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Should paediatric intensive care be centralised? Trent versus Victoria

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Summary

Background The mortality rate is lower among children admitted to specialist paediatric intensive care units (ICUs) than among those admitted to mixed adult and paediatric units in non-tertiary hospitals. In the UK, however, few children receive intensive care in specialist paediatric units. We compared the ICU mortality rate in children from the area of the Trent Health Authority, UK, with the rate in children from Victoria, Australia, where paediatric intensive care is highly centralised.

Methods We studied all children under 16 years of age from Trent and Victoria who received intensive care between April 1, 1994, and March 31, 1995. Children younger than 1 month were excluded unless they had cardiac disorders. We developed a logistic regression model that used information gathered at the time of admission to ICU to adjust for risk of mortality.

Findings The rates of admission of children to intensive care were similar for Trent and Victoria (1·22 and 1·18 per 1000 children per year), but the mean duration of an ICU stay was 3·93 days for Trent children compared with 2·14 days for children from Victoria. 74 (7·3%) of the 1014 children from Trent died, compared with 60 (5·0%) of the 1194 children from Victoria. With adjustment for severity of illness at the time of admission to ICU, the odds ratio for the risk of death for Trent versus Victoria was 2·09 (95% CI 1·37–3·19, p<0·0005). There were 31·7 (14·0–50·4) excess deaths in Trent children, which is equivalent to 42·8% of the deaths in ICU, and 11·1% of all deaths in children between the ages of 1 month and 16 years in Trent.

Interpretation If Trent is representative of the whole country, there are 453 (200–720) excess deaths a year in the UK that are probably due to suboptimal results from paediatric intensive care. If the ratio of paediatric ICUs to children were the same in the UK as in Victoria, there would be only 12 paediatric ICUs in the country. Our findings suggest that substantial reductions in mortality could be achieved if every UK child who needed endotracheal intubation for more than 12–24 h were admitted to one of 12 large specialist paediatric ICUs.

Lancet 1997; **349:** 1213–17

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Introduction

There is extensive evidence from cross-sectional[1,2] and longitudinal[3] studies that hospitals or units that care for many patients with a given disorder have better results on average than hospitals that care for fewer patients. Children looked after in specialist paediatric intensive care units (ICUs) or trauma units in tertiary hospitals have a lower mortality rate than children in mixed adult and paediatric units or units in non-tertiary hospitals.[2,4–6] The American College of Critical Care Medicine and the

Society of Critical Care Medicine have strongly endorsed the principle of regionalisation of paediatric intensive care.[7]

Although the UK has been urged to centralise paediatric intensive care services,[8,9] they remain fragmented. To study the effects of fragmentation, we compared the mortality rate among all children from the area of Trent Regional Health Authority, UK, who received intensive care during a 12-month period with the mortality rate of children from the State of Victoria, Australia, who received intensive care. Victoria has a similar population to Trent, but paediatric intensive care is highly centralised, whereas that in Trent is dispersed.

Methods

All children younger than 16 years who lived in the study regions were included in the study if they were admitted to intensive care (within the regions, or outside) between April 1, 1994, and March 31, 1995. So that we obtained information about paediatric rather than neonatal intensive care, we excluded children younger than 1 month unless they had cardiac disorders. A record was made of the child's age, diagnosis, response of pupils to light, base excess, arterial oxygen tension, fractional inspired oxygen concentration, and systolic pressure at the time of admission; whether the admission was elective; whether the child was ventilated within 1 h of admission to ICU; and whether there was a specified underlying illness (cardiac arrest, severe combined immune deficiency, leukaemia, cerebral haemorrhage, cardiomyopathy, hypoplastic left heart, HIV infection, severe mental retardation, or a neurodegenerative disorder). In addition, the information needed to calculate the PRISM (paediatric risk of mortality) score[10] was recorded in 85% of the children.

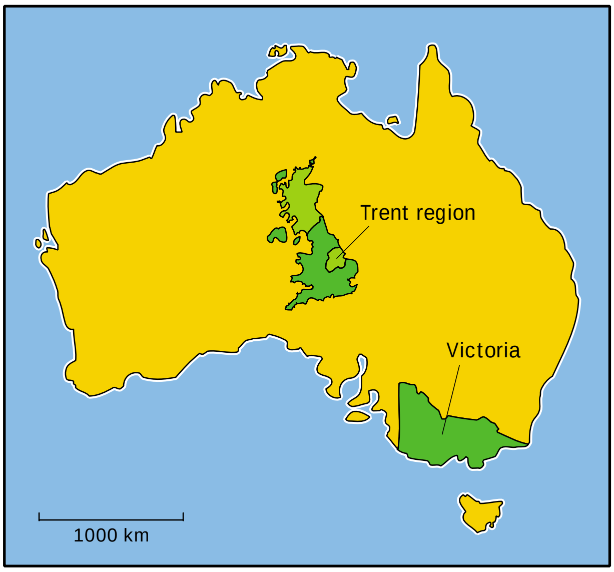
To check the accuracy of data collection, data for a subsample were collected independently by two investigators. All data were checked for internal consistency and physiological validity. So that the crude mortality rates in Trent and Victoria could be adjusted to allow for each individual child's risk of death at the time of admission to intensive care, we developed logistic regression models with death or survival as the dependent (outcome) variable. The explanatory variables used in the models were developed for use with the PIM (paediatric index of mortality) model.[11] We used contingency table analysis, Copas p by x plots,[12] Box-Tidwell analysis,[13] and partial residual plots to ensure that the explanatory variables were appropriately transformed; this process has been described in greater detail elsewhere.[11] The fit of the models was checked with graphs and tabulations of Pearson residuals, deviance residuals, leverage, and the change in the Pearson goodness-of-fit χ^2 and the deviance residuals that would result from deletion of an observation (and all others with the same covariate pattern).[13,14] Calibration was assessed by means of Hosmer and Lemeshow's goodness-of-fit χ^2 test, based on deciles of risk;[15] calibration measures how well the model classifies individuals into low and high risk categories (high p values suggest better classification). Discrimination was assessed by measurement of the area under the receiver-operating-characteristic (ROC) plot;[16] discrimination estimates how well the model distinguishes between individuals who lived and those who died (areas greater than 0·75 are generally agreed to indicate good discrimination).

To calculate the expected mortality rate with adjustment for the explanatory variables in the model, the location variable (Trent or Victoria) was set to the value for Victoria for all children in the study (which gave the number of deaths expected if all the ICUs had functioned to the same standard as Victorian ICUs). In addition, the data from Trent were analysed with a parametric bootstrap based on the maximum likelihood parameter estimates and the observed information matrix from all the data, with the location variable set to Trent and then to Victoria; the 95% CI for the number of excess deaths in Trent was obtained from the centiles of the differences between the two sets of expected values.

	Trent (n=1014)	Victoria (n=1194)
Median (IQR)*		
Age (months)	31 (6–86)	30 (10–103)
Base excess (mmol/L)	−2·2 (−4·9 to 0·9)	−2·1 (−5·5 to 0)
Systolic blood pressure (mm Hg)	104 (85–120)	105 (82–120)
$100\times FiO_2/PaO_2$	0·35 (0·24–0·63)	0·36 (0·23–0·83)
Number of children (% of total)		
Elective admission	409 (40·3%)	316 (26·5%)
Specified diagnosis	40 (3·9%)	48 (4·0%)
Ventilated in first hour	540 (53·3%)	510 (42·7%)
Pupils fixed in response to light	8 (0·8%)	25 (2·1%)

FiO_2=fractional inspired oxygen concentration; PaO_2=arterial oxygen tension in mm Hg. *Data were available from the following numbers of children: age (Trent, Victoria) n=996, n=1194; base excess n=568, n=624; systolic blood pressure n=731, n=891; $100\times FiO_2/PaO_2$ n=540, n=594.

Table 1: **Characteristics of children from Trent and Victoria**



Study regions in the UK and Australia
The maps of the two countries are drawn to the same scale.

Results

The figure shows the areas covered by the study. During the study period, 1014 children from Trent were admitted to intensive care (860 to 13 ICUs in Trent, and 154 to six ICUs outside Trent). 1194 children from Victoria were admitted to intensive care (1177 to 23 ICUs in Victoria, and 17 to two ICUs outside Victoria). 540 children from Trent and 510 from Victoria were ventilated during the first hour: 435 (85·3%) of those in Victoria were admitted to a single ICU in Victoria, whereas in Trent much smaller proportions were admitted to several ICUs (29%, 21%, 17%, 13%, and 9% to the five busiest ICUs). The characteristics of the children admitted to intensive care are shown in table 1.

In Victoria all children younger than 13 years (and all but 14 children aged 13–15 years) who were intubated for more than 24 h were admitted to two ICUs (Royal Children's Hospital or the Monash Medical Centre) except for four children with epiglottitis or croup who were admitted to country hospitals, and one child with convulsions. All the children younger than 16 years who died in ICU were admitted to the Royal Children's Hospital ICU or were transferred there, except for four children who died at Monash Medical Centre, and one 15 year-old who died from multiple trauma at the State

	Regression coefficient (SE)	
	PRISM model	PIM model
Constant	−1·845 (0·563)	−4·690 (0·284)
Location (Trent=1, Victoria=0)	0·734 (0·233)	0·738 (0·216)
Probability of death*	1·257 (0·819)	· ·
Natural log of probability of death*	0·678 (0·150)	· ·
$100\times FiO_2/PaO_2$	0·401 (0·146)	0·632 (0·139)
Pupils not reacting†	1·852 (0·555)	2·920 (0·437)
Specified diagnosis†	2·060 (0·323)	2·224 (0·307)
Elective admission†	· ·	−1·333 (0·280)
Ventilated within 1 h of admission†	· ·	1·530 (0·276)
Absolute base excess (mmol/L)	· ·	0·057 (0·020)

*Predicted by PRSM. †yes=1, no=0. PaO_2=arterial oxygen tension in mm Hg.

Table 2: **Logistic regression models**

Trauma Centre. By contrast, children from Trent died in nine different ICUs.

For the check on the accuracy of data collection, two investigators in Victoria and two in Trent collected data on subsamples of children independently (60 in Victoria, 122 in Trent). In Victoria, there were no differences between the investigators in any of the observations on pupils, whether the admission was elective, ventilation, or base excess. However, one child had a difference in 100×the ratio of fractional inspired oxygen to arterial oxygen tension of more than 0·1; two children had different entries for specified diagnosis; and six children had a difference in systolic blood pressure of more than 10 mm Hg. In Trent, there were no differences between the investigators in the observations on pupils, ventilation, base excess, ratio of fractional inspired oxygen to arterial oxygen tension, systolic blood pressure, and specified diagnosis; however, for four children the entries on whether the admission was elective differed.

Logistic regression with death in intensive care or survival as the dependent variable showed that the best model that included the probability of death as predicted by PRISM[10] also included the logarithm of the PRISM probability of death as an explanatory variable (table 2). This model fitted the data well (goodness-of-fit with 8 df p=0·15 for Trent, p=0·83 for Victoria) and discriminated well (area under the ROC plot 0·84 and 0·94, respectively). The information needed to calculate the PRISM score was available for 988 children from Trent and 887 children from Victoria.

Another model was developed (with the same variables as PIM[11]), which used only data obtained at the time the children were admitted to intensive care; this information was available for all patients (table 2). This model also

	Trent			Victoria		
	n	Deaths	Expected deaths*	n	Deaths	Expected deaths*
Total	1014	74	42·3	1194	60	60·0
Diagnostic category						
Respiratory	162	10	7·4	330	8	9·8
Cardiac	318	20	14·4	296	19	15·1
Postoperative	189	4	1·7	91	1	1·9
Accidents	137	13	7·5	197	10	14·2
Neurological	93	9	4·9	96	12	9·1
Other	115	18	6·5	184	10	10·0
Expected mortality						
<1%	381	5	2·4	528	1	4·2
1–4%	374	17	8·4	416	7	9·5
5–14%	226	36	16·9	185	15	14·5
15–29%	11	4	2·4	19	8	4·2
⩾30%	22	12	12·2	46	29	27·6

*Calculated with Trent/Victoria location variable set to Victoria.

Table 3: **Deaths in Trent and Victoria by diagnostic category and by expected mortality**

	Trent	Victoria
Population		
Total	4 200 000	4 500 000
<16 years	833 000	1 011 000
Deaths aged 1 month to <16 years		
Number	266	257
Per 100 000 <16 years	31·9	25·4
Child ICU admissions*		
Number per year*	1014	1194
Per 1000 <16 years*	1·22	1·18
Ventilated in first hour per 1000 <16 years*	10·65	0·05
Mean length of stay (days)*	3·93	2·14
Child ICU days/1000 <16 years*	4·80	2·53

*Children aged <16 years except for babies younger than 1 month without cardiac disorders.

Table 4: **Demographic and intensive care data for Trent and Victoria, 1994**

fitted the data well (goodness-of-fit with 8 df p=0·67 for Trent, and 0·64 for Victoria) and discriminated well (area under the ROC plot 0·82 and 0·92). There were no significant interactions between explanatory variables in the model; in particular, there were no significant interactions between location (Trent or Victoria) and the other variables.

The odds ratio of death for children from Trent relative to Victoria, adjusted for severity of illness by means of the other explanatory variables, was similar in the two models (2·09 [95% CI 1·32–3·29], p=0·002 for the model that incorporated PRISM; 2·09 [1·37–3·19], p<0·0005 for the model based on PIM variables). Because the models both fitted the data well and information was available for all patients for the PIM (admission data) model, it was used for the main analysis.

There were more deaths than expected in all diagnostic groups for Trent children, and the excess deaths occurred at all levels of risk of mortality except 30% or more (table 3). There were 60 deaths in Victoria, with 60·0 deaths expected from the model, whereas in Trent there were 74 deaths, with 42·3 deaths expected. Thus, there was an excess of 31·7 (95% CI 14·0–50·4) deaths in the children from Trent. This excess is equivalent to 42·8% (18·9–68·1) of the 74 deaths. The number of children younger than 16 years is 833 000 in Trent and 11 900 000 in the UK so, if Trent is representative of the whole country, the number of excess deaths in the UK is 453 per year (200–720).

The crude mortality rate was 7·3% in the 1014 Trent children admitted to intensive care, or 8·9 ICU deaths per 100 000 children younger than 16 years, and the standardised mortality rate was 175% (with Victoria defined as 100%). In Victoria, the crude mortality rate was 5·0% in the 1194 ICU admissions, or 5·6 ICU deaths per 100 000 children. The excess mortality in Trent children aged 1 month to 15 years was 29·4, which represents 11·1% of the 266 deaths in this age-group in 1994 (table 4). If these children had survived, the mortality rate in Trent would have fallen from 31·9 to 28·4 per 100 000 children.

The number of children younger than 16 years admitted to intensive care in the 12 months of the study was almost the same in the two regions—1·22 per 1000 children in Trent and 1·18 per 1000 in Victoria (table 4). However, the mean duration of an ICU stay was 3·93 days for children from Trent and only 2·14 days for children from Victoria (p<0·00005, Mann-Whitney *U* test), so there were 4·80 child ICU days per 1000 Trent children and only 2·53 in Victoria.

Discussion

We developed two logistic regression models that predict the risk of death in intensive care in children from Trent and Victoria. One model included the risk of death as predicted by the PRISM score,[10] and the other included only data available at the time of admission to ICU and used the variables developed for the PIM mortality prediction model.[11] We checked the validity of both models carefully. Both fitted the data for Trent and Victoria well, and both gave an odds ratio of 2·09 for death of children in Trent relative to Victoria. We had the information needed to calculate the risk of mortality for only 85% of children with the PRISM model and for all the children with the PIM model, so we used the latter model for the main analysis.

The variables used in the PIM model have been found to provide reliable prediction of mortality in children in intensive care in both Australia and the UK.[11] At the Birmingham Children's Hospital ICU, which is a large specialist paediatric unit in the region adjacent to Trent, there were slightly fewer deaths than predicted by PIM (21 deaths, 27·2 predicted).[11] The fact that the PIM variables have good predictive ability in Birmingham suggests that our model is a valid tool to use in Trent.

We calculated the number of deaths expected if ICUs looking after Trent children had achieved results equivalent to the ICUs in Victoria. 74 children from Trent died, which was 31·7 (95% CI 14·0–50·4) more than expected. This excess is unlikely to be a result of a defect in the model that made children from Trent appear to be less ill than they actually were—the PIM model slightly overpredicts mortality in the Birmingham Children's Hospital ICU (the children appear to be more ill); similar proportions of the populations of Trent and Victoria were admitted to intensive care (table 4); the numbers of ICU deaths predicted by the model were similar (5·1 per 100 000 Trent children and 5·9 per 100 000 children from Victoria); and the crude mortality rate in ICU was 7·3% for Trent (8·9 per 100 000 children) and only 5·0% for Victoria (5·6 per 100 000 children). Some ICUs in Trent may have performed well, but this possibility could not be tested because individual units admitted so few patients.

It is not clear whether the benefits of centralisation are attributable to larger paediatric ICUs, or to full-time specialist paediatric intensive care consultants, nurses, and residents.[1–6,17] However, the combination of large units and full-time specialist staff is clearly beneficial. Victoria (and Birmingham) have large paediatric ICUs that are staffed by full-time specialists in paediatric intensive care, and mortality is low. Intensive care in Trent is decentralised, and very few children are looked after by full-time specialists in paediatric intensive care; mortality is high. The delivery of intensive care to children from the Trent region appears to be typical of the pattern throughout the UK, where many ICUs provide intensive care to critically ill children within each region.[8] If Trent is typical of the UK, the 31·7 (95% CI 14·0–50·4) excess deaths can be extrapolated to 453 (CI 200–720) excess deaths per year in the whole country because of the suboptimal quality of care for children in some ICUs.

The excess of deaths in intensive care is of sufficient magnitude to affect child mortality in Trent. With the exclusion of babies younger than 1 month, there were 29·4 excess deaths in Trent children, which represents 11·1% of the 266 deaths in this age-group in 1994 (table 4). If these children had survived, the child mortality rate in Trent would have fallen from 31·9 to 28·4 per 100 000 children, close to the rate of 25·4 found in Victoria.

The other important finding of this study relates to the utilisation of intensive care resources. Previous data suggested that only about 0·7 children per 1000 were admitted to ICUs in the UK,[18] but a subsequent survey[8] and our study suggest that the actual rate is about 1·2 per 1000 children—the same as the rate we found for Victoria (table 4). However, the mean duration of an ICU stay was 3·93 days for Trent children and only 2·14 days for Victoria, so the same number of children used 90% more ICU bed days in Trent than in Victoria (table 4). The perceived shortage of intensive care beds for children in the UK[8,19] may be due to inefficient use of the available beds, rather than a lack of beds.

Of the 13 ICUs located in Trent that provided intensive care to children, three were designated as paediatric ICUs. All three of these units were physically distinct from an adult ICU, but only two had their own nursing establishment, only one had a full-time consultant in intensive care, and none had resident staff exclusively on call for the unit at all times. These three paediatric ICUs each admitted an average of only 245 children per year, and only 121 children who required ventilation per year.

In Victoria, almost all very ill children are looked after in a single paediatric ICU at the Royal Children's Hospital. There were 887 patients admitted to this unit during our study. 435 were ventilated. (In fact, 1238 children were admitted to the unit during the study, but many were from other Australian States or other countries.) This ICU employs four full-time consultants in paediatric intensive care, ten full-time ICU registrars with a minimum of 4 years of experience in paediatrics of anaesthesia, and nursing staff who are all trained or being trained in paediatric intensive care. A high standard of care can therefore be provided. On average, children stay only a short time in the unit, for several reasons. The high standard of care reduces the likelihood of complications, the continuous availability of at least two senior registrars means that children can be extubated throughout the day and night, and the general wards in this tertiary paediatric hospital are used to looking after sick children, so they accept children earlier than would general wards in district hospitals. In addition to the savings from shorter stays, paediatric ICUs that serve a large population are subject to less random variability in demand than small ICUs and so they need relatively fewer beds to ensure availability on a given proportion of days.[20]

If specialist paediatric emergency transport is available, the benefits of centralisation far outweigh the adverse effects of having to take children to a regional paediatric ICU. Victoria has one paediatric ICU serving an area of 87 884 square miles, which is almost equal to the area of Great Britain (figure). In Trent, three paediatric ICUs serve an area of only 5700 square miles.

Our study provides strong evidence that a centralised system staffed by full-time specialists in paediatric intensive care delivers care of higher quality and with much greater efficiency than the decentralised and fragmented system found in Trent and throughout the UK. If the UK had the same ratio of paediatric ICUs to children as Victoria, there would be only 12 paediatric units in the country, and each of these units could run a specialist transport team to collect very ill children from anywhere in their region. Our study suggests that, if all UK children who needed endotracheal intubation for longer than 12–24 h were admitted to one of 12 large specialist paediatric ICUs, there would be substantial reductions in mortality and in the cost of paediatric intensive care.

We thank all the ICUs in the study for their cooperation and the following people who collected data: N Abbott, F Bell, R Bonato, D Buckley, J Burden, C Cain, C Corke, M Coulthard, P Cranswick, S Cronin, G Derrick, T Duke, K Dunn, D Ernest, F Fabretti, G Frawley, B Frey, G Gutteridge, H Hewitt, C Hill, S Hodgens, V Hui, J Hurley, B Johnson, B Jones, S Keeley, S Kerr, M Losa, D Macrae, J McDonald, R McLean, E O'Sullivan, G Pallis, C Parshuram, S Parsons, C Ralston, R Ross-Russel, G Russell, J Santamaria, C Scheinkestel, E Sleight, T Sutherland, N Taga, P Talbot, I Webb, H Werner, V White, M Williams. L Draper supplied the OPCS survey data for Trent. J Carlin calculated the CI for the number of excess deaths in Trent.

This study was supported by a grant from the Trent Regional Health Authority.

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