Caring for critically ill adults in paediatric intensive care units in England during the COVID-19 pandemic: planning, implementation and lessons for the future

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ABSTRACT

Objective To describe the experience of paediatric intensive care units (PICUs) in England that repurposed their units, equipment and staff to care for critically ill adults during the first wave of the COVID-19 pandemic.

Design Descriptive study.

Setting Seven PICUs in England.

Main outcome measures (1) Modelling using historical Paediatric Intensive Care Audit Network data; (2) space, staff, equipment, clinical care, communication and governance considerations during repurposing of PICUs; (3) characteristics, interventions and outcomes of adults cared for in repurposed PICUs.

Results Seven English PICUs, accounting for 137 beds, repurposed their space, staff and equipment to admit critically ill adults. Neighbouring PICUs increased their bed capacity to maintain overall bed numbers for children, which was informed by historical data modelling (median 280–307 PICU beds were required in England from March to June). A total of 145 adult patients (median age 50–62 years) were cared for in repurposed PICUs (1553 bed-days). The vast majority of patients had COVID-19 (109/145, 75%); the majority required invasive ventilation (91/109, 85%). Nearly, a third of patients (42/145, 29%) underwent a tracheostomy. Renal replacement therapy was provided in 20/145 (14%) patients. Twenty adults died in PICU (14%).

Conclusion In a rapid and unprecedented effort during the first wave of the COVID-19 pandemic, seven PICUs in England were repurposed to care for adult patients. The success of this effort was underpinned by extensive local preparation, close collaboration with adult intensivists and careful national planning to safeguard paediatric critical care capacity.

What is already known on this topic?

- During the first wave of the COVID-19 pandemic in England, there was a significant demand for adult critical care beds.
- Surge critical care beds were created in theatres and recovery areas and respiratory wards, and in some parts of the country, in paediatric intensive care units (PICUs).
- There is a lack of national data on the extent to which PICUs were transformed to manage adult patients and how critical care services for children were maintained nationally.

What this study adds?

- Seven PICUs in England repurposed their space, equipment and staff to care for 145 critically ill adults during the first wave of the pandemic.
- Modelling based on historic national clinical audit data was used to predict national demand for PICU beds to maintain adequate provision for critically ill children in other units.
- Repurposed PICUs cared for nearly one in five adults needing critical care within their own hospitals.

INTRODUCTION

On 11 March 2020, WHO declared the COVID-19 outbreak a pandemic.[1] Experience from China and Italy indicated that 98% of all infections were in adults, and at least 5% of infected adults required critical care admission. Only 2% of infections were in children, of whom just 1%–2% required paediatric intensive care unit (PICU) admission.[2–5]

National and international modelling, together with early clinical experience, indicated that the demand for adult intensive care unit (AICU) beds during the pandemic was likely to rapidly outstrip bed capacity several-fold.[6–9] Increasing AICU surge capacity during pandemics and other mass-casualty disasters has been the subject of much discussion.[10–12] Since there are far fewer critical care beds for children than for adults, the use of AICU beds for critically ill/injured children has been an important consideration in pandemic plans (including during the H1N1 influenza pandemic in 2009), whereas the opposite scenario (utilisation of PICU beds for critically ill adults) has not featured heavily.[13 14]

In England, paediatric intensive care is a centralised, nationally commissioned service, comprising PICUs based in tertiary hospitals and

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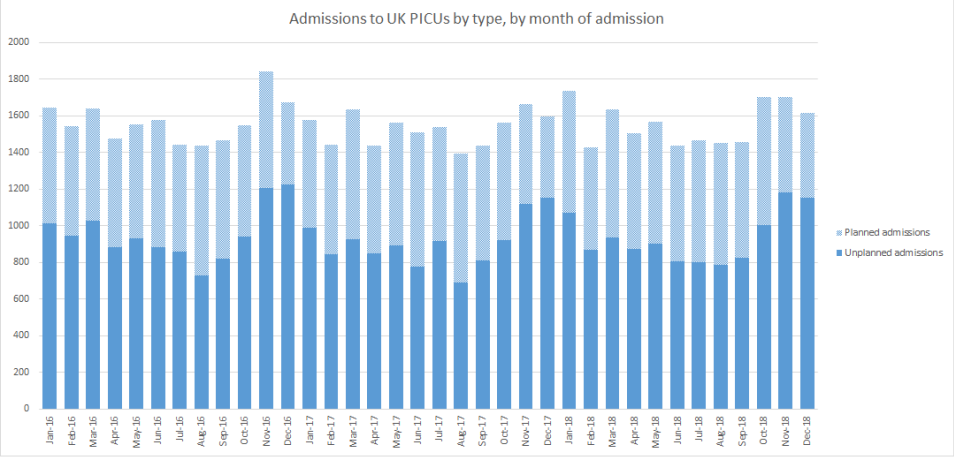

Figure 1 Seasonal pattern of unplanned admissions to paediatric intensive care units (PICUs) in England.

associated specialist retrieval teams.[15] Prior to the COVID-19 pandemic, there were 312 PICU beds in 22 hospitals (2.7 beds per 100 000 children aged <18 years), compared with 4123 AICU beds in over 150 hospitals (9 beds per 100 000 adults).[16 17] English PICUs admit around 15 000 children each year, nearly 10 000 of them being unplanned admissions.[18] Importantly, demand for PICU beds follows a seasonal pattern, with a 30% increase in unplanned respiratory admissions over winter.[19]

Table 1 Modelling predicted demand for paediatric intensive care beds in England using historical data from November 2018 through to June 2019

	England	North	Midlands and East	London	South
Nov-18					
Mean (SD)	341.6 (21.9)	98.0 (6.2)	77.5 (4.6)	127.0 (9.8)	43.4 (3.8)
Med (min-max)	338.5 (300, 388)	97.1 (82, 120)	77.3 (63, 90)	125.8 (97, 156)	43.5 (32, 54)
IQR	327–356	93.7–101.6	73.8–81.5	120.3–132.2	40.7–45.7
Dec-18					
Mean (SD)	324.7 (30.4)	93.6 (8.7)	71.8 (5.1)	121.4 (12.1)	39.3 (7.8)
Med (min-max)	332.0 (266, 370)	94.4 (64, 113)	72.3 (56, 85)	122.0 (92, 152)	41.6 (18, 54)
IQR	305–350	87.7–100.8	67.8–75.4	110.6–132.1	33.7–45.0
Jan-19					
Mean (SD)	307.4 (15.3)	90.7 (6.3)	71.4 (4.3)	109.5 (6.8)	37.3 (4.9)
Med (min-max)	311.0 (273, 328)	91.2 (72, 112)	71.5 (56, 83)	109.8 (89, 131)	36.8 (25, 50)
IQR	295–320	86.7–94.5	68.8–74.9	104.9–114.2	33.0–41.7
Feb-19					
Mean (SD)	308.6 (14.2)	91.1 (5.4)	69.0 (5.4)	105.9 (6.9)	42.0 (2.7)
Med (min-max)	310.5 (268, 328)	91.5 (71, 109)	69.5 (48, 83)	105.6 (84, 125)	42.2 (33, 51)
IQR	304–318.5	88.4–94.4	66.3–72.6	101.3–111.3	40.3–43.7
Mar-19					
Mean (SD)	296.0 (17.3)	79.3 (5.3)	66.5 (5.6)	108.7 (6.8)	38.7 (4.4)
Med (min-max)	296.0 (264, 327)	78.9 (64, 96)	66.0 (51, 83)	108.6 (85, 129)	39.0 (27, 50)
IQR	281.0–311.0	75.5–82.6	62.4–70.0	104.1–114.1	35.7–41.4
Apr-19					
Mean (SD)	301.2 (17.4)	77.8 (8.2)	68.2 (5.7)	110.4 (8.0)	43.1 (3.0)
Med (min-max)	307.0 (258, 325)	79.0 (51, 97)	68.4 (53, 84)	110.8 (88, 131)	42.9 (35, 52)
IQR	291.0–315.0	72.1–84.2	63.6–72.0	104.6–116.5	40.9–45.3
May-19					
Mean (SD)	293.1 (15.7)	80.1 (6.9)	64.8 (4.5)	105.0 (6.5)	39.2 (4.5)
Med (min-max)	293.0 (262, 316)	80.1 (62, 100)	64.9 (50, 80)	105.8 (82, 124)	38.7 (27, 51)
IQR	281.0–307.0	74.2–86.0	61.5–67.8	100.7–109.9	36.1–42.6
Jun-19					
Mean (SD)	278.7 (15.8)	73.9 (6.1)	60.8 (5.6)	103.2 (6.4)	35.5 (3.6)
Med (min-max)	280.5 (251, 304)	73.9 (56, 91)	61.0 (46, 78)	102.3 (84, 122)	35.5 (24, 45)
IQR	264.0–292.0	69.4–78.3	56.6–64.9	97.9–108.6	32.9–38.0

IQR, Inter-quartile range; SD, Standard deviation.

Table 2 Prepandemic characteristics of seven repurposed PICUs in England

Hospitals	St Mary's Hospital	Royal Brompton Hospital	Royal London Hospital	Alder Hey Children's Hospital	Royal Manchester Children's Hospital	King's College Hospital	Royal Stoke University Hospital	Total
Region	Northwest London	Northwest London	Northeast London	Northwest England	Northwest England	Southeast London	North Midlands	
Hospital characteristics								
Paediatric Emergency Department	Yes	No	Yes	Yes	Yes	Yes	Yes	
Retrieval Service	No	Yes (adult ECMO)	Yes (London Air Ambulance HEMS)	Yes	Yes	No	No	
Critical care characteristics								
Paediatric (level 3)*	11	16	6	21	15	8	6	83
Paediatric (level 2)†	4	8	4	14	12	8	4	54
Paediatric ECMO	No	Yes	No	Yes	No	No	No	
Adult (level 2 and 3)	32	42	44	0	56	69	52	295
PICU characteristics								
Annual admissions	412	569	369	951	1133	642	277	4353
External admission sources	CATS and STRS	CATS and STRS	CATS and STRS	NWTS	NWTS	STRS and CATS	KIDS and NWTS	
Usual PICU case-mix	Medical-surgical	Cardiorespiratory	Medical-surgical	Medical-surgical and cardiac	Medical-surgical	Medical-surgical	Medical-surgical	
Specialist services	Paediatric Major trauma centre Paediatric HCID-A centre Non-oncological bone marrow transplant centre	Congenital heart surgery (all ages) Long-term ventilation (all ages) Adult unit is one of five centrally funded ECMO centres for acute respiratory failure	Major trauma centre (all ages) National referral centre for bone marrow failure syndromes, Tertiary gastroenterology and endocrinology	Paediatric Major Trauma centre Paediatric ECMO centre (cardiac and respiratory) Congenital heart surgery Paediatric HCID-A centre Designated Vein of Galen centre	Metabolic service Bone marrow transplant service	Major trauma centre Tertiary gastroenterology National Liver Transplant Centre Neurosciences		

*Level 3 critical care defined as invasive organ support (intensive care).
†Level 2 critical care defined as high dependency care.
CATS, Children's Acute Transport Service; ECMO, extracorporeal membrane oxygenation; HCID-A, High Consequence Infectious Disease—Airborne; HEMS, Helicopter Emergency Medical Service; KIDS, Kids Intensive Care and Decision Support; PICU, paediatric intensive care unit; STRS, South Thames Retrieval Service.

While many PICUs supported adult critical care expansion through loan of space and equipment during the COVID-19 pandemic, single-centre reports from Europe and the USA describe how they repurposed their entire PICUs, including staff, to care for critically ill adults[20 21]; however, there is a dearth of national data on this topic.

The National Health Service declared a level 4 incident in early March 2020.[22] Plans to rapidly increase AICU bed capacity were implemented initially by cancelling elective surgery, then creation of additional critical care beds outside AICU areas through stepwise escalation—high dependency units, operating theatres and recovery areas, followed by other acute wards and finally, the newly built Nightingale hospitals.[23 24] Since surge planning occurred at a regional and individual hospital level, plans to use PICU beds to care for adult patients featured in some regions and not in others. In this article, we describe how seven PICUs in England repurposed their units, equipment and staff to look after adult patients during the first wave of the COVID-19 pandemic; how regional and national level planning maintained overall PICU bed capacity for critically ill children; the characteristics, interventions and outcomes of adult patients cared for in repurposed PICUs and lessons learnt for future waves of the pandemic.

METHODS

National planning

Paediatric intensive care has a limited number of units configured in long-established 'hub-and-spoke' networks with dedicated transport teams.[25] To support adult critical care demands on paediatric critical care, the UK Paediatric Intensive Care Society (PICS) coordinated national planning and support for all PICUs through: a) weekly web conferences for clinicians from individual PICUs to jointly discuss their bed capacity and regional surge arrangements, allowing for a 'birds-eye' view of national PICU capacity; and b) rapid national clinical guidance to cover various 'hot' topics relevant to these clinical teams.

Modelling PICU demand

If some PICUs were being repurposed to care for adults, plans for maintaining adequate capacity for critically ill children in England crucially depended on estimation of anticipated demand for PICU beds at a regional and national level. In late March 2020, we analysed routine audit data from the Paediatric Intensive Care Audit Network (PICANet) database, a high-quality clinical database to which all UK PICUs submit data, to estimate the average (and minimum) demand for PICU beds nationally and regionally in England from March through to June. Historical

Table 3 Plans for expanding critical care capacity to look after adults using repurposed PICU space and staff

Hospitals	St Mary's Hospital	Royal Brompton Hospital	Royal London Hospital	Alder Hey Children's Hospital	Royal Manchester Children's Hospital	King's College Hospital	Royal Stoke University Hospital
Ring-fenced arrangements for paediatric critical care patients	2 bed-spaces for internal emergency	1 bed-space for internal emergency on a separate ward	2 bed-spaces for internal emergency	Bed-spaces for ECMO service and emergency cardiac surgery	15 bed-spaces for internal emergency Accept external time-critical admissions and specialist local service referrals	4 bed-spaces for internal emergency, mainly liver and neurosciences Accept external admissions for neurosurgery and liver referrals	No bed-spaces
Diversion arrangements	Divert CATS admissions to GOSH/ELCH	Divert CATS/STRS admissions to GOSH/ELCH	Divert CATS/STRS admissions to GOSH/ELCH	None	Divert referrals	Diverts all CATS/STRS admissions to GOSH/ELCH	Divert KIDS admissions to BCH
Alternative provision				PHDU relocated to a general ward Burns unit relocated	Satellite level 2 paediatric critical care facility on general ward		
Admission capacity for level 2–3 adult critical care	15 COVID	18 COVID, including ECMO	12 non-COVID and COVID	19 non-COVID and COVID	21 COVID	12 non-COVID	10 COVID

BCH, Birmingham Children's Hospital; CATS, Children Acute Transport Service; ELCH, Evelina London Children's Hospital; GOSH, Great Ormond Street Hospital; KIDS, Kids Intensive Care and Decision Support; PHDU, paediatric high dependency unit; PICU, paediatric intensive care unit; STRS, South Thames Retrieval Service.

data from November 2018 to June 2019 were used for modelling. Since over 60% of PICU admissions are unplanned, and even planned admissions for major complex surgery (eg, congenital heart disease) cannot safely be postponed for longer than a few weeks, 500 scenarios were simulated for each month and region with 10% of planned admissions randomly removed without replacement. Summary statistics for the number of bed days estimated to be required (should 10% of planned workload be removed for each month in 2019–2020) were then calculated at regional level based on these simulated datasets.

Repurposing PICU

In line with recent guidance,[26–28] the challenges for the repurposed units were broadly categorised into: space, staff, equipment, clinical care, communication and governance. Details regarding how PICUs were repurposed along these principles, as well as how they were adapted to local requirements, were collected from the individual units. Repurposed PICUs also collected data on the clinical characteristics, interventions performed and outcomes of adults cared for in their units, as well as numbers of children cared for at the same time (if any) and transfers out of children from their hospital to other PICUs. Summary data were pooled by the lead author from all units for descriptive analysis.

RESULTS

From 19 March to 2 June 2020, 13 national web conferences were organised by PICS, with representation from all PICUs in England. In anticipation of significant demand for adult critical care beds, PICS and their adult counterpart, the ICS, published a joint position statement in early March supporting the flexible use of PICU beds for specific cohorts of young adults.[29] However, it became rapidly obvious that the majority of critically ill adults were older than 40 years, therefore significant redeployment of PICU staff and equipment to adult ICUs was needed to support critical care expansion.[30]

Data modelling

Figure 1 shows the seasonal demand for PICU beds in the UK, with the number of unplanned admissions lowest in summer, followed by a 20% rise in demand over winter. In table 1, the mean and median bed activity data for each region in the UK is summarised by month covering the period from November 2018 to June 2019. The median bed activity in the pandemic months (March–June) in England was estimated from historical data to be 280–307, with a minimum of 251 beds. These numbers accounted for the cancellation of planned surgery. The median bed activity in winter months was estimated to be a median of 310–338, with a minimum estimate of 266. The COVID-19 pandemic occurred during spring/summer months, when demand for unplanned admissions to PICU was nearly 20% lower than in winter months.

Repurposing PICUs

Seven PICUs in England admitted critically ill adults to their fully repurposed units. As shown in tables 2 and 3, they accounted for a total of 83 PICU and 54 high-dependency care beds prior to the pandemic. Staff redeployment affected almost all UK PICUs; however, the choices around whether to maintain familiarity (keeping the teams together in their usual environment), or to redeploy staff to help adult services, involved making complex decisions at a time of great stress, and these seven units chose to keep their teams together in their usual environment. In most cases, staff had never been trained to care for adults or had not looked after adults for many years.

Considerations during repurposing included:

1. *Space*: the re-organisation of the physical PICU space to identify 'green' and 'red' areas with donning and doffing facilities for personal protective equipment (PPE).
2. *Staffing (skills)*: the rapid credentialing of paediatric-trained staff to identify those with recent ICU experience, redeployment and training on the basics of management of critically ill adults (including those with COVID-19), via remote, face-to-face and simulated educational sessions.
3. *Staffing models*: the overhaul of medical and nursing rotas to provide for additional layers of cover in the context of COVID-19 related illness and/or quarantine requirements. Some units needed to rapidly implement full shift, resident consultant rotas.

Table 4 Logistics involved in repurposing seven PICUs to care for critically ill adults—space, staff and equipment

Hospitals	St Mary's Hospital	Royal Brompton Hospital	Royal London Hospital	Alder Hey Children's Hospital	Royal Manchester Children's Hospital	King's College Hospital	Royal Stoke University Hospital
Space management	Entire PICU designated as COVID 'red' clinical zone. Designated green zone for breaks and meetings to meet social distancing guidelines. Internal paediatric emergencies needing critical care admitted to two negative-pressure cubicles.	Entire PICU designated as COVID 'red' clinical zone, and reorganisation of PICU/entrance to accommodate doffing. Paediatric sleep unit converted as 'green' command-control centre and staff donning area. Virtual handover and rounds allow maximising of the limited 'green' clinical space, so staff could join remotely.	Two cubicles kept for sole paediatric use. Space around entrance and cubicles kept green. Designated areas for donning and AITU equipment created. New adult CD cupboard installed. Two five-bedded bays increased to six beds each for adult patients tested positive for COVID. Towards end of the surge, newly expanded AITU was created to take patients tested positive for COVID, then PICU bays were used for green AITU patients. Parent bedrooms converted to staff showering facitilites. Well-being space created. Designated green areas for staff breaks and handover.	Entire PICU+PHDU as COVID 'red' clinical zone. Designated green zones for breaks and meetings. Reconfigurated entrance and exit, and desginated donning-doffing areas. PICU handovers in seminar room, AICU handovers in PPE in COVID pods.	Original PICU designated as COVID 'red' zone, primarily for adults, but one paediatric COVID case also cared for in this area. Original PHDU refitted to accommodate 15 bed-spaces ring-fenced for PICU patients. Burns unit closed to allow for separation of COVID zone staff for changing and refreshments, and donning/doffing. Two separate handovers took place; a 'COVID' handover and a 'non-COVID' handover for the critically ill children now being cared for in the original PHDU.	Entire PICU as only 'green' zone that provided level 3 care for adult patients tested negative for COVID. New King's Critical Care Centre started functioning ahead of schedule provided space for 29 beds.	Entire PICU as COVID 'red' clinical zone.
Staffing Medical: senior tier Medical: middle and junior tiers nursing	Led by PICU consultants on resident rota. AICU consultants available on phone for advice. PICU staff, mostly general paediatric trainees. PICU nursing pool (some with previous AICU experience).	Led by PICU consultants on resident rota. Day supporting rota of paediatric respiratory and cardiology consultants. Senior AICU middle grade and consultants available for advice. Middle-grade and junior-grade paediatric trainees from PICU, supplemented from cardiology and respiratory PICU and AICU nursing pool, including some from recovery. Paediatric ward nurses trained to supervise PPE donning and doffing stations.	Led by PICU consultants. AICU consultants available for support, and anaesthetic consultants ad hoc. PICU staff rota, included redeployed SHOs, neonatal fellows, surgical trainees. Adult patients: AICU nurses supported by ODP and PICU nurses; while PICU nurses were redeployed to AICU. Paediatric patients: PICU nurses.	Led by PICU consultants on resident rota. Rota of seconded paediatric anaesthetic consultants. AICU consultants available for phone advice. Usual PICU rota plus three seconded paediatric SpRs and one anaesthetic fellow. PICU nurses, operating theatre staff and previous staff with PICU experience.	PICU and AICU consultants jointly led till peak. After peak, PICU consultants solely cared for paediatric patients, while AICU consultants and paediatric anaesthetists shared rota to care for adult patients. Resident rota of PICU staff included ANPs, fellows, adult ICU and emergency medicine trainees, redeployed neonatal fellows and paediatric SHOs. Adult trainees worked mainly in the COVID zone allowing paediatric and neonatal trainees to manage the non-COVID critically ill children in the repurposed PHDU. PICU nurses assisted by theatre-recovery staff. Past PICU nurses redeployed from community and research roles.	Led by PICU consultants. Supporting anaesthetists and AICU middle grade with twice daily adult consultant support rounds. PICU staff and AICU trainees who previously rotated in PICU. Dual-trained nursing pool, working alongside PICU nurses. Paediatric clinical nurse specialists redeployed to PICU.	Led by PICU consultants on resident rota, supported by AICU consultants and general paediatricians. Middle-grade paediatric trainees. PICU nursing pool, supplemented from PHDU and general paediatric.
Education and training	Webinars by AICU team. Simulation training with anaesthetists and PICU multidisciplines. AICU learning package: 'ICU for non-adult intensivists'. Daily support from regional adult critical care network.	Simulation training within the paediatric department led by the education teams. Co-training with the adult team led by the anaesthetic department. 'How to ICU' portal access for protocol training.	Presurge training seminar. Daily updates from AITU team via WhatsApp. Access to AITU guidelines and protocols, daily check list. Support from adult regional critical care network as needed. AICU nurses supporting PICU nurses on the job.	AICU visit by Matron and PICU consultants. Simulation and OSCE-style teaching by PICU nurses/ANPs. Regional AICU guidelines, new regional and national COVID guidelines. National and international webinars. Daily support from adult regional critical care network.	Online resources. Simulation sessions in paediatric theatres for PICU/PHDU staff. Shift rotation of PICU staff onto adult COVID areas prior to use of PICU for admission of adult patients. Daily support from adult regional critical care network.	Simulation and virtual training sessions to upskill non-AICU staff. Daily clinical and non-management updates from local trust and international societies.	Simulation training by AICU team. Training on AICU patient data management system with access to all adult guidelines.

Continued

Table 4 Continued

Hospitals	St Mary's Hospital	Royal Brompton Hospital	Royal London Hospital	Alder Hey Children's Hospital	Royal Manchester Children's Hospital	King's College Hospital	Royal Stoke University Hospital
Equipment Challenges Solutions	Medicines. Dialysis fluids. Imaging. Airway management. Ventilators. PPE. ► Regular discussions with pharmacy and AICU. ► Network approach to transfer to another centre for RRT. ► Two additional hand-held USS probes. ► Adult trolleys including McGrath blades.	Ventilators. PPE. Dialysis fluids. Airway management. ► NIV ventilators repurposed for use. ► London Fashion School staff tailored theatre drapes to gowns. ► RRT planning or collaboration with regional dialysis centre at Northwick Park Hospital. ► Reorganised paediatric airway trolley with adult equipment.	Ventilators initially loaned to AITU. RRT. Adult equipment storage. Storage of medications. Maintenance of sufficient supply of ventilators for paediatric admissions. New CD cupboard. Adult airways trolleys and central line trolleys. Transfer to original AICU or RLH dialysis centre.	PPE. Ventilators. ► Specific donners and doffers for all pods. ► PICU consultant shifts changed from 24 hours shift pattern to 13 hours resident shifts. ► Changed all ventilators from anaesthetic machines to Draeger in adult pod.	Medicines. PPE. -AnaConDa product to save on syringe drivers and intravenous drugs.	Ventilators. Dialysis fluids and RRT admissions. Medicines. Staffing. ► Plans to repurpose neonatal ventilators and transport ventilators if necessary. ► Leadership updates and planning for alternatives when in short supply. ► Occupational health involvement to get directives on who and when to return to work. Extra RRT machines sourced from industry and the fluids from the private sector.	Infusion pumps. Airway management. PPE. ► Reprogrammed Pumps for adult volume. ► Difficult airway trolley from AICU.

ANP, advanced nurse practitioners; ODP, Operating Department Practitioner; OSCE, Objective Structured Clinical Examination; PHDU, paediatric high dependency unit; PICU, paediatric intensive care unit; PPE, personal protective equipment; SHO, Senior House Officer; SpR, Specialist Registrars.

4. *Equipment*: the re-stocking of storerooms with adult appropriate equipment such as renal replacement filters, endotracheal tubes, intravenous access catheters and pharmacy stores. Many units needed both adult and paediatric resuscitation and difficult airway trolleys that were easily distinguishable.
5. *Clinical care*: the development of adult-specific clinical guidance, including bespoke checklists, quick guides and common drug doses. These were rapidly disseminated and frequently updated as new guidance emerged via critical care networks and the Intensive Care Society (ICS). Regular multidisciplinary team (MDT) meetings with adult medical and critical care colleagues, pharmacists and allied healthcare professionals supported patient flow, clinical decision making and dealing with resource limitations. Task-specific teams were developed to streamline workload in ICU areas.[31]
6. *Communication*: information and technology resources including bedside webcams, hand-held devices for point-of-care ultrasound and professional online collaboration platforms such as Microsoft Teams were used to aid communication with families and within clinical teams.
7. *Governance*: a Joint Statement from Statutory Regulators of Heath and Care Professionals provided some reassurance to the paediatric nurses and doctors that working cooperatively with adult specialists and using the best available evidence in these challenging circumstances was acceptable to their respective regulatory bodies.[32]

Tables 4 and 5 summarise how the above challenges were approached by each PICU. Although all seven units broadly adopted similar processes within a short time frame to meet the challenges of accommodating adult patients, local factors also played an important role in determining how beds were configured. Some PICUs needed to ring-fence a few PICU beds for highly specialised paediatric services such as liver transplant and trauma/neurosurgery, and for children presenting to their own emergency department or those acutely deteriorating on the paediatric wards. Hence, in all but two units a small number of critically ill children were cared for alongside critically ill adults. PICU staff usually managed adult patients in close consultation with AICU teams, although frontline-staffing models varied.

Table 6 shows the numbers of adult patients cared for by the seven PICUs. Overall, 145 critically ill adults were cared for in these PICUs, accounting for a total of 1553 bed-days. Notably, the six PICUs that were co-located with AICUs admitted nearly one out of five adults cared for in those hospitals. Overall mortality on PICU was 14%. Table 6 also shows how many children were cared for in the same period in these PICUs. One PICU retrieval team in London set up an additional team staffed by paediatric anaesthetists to undertake 12 interhospital transfers of adult COVID-19 patients during the peak of the surge.

Other PICUs followed different models: stand-alone children's hospitals increased their capacity to absorb critically ill children diverted from repurposed units, some PICUs relocated to other wards to give up their space and equipment for adults and others adopted a hybrid approach, admitting both paediatric and adult patients. PICU retrieval teams decanted existing paediatric inpatients from PICUs repurposed for adults, including those on advanced life support such as extracorporeal membrane oxygenation, and over the ensuing weeks, functioned in a coordinated fashion to divert emergency admissions to 'ring-fenced' PICU beds in other units.

DISCUSSION

Many lessons were learnt by the PICU community in England as a result of this extraordinary healthcare response to the COVID-19 pandemic. This transformation into adult ICUs was based on well-described principles[28 30] applied to local requirements, allowing a proportion of adult critical care demand to be met by PICU teams alone, either by repurposing entire PICUs or by maintaining a hybrid model where adults and children were cared for on the same unit. We found that paediatric teams can deliver excellent care to adults with outcomes comparable to adult ICUs as long as there is strong leadership and effective communication. These PICU teams were performing interventions such as adult cardiopulmonary resuscitation, treating unfamiliar conditions such as fast atrial fibrillation or pulmonary embolism, and prescribing unfamiliar medications. The physical size of the patients, as well as the fact that they needed to be proned for prolonged

Table 5 Clinical care delivery in seven repurposed PICUs to care for critically ill adults

Hospitals	St Mary's Hospital	Royal Brompton Hospital	Royal London Hospital	Alder Hey Children's Hospital	Royal Manchester Children's Hospital	King's College Hospital	Royal Stoke University Hospital
Procedure-specific teams: MERIT (Mobile Emergency Rapid Intubating Team) Vascular Access Proning Other **Family liaison**	Anaesthetists-led MERIT. Vascular access teams set up but not needed—procedures performed by PICU teams. Proning teams included paediatric physiotherapists. Dedicated tracheostomy lists. Non-critical care consultants led on MDT and existing PICU family liaison nurses.	Anaesthetists-led. Adult and paediatric respiratory nurse specialists led on tracheostomy safety rounds. Non-critical care consultants (adults and paediatric directorate) led on MDT and family liaison.	Airway team. Anaesthetists-led, with staff rota. Vascular access teams—MDT staff including surgical and transplant consultants. Proning teams MDT staff. Weekly dedicated tracheostomy theatre list. Adult ID ward round. Clinical psychologists, medical and nursing staff family liaison teams.	Anaesthetist-led, with staff rota including consultant paediatric surgeons. Consultant paediatric surgeon led with staff rota of paediatric respiratory consultants, PICU nurse consultants and non-PICU consultants.	Task teams set up, but was not required. Existing PICU Family Care Team of band 6 and band 7 nurses.	Anaesthetists-led. Existing PICU family liaison nurses.	AICU staff-led. PICU medical and nursing staff.
Clinical resources developed for adult patients	► COVID daily ward round template (appendix). ► Quick nursing guides (appendix). ► Quick reference guide to common AICU medications.	► Ward round template as per AICU. ► Handover operational checklist. ► Common Medicines Quick Guide (appendix). ► Extubation algorithm (appendix). ► Tracheostomy referral form.	COVID checklists for daily plans. Research guide including patient selection and contacts.	► AICU admission sheet. ► Daily documentation adapted into PICU EPR, including all communication and procedures. ► Nursing documentation added to electronic medical records.	- Electronic patient information system integrated with adult documentation including a simplified specific COVID Daily Ward Round template. 'Idiot's Guide to COVID Intensive Care' developed by AICU team. PICM and AICM trainees developed a 'differences between PICU and AICU' guide.	► Adult guidelines app. ► Same clinical information system for adults as for PICU. ► Admission and discharge on EPR.	► Patient Data Management System as per AICU to access all adult guidelines. ► Paediatric bedside charts for fluid balance.
Communications	Daily AICU/PICU/anaesthetics meetings to clarify operational logistics. Daily management leadership dial-in updates on latest operational issues. Three times per week respiratory/ICU MDT. Dedicated mobile phones for referrals, investigation requests and family communications. Microsoft teams for communication between 'red' and 'green' zones.	Daily respiratory, radiology, pharmacy, family liaison rounds. Regular visiting consults from microbiology, haematology, pulmonary hypertension, neurology, nephrology. Webcam on all bed spaces. Microsoft teams for full range of virtual rounds (including education, and governance) across all three operational critical care areas.	Coordinating AICU consultant on every shift. Joint MDT decision-making for complex patients and end-of-life discussions. WhatsApp and email between AICU and PICU. Daily calls to updates families and access to video calling. 'Walkie talkies' and dedicated phone lines to cubicles and bays, wipeable white boards.	Daily tactical leadership teleconference with local adult CCN to identify operational issues and potential patient transfers. Twice daily nurse huddles and medical handovers; daily micro/ID consults and family liaison rounds. Liaise with adult colleagues on challenging or end-of-life decisions. Microsoft teams for communications across all critical care pods.	Twice daily Silver Command meetings Reverted to historic numerical assignment of the wards instead of naming as "PICU" during the mixed board of adult and paediatric patients Well-being hubs Microsoft Teams for twice weekly Infectious Diseases Rounds	Daily tactical leadership updates to clarify operational issues Well-being hubs. Pharmacy, procurement and HR included in leadership updates. Microsoft teams in use.	Twice daily ward round by paediatric staff including adult pharmacist. Twice daily ward round by AICU consultant. Daily/twice daily medical and nursing team huddle to provide mutual support.

MDT, multidisciplinary team; PICU, paediatric intensive care unit; RRT, renal replacement therapy.

periods of time, also introduced new challenges.[33] Extended lengths of stay and the slow pace of recovery in adults with COVID-19 were in stark contrast to the short length of stay seen in critically ill children in general (median length of PICU stay 3.2 days). Mortality in adults with COVID-19 was also much higher compared with the usual PICU patients (14% vs 5.1%).[18 34] Supporting staff well-being in the face of these challenges was crucial in maintaining team morale and achieving optimal outcomes. Particularly challenging was looking after children as well as adults on the same unit, necessitating a frequent reset of mental models of care.

Our modelling demonstrated that compared with March/April, an additional 20%–25% PICU capacity is required in November/December to satisfy winter demand for emergency paediatric admissions in England. Plans for adult critical care expansion in case of future COVID-19 waves need to take this into account—each year, PICU's 'winter surge' is managed by cancellation of elective complex surgery, ad hoc and temporary relaxation of PICS standards for staffing ratios,[35] and redeployment of non-clinical staff to the frontline. Children are often transferred to distant units due to lack of regional PICU beds, an issue that is frequently highlighted in the press.[36 37] Replicating the previous PICU response during further COVID-19 surges will be challenging during winter. In addition, since the majority of planned complex surgery in children cannot be postponed for long (eg, cardiac surgery), long-term outcome data are crucial to support the ethical and legal implications of denying children access to such surgery by using PICU beds for adult patients in future waves.

Table 6 Characteristics, interventions and outcomes of patients admitted to the seven PICUs repurposed to care for adults

Hospitals	St Mary's Hospital	Royal Brompton Hospital	Royal London Hospital	Alder Hey Children's Hospital	Royal Manchester Children's Hospital	King's College Hospital	Royal Stoke University Hospital	Total
Period during which PICU was repurposed	9 weeks (20 March–22 May)	6 weeks (3 April–13 May)	7 weeks (23 March–12 May)	3 weeks (6 April–1 May)	6 weeks (8 March–21 April)	6 weeks (27 March–10 May)	5 weeks (30 March–6 May)	
Total number of patients in adult critical care (COVID and non-COVID) in the same hospital during the same time period	118	110	187	11	115	101	70	712
Repurposed PICU activity for adults								
Number of patients without COVID	5	0	8	0	0	23	0	36
IMV	5	0	6	0	0	23	0	34
HFNC	0	0	2	0	0	0	0	2
Total number of patients with COVID	23	29	26	11	9	0	11	109
ECMO	1	5	0	0	0	0	0	6
IMV	22	24	8	11	9	0	11	85
NIV	0	0	10	0	0	0	0	10
HFNC	0	0	8	0	0	0	0	8
Patient-bed days	434	324	197	169	81	229	119	1553
Median age in years (range)	57 (32–76)	50 (36–77)	57 (19–78)	62 (44–7)	60 (50–70)	53 (19–77)	55 (20–73)	
Interventions								
ECMO	1	5	0	0	0	0	0	6
RRT	6	9	0	4	0	0	1	20
CPR	2	1	0	1	1	2	0	7
Tracheostomy	9	14	0	0	6	10	3	42
Outcome								
Died in PICU	8	2	3	4	1	0	2	20
Discharged from PICU	20	27	31	7	8	23	9	125
Repurposed PICU activity for children								
Bed capacity	2	1	2	43	15	4	0	67
Non-COVID children	24	0	8	34	59	21	0	146
COVID children	5	0	1	2 (1 on ECMO)	1	4	0	13
Refusals/Transfers out	6	0	1	0	0	8	0	15

CPR, cardiopulmonary resuscitation; ECMO, extracorporeal membrane oxygenation; HFNC, high flow nasal cannula therapy; IMV, invasive mechanical ventilation; NIV, non-invasive ventilation; PICU, paediatric intensive care unit; RRT, renal replacement therapy.

This unique experience has highlighted the need in future waves to maintain up-to-date records of staff training and credentials, mechanisms to swiftly develop and communicate guidance in the face of rapidly accumulating experience, systems for responsive rostering to adapt to changing demands, closer liaison between adult and paediatric ICU teams in general, adoption of techniques for positioning heavy patients, greater emphasis on delirium prevention and management and embedding well-being interventions into routine practice to support staff.

PICU staff recognised the challenges of working outside their normal practice with close cooperation with adult teams working to the best available evidence: this was feasible, safe and supported by regulatory bodies. Had children been predominantly more affected than adults, it is arguable whether transformation of AICUs would have been as rapidly achievable. The dedicated task-specific teams used were usually led by adult anaesthetists, some with little experience of managing critically ill children, highlighting the importance of shared training and professional development for the future.

The strengths of this study are the inclusion of all seven PICUs who repurposed their entire units (providing a national picture) and availability of detailed data on how the units were repurposed and the characteristics and outcomes of adults treated on these units. We were however limited by the unavailability of activity data from other PICUs during the same period to indicate the impact of these changes and outcome data for adults discharged from the PICUs to other areas (providing a lower mortality rate than expected from adult ICUs).

CONCLUSIONS

In an unprecedented transformative effort, seven PICU teams in England repurposed to manage critically ill adults in spring 2020 and contributed significantly to the national expansion effort for adult critical care. This effort was supported by national-level planning within the PICU community, ensuring that critically ill children continued to have access to PICU beds.

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