventilator
Total number of patients with COVID-19 who are in the hospital
Total number of ventilated patients within ICU
Total number of patients on haemofiltration /dialysis within each ICU
Total number of patients receiving extra-corporeal membrane oxygenation
Total number of spare ICU ventilators
Total number of spare haemofilters/dialysis machines
Total number of spare ICU ventilators
Total numbers of critical care staff unavailable due to COVID-19 exposure or disease
Calculated metrics derived from data extracted from CHRIS
ICU occupancy ICU occupancy = the number of patients needing 1:1 nursing care (ICU patients), added to 0.5 x the number of patients needing 1:2 nursing care (HDU patients), divided by the total number of open staffed ICU beds
Additional open ICU beds over baseline The number of additional open ICU beds over the baseline reported by the ICU at the beginning of the study period
ICU Activity Index One point for each patient with confirmed COVID-19 and a further point for each of the following therapies provided to any patient within the ICU: invasive ventilation, renal replacement, or extra-corporeal membrane oxygenation. The total was then divided by the number of open staffed ICU beds

Appendix Table 2

Daily characteristics of referring ICUs grouped by geographical region

	All hospitals	North-western Melbourne	South-eastern Melbourne	Regional Victoria
Number of hospitals with an ICU	45	12	17	16
Number of hospitals which transferred a patient	29	7	9	13
Number of patients transferred	150	58	27	65
Site-days with a critical care transfer	4.4% (143/3240)	5.9% (51/864)	2.2% (27/1224)	5.6% (65/1152)
Daily ICU Activity Index	0.7 (0.3 to 1.2) [0, 3.3]	1.2 (0.5 to 1.6) [0, 2.8]	0.6 (0.3 to 1.1) [0, 2.5]	0.3 (0 to 0.8) [0, 3.3]
Site-days with ICU Activity Index >1.6	11% (288/2609)	23% (170/741)	9% (90/1038)	3% (28/830)
Site-days with ICU Activity Index <0.6	47% (1231/2609)	27% (199/741)	48% (497/1038)	64% (535/830)
Daily physical ICU beds per site	12 (8 to 20) [0 ,139]	13 (10 to 26) [0 ,82]	13 (10 to 20) [0 ,139]	10 (6 to 13) [0 ,66]
Total daily open available ICU beds per site	7 (5 to 11) [0 ,60]	9 (7 to 15) [0 ,42]	9 (6 to 12) [0 ,60]	5 (3 to 8) [0 ,17]
Additional ICU beds opened per site*	0 (-2 to 0) [-14 ,16]	0 (-1 to 0) [-10 ,12]	0 (-2 to 0) [-14 ,16]	0 (-1 to 0) [-13 ,7]
Daily occupancy	61% (40% to 83%) [0%, 250%]	73% (50% to 90%) [0%, 233%]	60% (38% to 84%) [0%, 250%]	50% (33% to 75%) [0%, 200%]
Daily number of patients in ICU	6 (4 to 9) [0 ,50]	8 (5 to 13) [0 ,38]	7 (3 to 10) [0 ,50]	5 (3 to 6) [0 ,19]
Daily number of ventilated patients	1 (0 to 3) [0 ,31]	3 (1 to 5) [0 ,29]	1 (0 to 3) [0 ,31]	0 (0 to 1) [0 ,10]
Daily number of COVID-19 patients	0 (0 to 1) [0 ,10]	1 (0 to 3) [0 ,10]	0 (0 to 0) [0 ,8]	0 (0 to 0) [0 ,2]
Daily number of ventilated COVID-19 patients	0 (0 to 0) [0 ,8]	0 (0 to 2) [0 ,8]	0 (0 to 0) [0 ,6]	0 (0 to 0) [0 ,1]
Daily number of spare ventilators	8 (6 to 15) [0 ,73]	12 (7 to 21) [2 ,73]	10 (6 to 15) [0 ,53]	5 (4 to 9) [0 ,47]
Daily proportion of site's ventilators in use	9% (0% to 20%) [0%, 83%]	16% (7% to 26%) [0%, 70%]	8% (0% to 19%) [0%, 60%]	0% (0% to 14%) [0%, 83%]
Daily number on renal replacement therapy	0 (0 to 1) [0 ,8]	0 (0 to 1) [0 ,8]	0 (0 to 1) [0 ,8]	0 (0 to 0) [0 ,5]
Daily number of spare ICU dialysis machines	2 (1 to 4) [0 ,16]	4 (2 to 5) [0 ,16]	2 (2 to 3) [0 ,16]	1 (1 to 2) [0 ,11]
Daily proportion of dialysis machines in use	0% (0% to 20%) [0%, 100%]	0% (0% to 20%) [0%, 100%]	0% (0% to 24%) [0%, 100%]	0% (0% to 0%) [0%, 100%]
Daily number of critical care staff unavailable**	0 (0 to 1) [0 ,42]	0 (0 to 2) [0 ,42]	0 (0 to 0) [0 ,41]	0 (0 to 0) [0 ,7]

ICU = Intensive Care Unit, A 'site-day' represents one day per site.

Statistics displayed are median (interquartile range), [minimum, maximum] daily values for each ICU, unless stated.

P values for all comparison of additional ICU beds across geo-graphic regions = 0.029, all other comparisons P<0.001

* Additional open ICU beds over baseline = the number of additional open ICU beds over the baseline reported by the ICU at the beginning of the study period

** Number of critical care staff unavailable due to COVID-19 exposure or COVID-19 disease (not health care worker related infections)

Appendix Table 3

Characteristics of 150 critically ill patients transferred on 143 days grouped by geographical region of origin hospital.

	Total	North-western Melbourne	South-eastern Melbourne	Regional Victoria	P value
Number of patients transferred	150	39% (58/150)	18% (27/150)	43% (65/150)	
Number of hospitals from which patients were transferred	29	24% (7/29)	31% (9/29)	45% (13/29)	
Ventilated	52% (78/150)	81% (47/58)	44% (12/27)	29% (19/65)	<0.001
Transferred because no ICU or HDU bed available	17% (25/150)	28% (16/58)	30% (8/27)	2% (1/65)	0.006
Transferred from Emergency Department	43% (65/150)	28% (16/58)	59% (16/27)	51% (33/65)	0.003
Transferred from ICU	53% (80/150)	71% (41/58)	41% (11/27)	43% (28/65)	<0.001
Diagnosis					
Respiratory	33% (50/150)	57% (33/58)	19% (5/27)	18% (12/65)	
Gastrointestinal	14% (21/150)	7% (4/58)	11% (3/27)	22% (14/65)	
Sepsis	13% (20/150)	9% (5/58)	26% (7/27)	12% (8/65)	<0.001
Toxicological	7% (10/150)	9% (5/58)	11% (3/27)	3% (2/65)	
Other	33% (49/150)	19% (11/58)	33% (9/27)	45% (29/65)	

ICU= Intensive Care Unit, HDU = High Dependency Unit

A total of 298 patients who were considered as critical care transfers were excluded from the study for the following reasons: 99 specialist cardiac/cardiothoracic, 85 specialist trauma, 69 specialist neurological/neurosurgical, 15 specialist gastro-enterological, 28 other specialist/non-ICU hospitals, 2 transfers to interstate hospitals.

Appendix Table 4

Sensitivity, specificity, positive predictive value and negative predictive value of high (1.6) and low (0.6) ICU Activity Index levels cut off points in predicting a critical care transfer, for all hospitals and for individual hospital types, reported with 95% confidence intervals.

Type	ICU Activity Index	Sensitivity	Specificity	PPV	NPV
All hospitals	0.6	72% (63% - 80%)	48% (46% - 50%)	7% (5% - 8%)	97% (96% - 98%)
	1.6	28% (20% - 36%)	90% (89% - 91%)	12% (8% - 16%)	96% (95% - 97%)
Public Tertiary	0.6	100% (77% - 100%)	1% (0.4% - 3%)	3% (2% - 6%)	100% (48% - 100%)
	1.6	79% (49% - 95%)	66% (61% - 71%)	7% (4% - 13%)	99% (97% - 100%)
Public Metro	0.6	98% (91% - 100%)	27% (23% - 30%)	11% (8% - 14%)	99% (97% - 100%)
	1.6	38% (26% – 52%)	86% (83% - 89%)	20% (13% - 29%)	94% (92% - 96%)
Public Rural	0.6	35% (21% - 50%)	65% (61% - 69%)	8% (5% - 13%)	8% (5% - 13%)
	1.6	2% (0.1% - 12%)	98% (97% - 99%)	11% (0% - 48%)	11% (0% - 48%)
Private	0.6	40% (5% - 85%)	74% (71% - 77%)	1% (0% - 3%)	100% (99% - 100%)
	1.6	0% (0% - 52%)	98% (97% - 99%)	0% (0% - 17%)	100% (99% - 100%)

PPV = Positive Predictive Value
NPV = Negative Predictive Value

Appendix Table 5

Characteristics of ICUs on days (i.e. site-days) with low (<0.6), intermediate (0.6 to 1.6) and high (≥1.6) ICU Activity Index levels.

	Activity Index		
	<0.6	0.6 to 1.6	≥1.6
Sites-days when critical care transfers occurred	3% (34/1231)	5% (55/1090)	12% (34/288)
Physical ICU beds	12 (7 to 13) [2, 66]	18 (12 to 26) [2, 138]	26 (15 to 80) [3, 139]
Total daily open available ICU beds	6 (4 to 9) [2, 26]	10 (6 to 15) [2, 60]	15 (9 to 30) [2, 46]
Additional open ICU beds over baseline	0 (0 to 0) [-9, 10]	0 (-1 to 0) [-14, 16]	0 (0 to 1) [-10, 12]
Occupancy	42% (29% - 50%) [7%, 200%]	78% (67% - 90%) [29%, 250%]	95% (90% - 100%) [33%, 225%]
Number of critical care staff unavailable	0 (0 to 0) [0, 17]	0 (0 to 1) [0, 42]	1 (0 to 3) [0, 25]
Number of patients in ICU	4 (3 to 6) [1, 17]	9 (6 to 13) [1, 48]	15 (9 to 28) [2, 50]
Number of ventilated patients	0 (0 to 1) [0, 3]	3 (1 to 5) [0, 25]	8 (5 to 17) [0, 31]
Number of COVID-19 patients	0 (0 to 0) [0, 2]	0 (0 to 1) [0, 10]	3 (1 to 5) [0, 10]
Number of ventilated COVID-19 patients	0 (0 to 0) [0, 1]	0 (0 to 1) [0, 8]	2 (1 to 4) [0, 8]
COVID-19 patients (%)*	0% (0% - 0%) [0%, 25%]	0% (0% - 13%) [0%, 75%]	14% (6% - 33%) [0%, 89%]
Ventilated COVID-19 patients (%)*	0% (0% - 0%) [0%, 10%]	0% (0% - 7%) [0%, 50%]	10% (2% - 22%) [0%, 67%]
Ventilated patients (%)*	0% (0% - 9%) [0%, 29%]	30% (20% - 40%) [0%, 71%]	56% (50% - 67%) [0%, 100%]
Renal replacement therapy (%)*	0% (0% - 0%) [0%, 25%]	3% (0% - 11%) [0%, 50%]	11% (5% - 17%) [0%, 50%]

P values comparisons across all groups <0.001
Statistics displayed are median (interquartile range), [minimum, maximum] daily values for each ICU, unless stated
A 'site-day' represents one day per site.
Additional open ICU beds over baseline = the number of additional open ICU beds over the baseline reported by the ICU at the beginning of the study period

Appendix Table 6a:

Sensitivity analysis - hierarchical logistic regression model (with side as random effect) including ICU Activity Index, Occupancy, number of critical care staff unavailable, type of hospital and geographic region.

	Odds ratio (95% confidence interval)	P value
ICU Activity index	3.93 (2.23 - 6.92)	<0.001
Occupancy	0.52 (0.15 - 1.74)	0.29
Critical care staff unavailable*	1.00 (0.95 - 1.05)	0.92
Hospital Type		
Public Tertiary	1.00 (Reference value)	
Public Metropolitan	4.45 (1.59 - 12.48)	0.005
Public Rural	4.22 (0.87 - 20.52)	0.07
Private	0.41 (0.11 - 1.54)	0.19
Geographical region		
Regional Victoria	1.00 (Reference value)	
North-western Melbourne	0.50 (0.11 - 2.33)	0.38
South-eastern Melbourne	0.39 (0.08 - 1.82)	0.23

* Critical care staff unavailable at each site each day due to COVID-19 exposure or disease
Hospital site entered as a random effect (variance 0.51, 95%CI: 0.22 - 1.22)
Area under receiver operating characteristic 0.84 (95%CI 0.81-0.87)

Appendix Table 6b:

Sensitivity analysis - hierarchical logistic regression model (with side as random effect) including ICU Activity Index, Occupancy, number of critical care staff unavailable and geographic region.

	Odds ratio (95% confidence interval)	P value
ICU Activity index	4.27 (2.45 - 7.44)	<0.001
Occupancy	0.61 (0.18 - 2.03)	0.42
Critical care staff unavailable*	1.00 (0.95 - 1.05)	0.92
Geo-graphical region		
South-eastern Melbourne	1.00 (Reference value)	
North-western Melbourne	1.22 (0.4 - 3.69)	0.73
Regional Victoria	4.18 (1.52 - 11.48)	0.005

 * Critical care staff unavailable at each site each day due to COVID-19 exposure or disease

Hospital site entered as a random effect (variance 1.24, 95%CI: 0.60 – 2.56)

Area under receiver operating characteristic 0.85 (95%CI 0.82-0.88)

Appendix Table 6c:

Sensitivity analysis - hierarchical logistic regression model (with side as random effect) including ICU Activity Index, Occupancy, number of critical care staff unavailable and geographic region.

	Odds ratio (95% confidence interval)	P value
ICU Activity index	3.11 (1.97 - 4.91)	<0.001
Total daily number of open available ICU beds	0.98 (0.88 - 1.10)	0.77
Additional open ICU beds over baseline*	1.06 (0.92 - 1.22)	0.40
Total number of patients in ICU	1.05 (0.95 - 1.17)	0.33
Critical care staff unavailable**	1.01 (0.95 - 1.06)	0.82
Hospital Type		
Public Tertiary	1.00 (Reference value)	
Public Metropolitan	7.82 (1.54 - 39.8)	0.013
Public Rural	17.87 (3.01 - 106.12)	0.002
Private	0.99 (0.16 - 5.93)	0.99

* The number of additional open ICU beds over the baseline reported by the ICU at the beginning of the study period

** Critical care staff unavailable at each site each day due to COVID-19 exposure or disease

Hospital site entered as a random effect (variance 0.57.95%CI: 0.25 - 1.34)

Area under receiver operating characteristic 0.84 (95%CI 0.81-0.87)

Appendix Table 6d:

Sensitivity analysis - hierarchical logistic regression model (with side as random effect) including ICU Activity Index, Occupancy, number of critical care staff unavailable for public hospitals only.

	Odds ratio (95% confidence interval)	P value
ICU Activity index	4.27 (2.31 – 7.90)	<0.001
Occupancy	0.47 (0.13 - 1.72)	0.25
Critical care staff unavailable*	1.00 (0.94 - 1.05)	0.85
Hospital Type		
Public Tertiary	1.00 (Reference value)	
Public Metropolitan	3.78 (1.34 – 10.7)	0.012
Public Rural	8.46 (2.74 – 26.1)	<0.001

* Critical care staff unavailable at each site each day due to COVID-19 exposure or disease
Hospital site entered as a random effect (variance 0.61.95%CI: 0.25 - 1.46)
Area under receiver operating characteristic 0.84 (95%CI 0.81-0.87)

Sensitivity analyses: Hierarchical logistic regression models to identify factors associated with transfer of one or more critical care patient each day: Table 6a includes both type of hospital and geo-graphic region as confounders; Table 6b includes only geographic region as a confounder; Table 6c includes daily number of open ICU beds, number of open ICU over baseline, total number of patients in ICU (rather than occupancy); and Table 6d includes only public hospitals. These models were not reported as the main analysis due to high co-linearity between Hospital Type and Geographical region (Table 6a), or due to worse overall model performance characteristics using Akaike and Bayesian Information Criteria (Table 6a, 6b and 6c), or due to this being analysis of a subgroup of total hospitals (Table 6d).
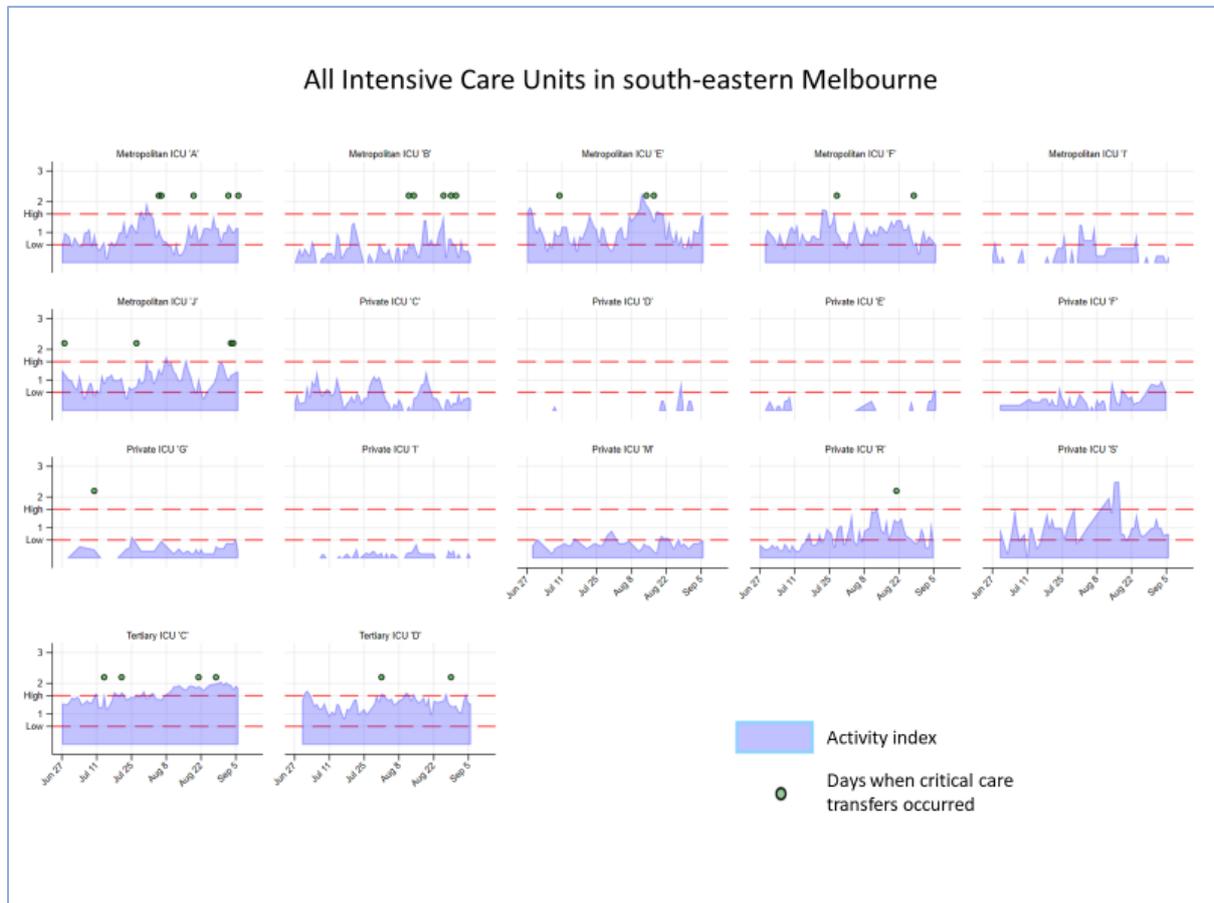
Appendix Figure 1a

ICU Activity Index (blue shading) and days when critical care patients were transferred (dots) from hospitals in north-western Melbourne
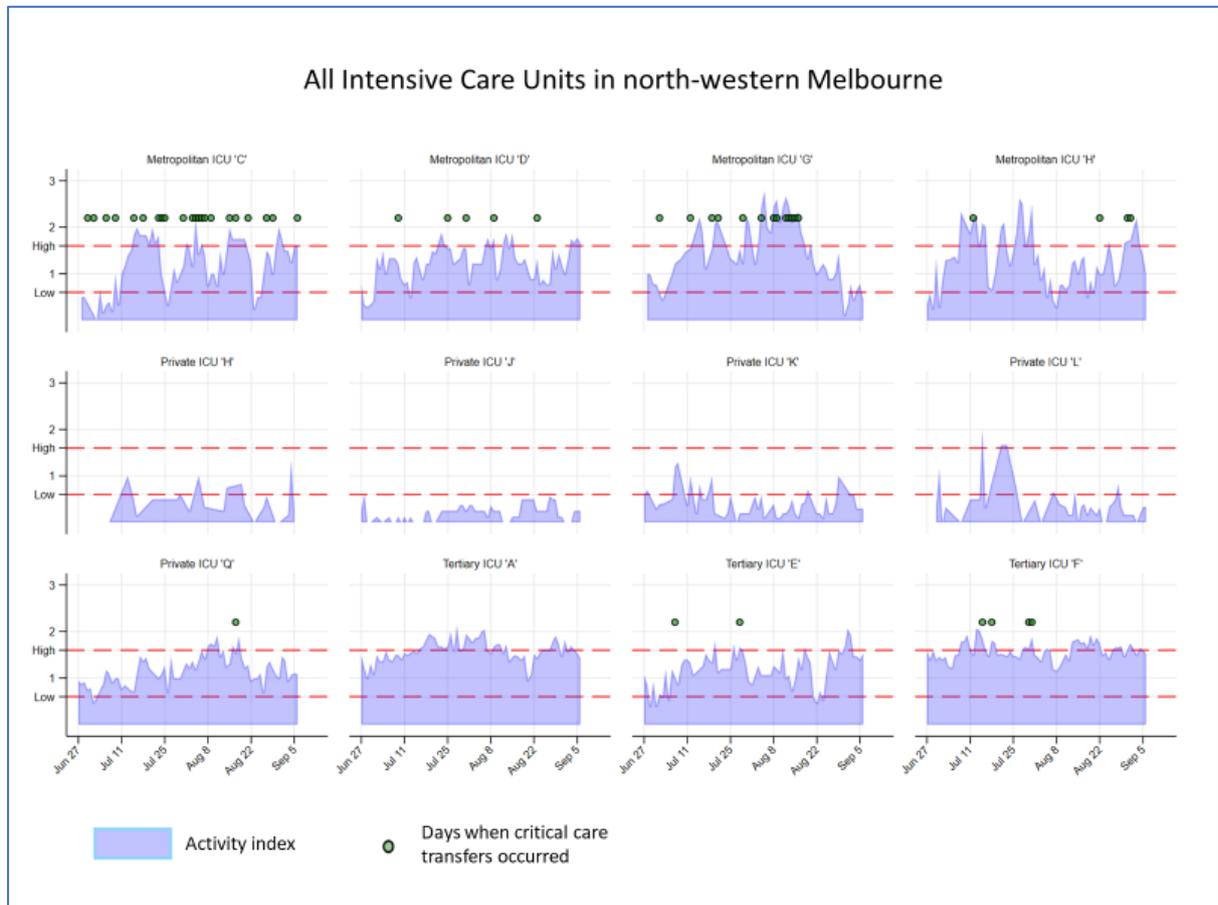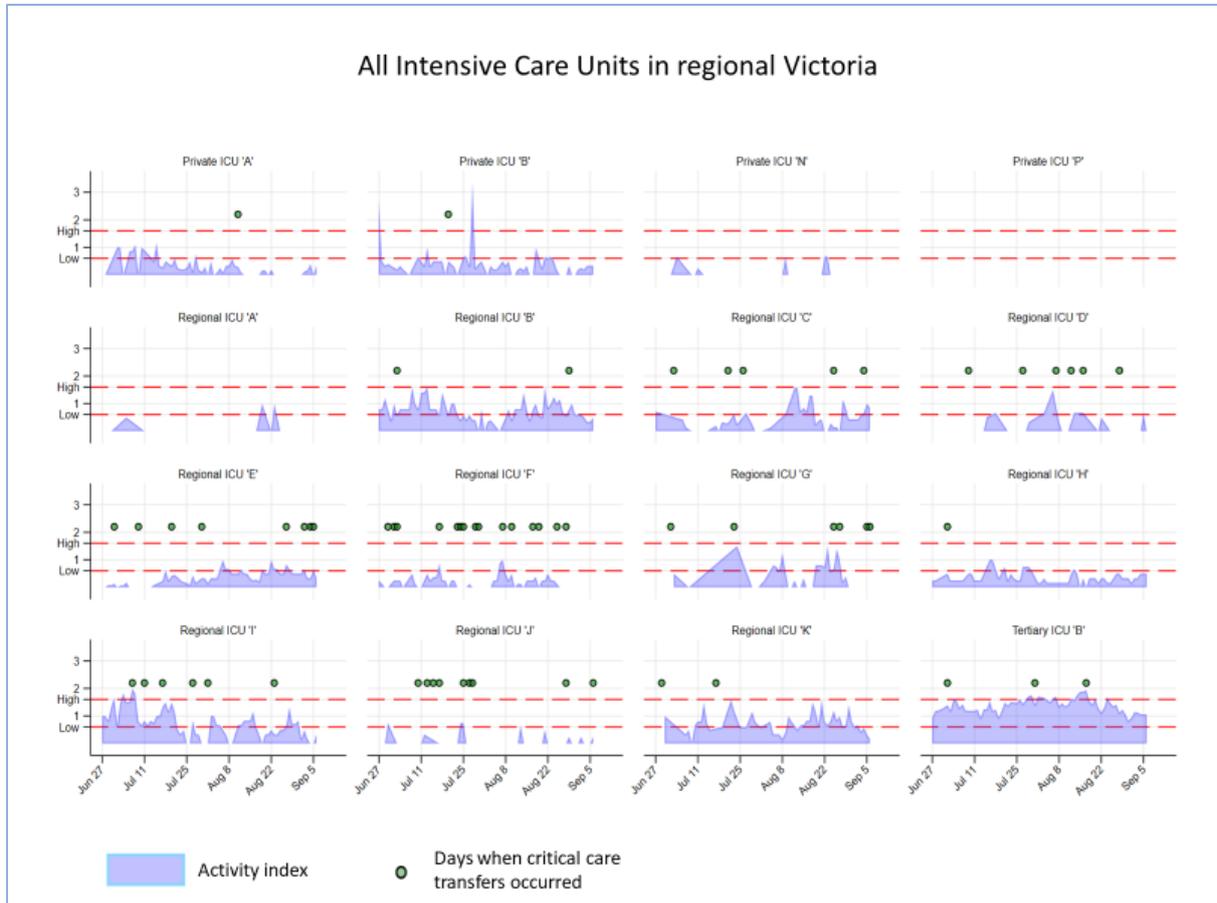
Appendix Figure 1b

ICU Activity Index (blue shading) and days when critical care patients were transferred (dots) from hospitals in south-eastern Melbourne
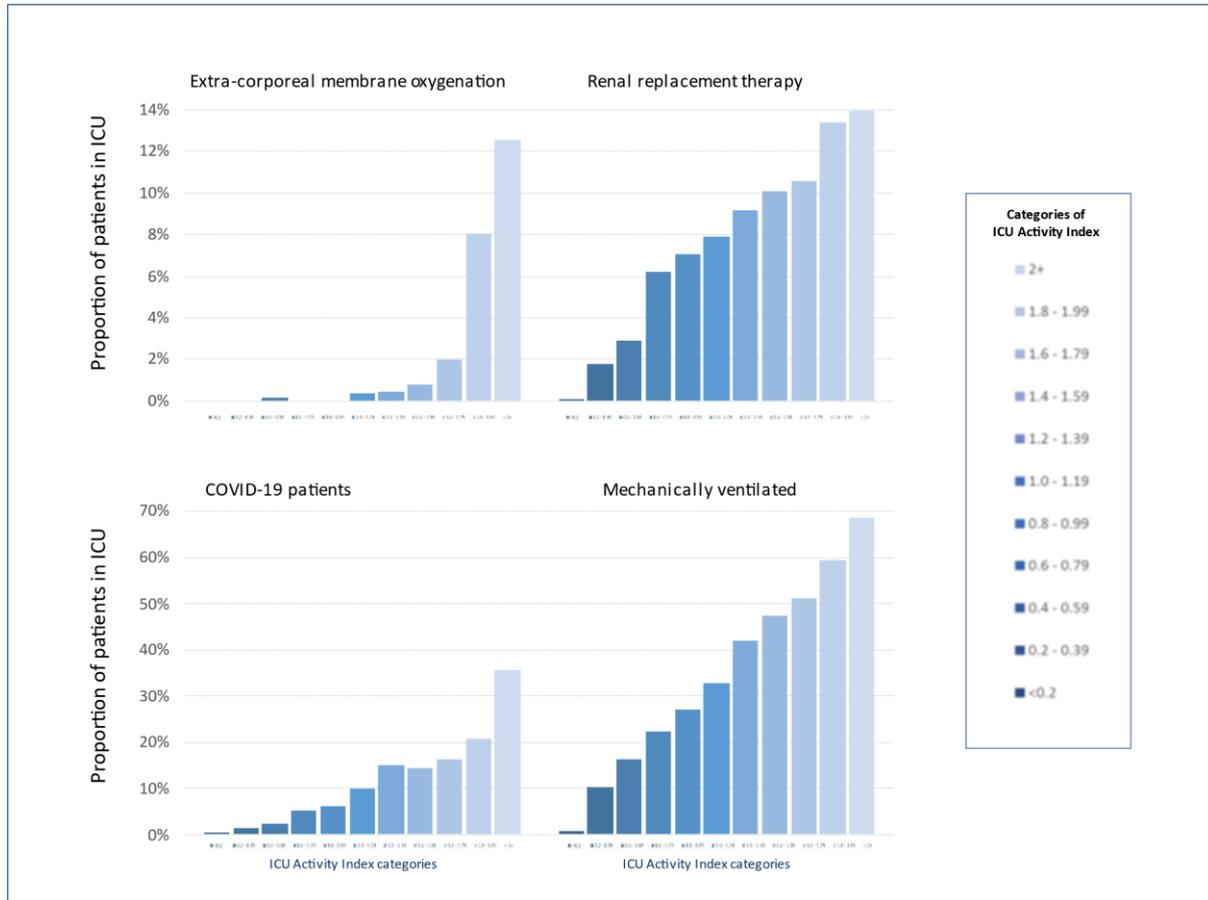
Appendix Figure 1c

ICU Activity Index (blue shading) and days when critical care patients were transferred (dots) from hospitals in regional Victoria

Appendix Figure 2

Mean proportion of patients within each ICU each day who received mechanical ventilation, renal replacement therapy or extra-corporeal membrane oxygenation, or who had COVID-19, plotted against rising ICU Activity Index categories.

Appendix Figure 3

Kernel density plot of ICU Activity Index at every site each day grouped by critical care transfer status