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ORIGINAL ARTICLE

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CT in the evaluation of patients on ECMO due to acute respiratory failure

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Abstract *Background*: In patients with acute severe respiratory failure (ARF) treated with extracorporeal membrane oxygenation (ECMO) the radiological evaluation has until now almost exclusively relied on bedside radiography and US. At St. Göran/Karolinska ECMO centre CT has become a routine complement to bedside examinations. *Objective*: To review retrospectively the frequency, indications and findings on CT of patients with ARF on ECMO and to evaluate the risk of complications associated with transportation for CT examinations. *Materials and methods*: One hundred twelve neonates, children and adults were treated with ECMO from May 1994 to January 2001. Forty-six per cent of these patients had CT examinations on one or more occasions during ECMO, giving a total number of 238 examination sites on 104 occasions. All CT examinations were performed in the Paediatric Radiology Department and included a 10-min transport using a mobile ECMO system. *Results*: CT was more often performed in older patients and in patients with long ECMO runs. The main indications were suspected complications of ECMO and/or the underlying disease or a delay in clinical improvement. In 57% of the CT occasions, significant findings affecting treatment were revealed. There were no complications associated with the examinations or transport. *Conclusions*: CT is safe and useful in evaluation of patients with ARF during ECMO.

Keywords ECMO · CT

Introduction

Extracorporeal membrane oxygenation (ECMO) has been used for more than 20 years in patients with acute extremely severe, but potentially reversible pulmonary disorders [1]. ECMO is a modified cardiopulmonary bypass technique for long-term pulmonary support. It is initiated when there is lack of response to maximal ventilatory support and pharmaceutical treatment. Gas exchange takes place through an extracorporeal oxygenator and provides oxygenation and carbon dioxide removal without interfering with the lungs, thereby limiting the damage from mechanical ventilation. In neonates, randomised studies have proven ECMO to be a life-saving therapy in pulmonary disorders [2, 3], and several non-randomised investigations have demonstrated promising results in children [4, 5] and adults [6, 7, 8].

Radiology has an important role in monitoring the severity of lung disease, evaluating the position of ECMO cannulae and in detecting complications during treatment [9, 10, 11]. Traditional evaluation has almost exclusively relied on bedside radiography and US. CT has only sporadically been used, probably because most ECMO systems are not mobile, and even when mobile systems are used, there has been reluctance to move

these unstable patients with complicated equipment from the intensive care unit.

At St Göran/Karolinska Hospital ECMO Centre, neonatal, paediatric and adult patients have been treated for more than 10 years. A CT scanner was installed in the Paediatric Radiology Department in May 1994 and since then, we have used CT routinely in many of our ECMO patients.

The purpose of this study was to review retrospectively the number, indications and findings of the CT examinations and to evaluate the risk of complications during transports and examinations of the patients.

Materials and methods

Materials

One hundred twelve patients with acute respiratory failure (ARF) were treated with ECMO at St Göran/Karolinska Hospital ECMO Centre between May 1994 until January 2001. There were 53 neonates, 23 children and 25 adults (Table 1). The most frequent diagnoses for the neonates were congenital diaphragmatic hernia (CDH) and meconium aspiration syndrome (MAS); for the paediatric patients pneumonia and aspiration; and for the adults the diagnoses were pneumonia and trauma with acute respiratory distress syndrome (ARDS). In addition, 11 children were on cardiopulmonary resuscitation (CPR) ECMO because of circulatory collapse, most often secondary to septic shock.

The survival rates were 77% for neonates, 69% for children and 76% for adults. Only one of the children on CPR ECMO survived (9%).

During the study period of 80 months, 52 (46%) of the 112 patients had CT examinations on one or more occasions during ECMO treatment, giving a total number of 238 examination sites on 104 occasions (Fig. 1). Ninety-two of the examinations were cranial, 92 thoracic and 54 abdominal.

Methods

ECMO technique

A standard ECMO technique was used in all patients [12]. The blood was drained from the right atrium, pumped with a roller pump through the membrane oxygenator and a heat exchanger in parallel, and returned in venoarterial (V-A) ECMO to the right common carotid artery or in veno-venous (V-V) ECMO to one femoral or iliac vein.

The standard ECMO cart used (Stöckert SIII, Stöckert Instruments, Munich, Germany) is equipped with a battery backup and monitoring devices, thus being mobile with only gas supply added. Standard ECMO disposables were used [8] with the size of

Table 1. Materials. Patients treated with ECMO at St Göran/Karolinska ECMO Centre during the study time. (*MAS* meconium aspiration syndrome, *CDH* congenital diaphragmatic hernia, *CPR* cardiopulmonary resuscitation)

	Number (*n*)	Diagnosis		Time on ECMO (hours)	Survival rate (%)
Neonates	53	MAS	21(40%)	2–480 (mean 158)	77%
		CDH	19(36%)		
		Others	13(24%)		
Children	23	Pneumonia	13(56%)	36–1183 (mean 361)	69%
		Aspiration	4(17%)		
		Others	6(26%)		
CPR (children)	11	Septic shock	7(64%)	6–435 (mean 114)	9%
		Others	4(36%)		
Adults	25	Pneumonia	16(64%)	2–1298 (mean 322)	76%
		Pulmonary haemorrhage	3(12%)		
		Others	6 (24%)		
All	112			2–1298 (mean 233)	75%(excl CPR)

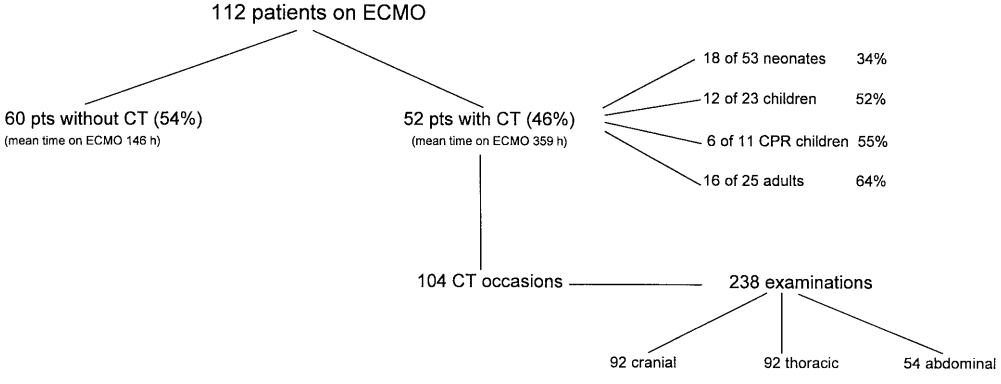


Fig. 1. Frequency of CT during ECMO

the devices adjusted to the weight of the patient and with 100 cm of extra tubing added to facilitate transport.

Transportation For CT examinations, the patients were transported from ICU to the CT unit in their ordinary bed and on the ventilator with the mobile ECMO system (Fig. 2). This included three floors in the elevator and took 10 min. The transport was managed by four staff members. The time for preparation of a transport was about 20 min. The total time outside the ICU was less than 60 min in all patients and included transport, transfer from the ordinary bed to the CT table, CT examination and return to the ICU.

CT examinations All CT examinations were performed on a General Electric High Speed Advantage CT scanner (General Electric Medical, Milwaukee, Wis., USA) using the radiology department's standard protocols for the examined body region and patient's age.

Intravascular contrast medium was used in 52% of the occasions, mainly for abdominal and thoracic examinations, and was administrated into the arterial line after the membrane oxygenator to prevent dilution of the contrast medium in the ECMO system. In patients on V-V ECMO, the pump flow was, if possible, reduced during the contrast-enhanced scan to minimise the amount of contrast medium passing through the membrane oxygenator. Contrast dose was 2 ml/kg of iodixanol 270 mgI/ml (Visipaque, Nycomed Amersham, Sweden) up to a maximum adult dose of 100 ml. The delay from contrast medium injection to the start of scanning of the thorax and abdomen was approximately 60 s. Before scanning we always made sure that the movements of the CT table were in the range of the length of the ECMO tubing.

The CT examinations were primarily evaluated by the attending paediatric radiologist with service on a 24-h basis.

Results

Frequency of CT examinations

CT was performed in 52 (46%) of the 112 patients. The frequency of CT examinations, however, varied in the different patient groups. CT was more commonly used in the older patients, with 64% of the adult patients having CT examinations during time on ECMO, 52% of the paediatric patients and only 34% of the neonates. Fifty-five-per cent of the children on CPR ECMO had CT examinations. Irrespective of age, CT was more often performed on patients on ECMO for a long time. The mean time on ECMO was 359 h for patients having CT during treatment compared to 146 h for ECMO patients with no CT requirements (Fig. 1).

A review of CT examinations over time shows an increasing number of examinations since the first in 1994 (Fig. 3).

Fig. 2. Transportation of a neonate on ECMO from ICU to the CT unit. Neonate on the left and mobile ECMO system on the right

Indications for CT examinations

The major indication for CT was suspected complications of the underlying disease and/or ECMO treatment ($n = 66$ (64%); Table 2). Among these were adult and paediatric patients with clinical neurological symptoms and neonates with unclear pathological findings on cranial US examinations. Others had unexplained blood loss or suspicion of bleeding on bedside chest or abdominal radiographs or US.

At 19 (18%) occasions the indication was follow-up of previous findings on CT. Patients with intracranial haemorrhage, cerebral oedema or hydrocephalus, for example, often had follow-up CT to exclude progress of pathology. Many of the examinations were after treatment of identified pathology. Among these were patients with haemothorax or pericardial tamponade who frequently had CT after thoracotomy or percutaneous drainage.

On 15 (14%) occasions, the indication was an unexplained delay in clinical improvement without focal signs. One examination (1%) was a therapeutic CT-guided placement of a pericardial catheter because of pericardial tamponade and in one patient, CT was used on three occasions, before, during and after perfluorocarbon treatment, to assess the distribution and effect of treatment (Fig. 4).

Findings

In a total of 104 CT occasions 59 (57%) revealed significant findings that affected treatment of the patient (Fig. 5). These changes in management included several surgical procedures, percutaneous intervention, weaning from ECMO or withdrawal of treatment.

CNS

Significant CNS findings were revealed on 32 (31%) occasions (Fig. 5). Thirteen patients had intracranial haemorrhages or haemorrhagic infarctions (Fig. 6); ten were large bleedings over 1 cm and three were smaller than 1 cm.

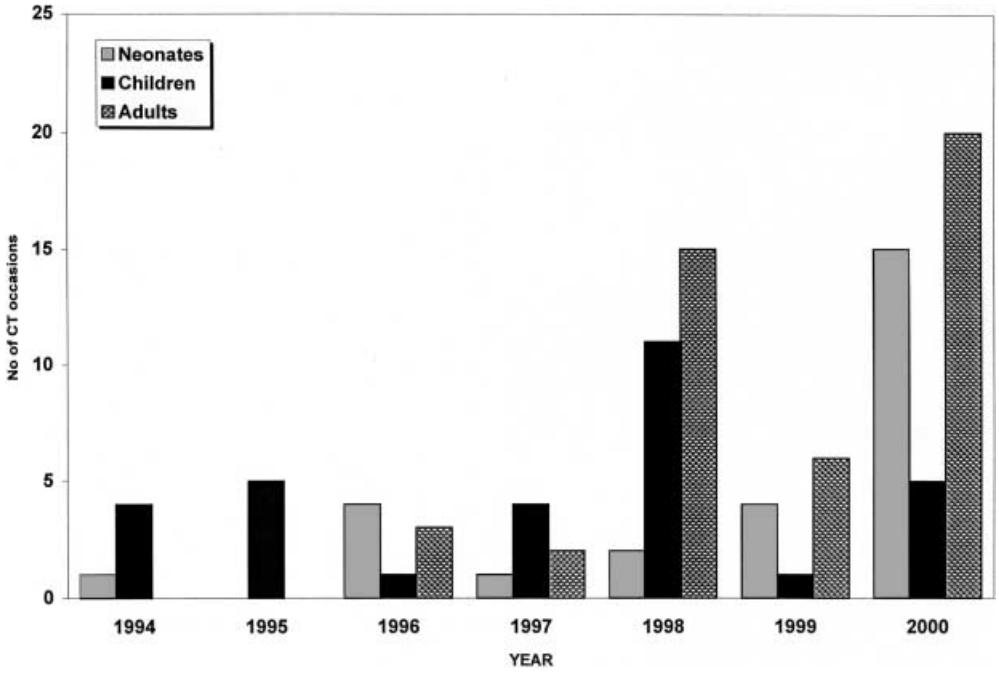


Fig. 3. Number of CT occasions in patients on ECMO over time

Table 2. Indications for CT during ECMO

Indications for CT	No. of CT occasions
Suspected complication to underlying disease and/or ECMO treatment	66 (64%)
Controls of previous CT findings	19 (18%)
Delay of improvement in underlying disease	15 (14%)
Control of therapy (perfluorocarbon treatment)	3 (3%)
CT-guided invasive procedure	1 (1%)
Total	104 (100%)

Sixteen patients had non-haemorrhagic infarctions or hypoxic-ischaemic oedema (Fig. 7). Four of these were small infarctions with limited clinical significance and 12 involved large areas with poor prognosis. Six patients with generalised oedema were patients on CPR ECMO. In two of these patients follow-up CT showed progress with loss of detectable intracranial circulation. One patient developed hydrocephalus after a cerebellar haemorrhage.

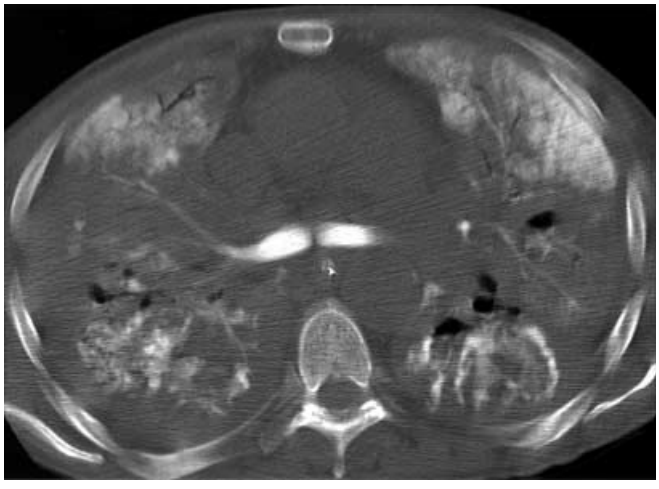


Fig. 4. Patient with ECMO-induced thrombocytopenia after 13 days on ECMO. Partial liquid ventilation with perfluorocarbon was commenced in the hope of improving lung function enough to wean the patient from ECMO support. CT of the mid-thorax, showing the distribution of perfluorocarbon in lungs and airways shortly after instillation

Thoracic

Thoracic findings affecting the choice of treatment were demonstrated in 19 (18%) cases. Ten patients had a haemothorax or significant pleural effusion (Fig. 8), four pericardial tamponade (Fig. 9) and one patient both pericardial tamponade and pleural fluid. One patient each had mediastinal haemorrhage, lung abscess, pneumocardia and a suspected broncho-pleural fistula.

Abdominal

Abdominal findings of importance were revealed on eight (8%) occasions. Three patients had intraperitoneal haemorrhage, two abdominal wall bleeding (Fig. 10), two adrenal haemorrhages and one showed infarction of the left lobe of the liver.

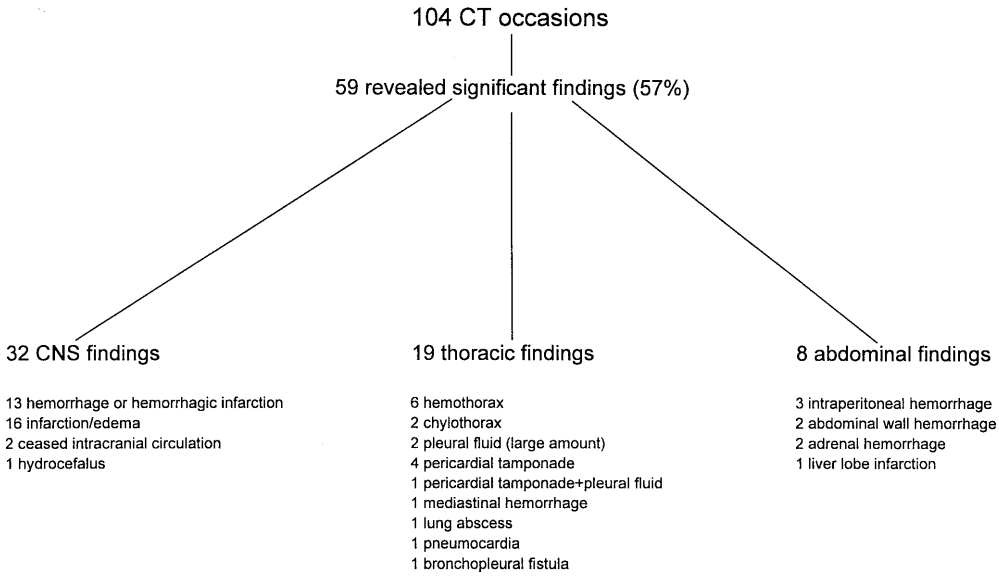


Fig. 5. CT findings of clinical significance

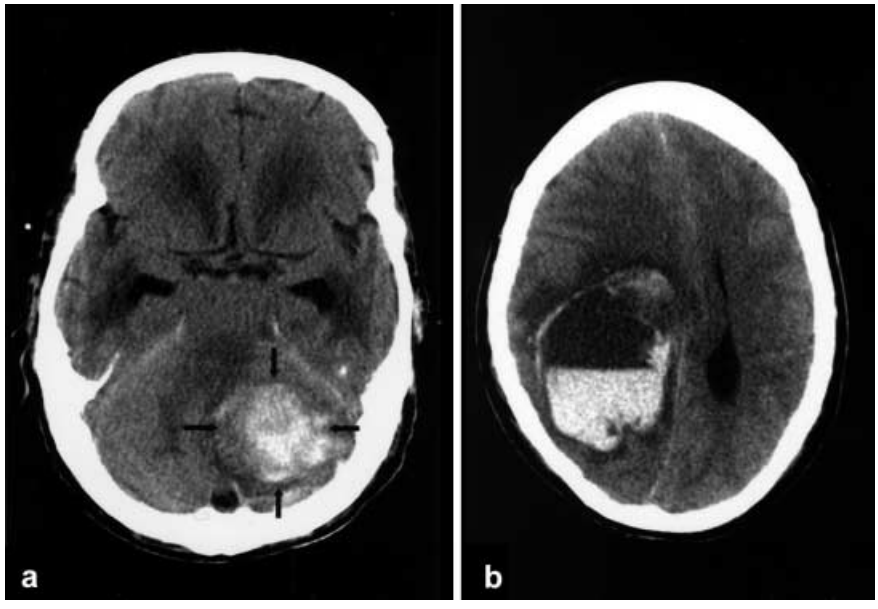


Fig. 6. **a** Clinically silent cerebellar haemorrhage in a patient having follow-up CT after thoracotomy for pericardial tamponade. The patient was weaned from ECMO and the bleeding did not progress. **b** Large fatal intracranial bleeding in a young woman

Complications

There were no complications related to transportation, the mobile ECMO equipment, the CT examinations or the use of IV contrast medium.

Discussion

The main message of this study is that CT is feasible, safe and adds important information in the management of all kinds of patients on ECMO because of severe ARF. To our knowledge, the experience of CT examinations during ECMO is very limited [13]. At St Göran/Karolinska Hospital ECMO Centre, CT has been used as a routine complement to bedside radiographs and US with increasing frequency since 1994 (Fig. 3). Almost half the patients had CT examinations during ECMO (Fig. 1). Most patients had a combination of cranial, thoracic and/or abdominal examinations on each occasion for optimal information and to avoid unnecessary transportation. The increasing number of CT examinations with time is probably a result of the obvious benefit of CT in combination with the growth of routine transportation of patients on ECMO.

Even though CT was used frequently in all age groups, examinations were more frequently required in children and adults compared to neonates (Fig. 1). This

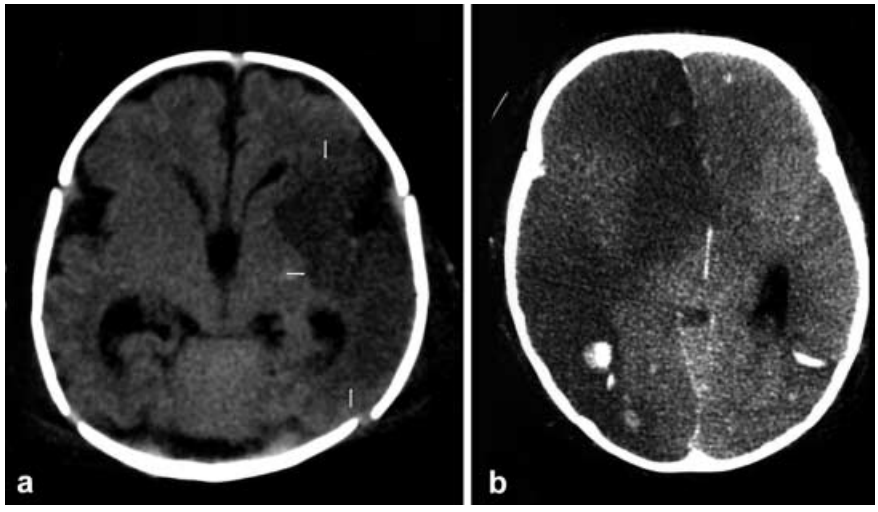
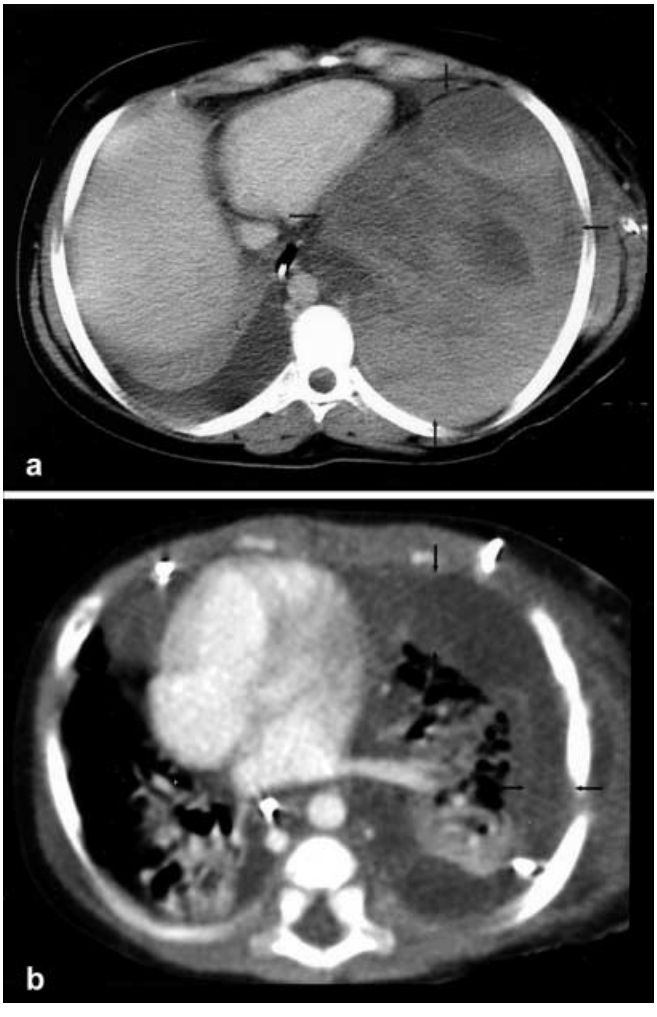


Fig. 7. **a** Neonatal treated for CDH with left-sided infarction (*arrows*) of probable embolic origin. US was non-diagnostic. The patient survived. **b** One-year-old boy on ECMO because of septic shock with marked generalised brain oedema. ECMO support was withdrawn

can be explained by longer ECMO runs with a higher risk for complications in the older groups as a result of different primary diagnoses. In neonates, CT was also performed more frequently in those on ECMO for a long time. For example, 14 (70%) of 20 neonates with CDH, who had the longest treatment times (mean 259 h) underwent CT, while only 2 (9%) of 21 neonates with MAS, who had the shortest times on ECMO (mean 79 h), had CT examinations. The large numbers of CT examinations in children on CPR ECMO is explained by the high complication rate, often hypoxic-ischemic cerebral injury secondary to initial shock.



Indications for the CT examination were, in the majority of cases, suspected complications of the underlying disease, of ECMO itself or lack of clinical improvement during ECMO. In large multicentre series, the average frequency of serious patient complications range from 1.8 to 2.1 per case [14, 15] The most feared complication of ECMO is haemorrhage owing to systemic anticoagulant therapy and ECMO-induced coagulopathy [14]. Radiographic and sonographic signs of cranial, thoracic and abdominal complications have been described [9, 11, 16]. However, chest radiographs can be difficult to evaluate because of the often pronounced opacification of the lungs in patients on ECMO [10, 17]. US of the thorax and abdomen is sometimes non-diagnostic because of overlying dressings, obscuring air in the lungs and gas-filled bowel loops in the abdomen [18]. Furthermore, US is not useful for neuroimaging in older children and adults, and CT has been shown to be more accurate than US in the neurological assessment of neonates [11, 19]. In addition, CT, besides having superior resolution, gives a more complete survey of the examined region than bedside methods. This is of obvious advantage in ECMO

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Fig. 8. **a** A girl with a huge tension haemothorax (*arrows*) as a result of bleeding after chest tube placement. **b** Neonate with persistent chylothorax (*arrows*) after left-sided CDH repair. Both patients survived after surgery and percutaneous drainage, respectively

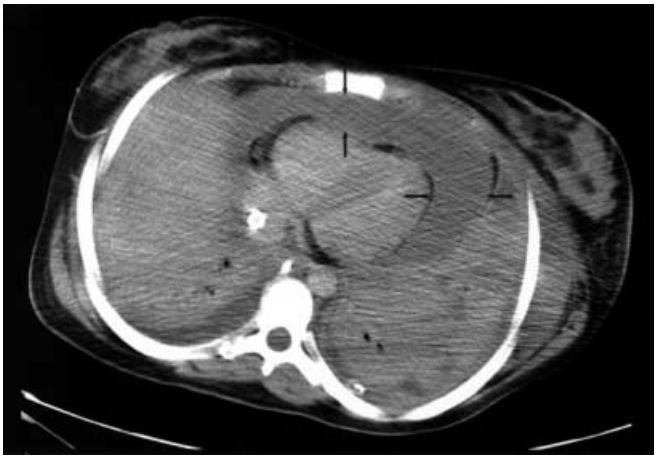

Fig. 9. Pericardial haemorrhage (*arrows*) from low placement of the venous ECMO cannula, here seen in the bottom of the right atrium, with perforation of the right atrial wall. The patient was successfully treated with percutaneous drainage

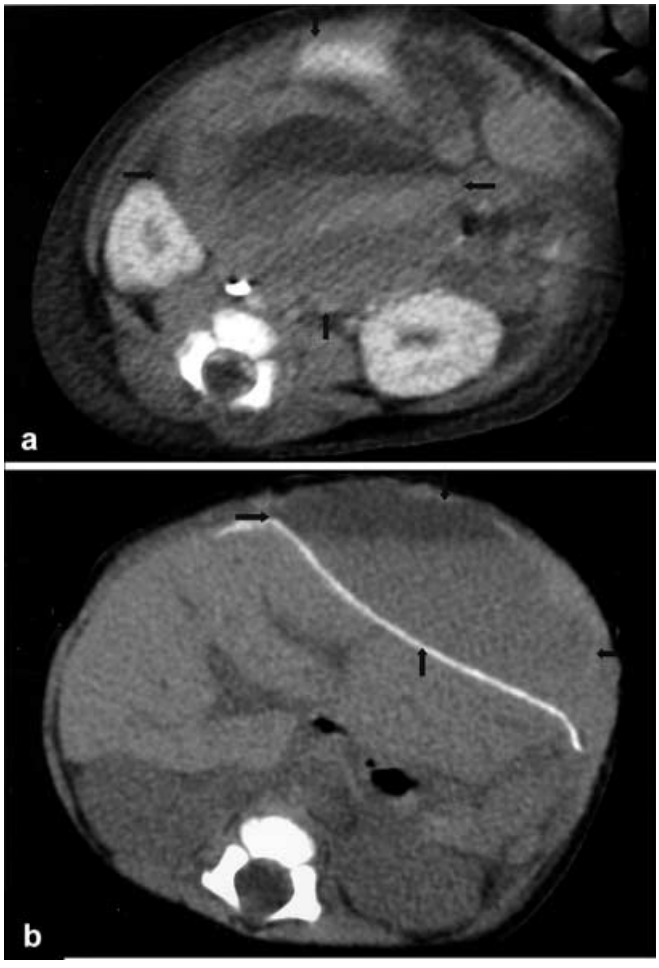

Fig. 10a, b. Two neonates on ECMO after surgical repair of CDH. **a** A large intra-abdominal haemorrhage (*arrows*) from a tear in the liver. **b** Abdominal wall bleeding superficial to the patch (*arrows*) causing symptomatic blood loss. Note the fluid-fluid levels in the haemorrhages. Both patients underwent further surgery

patients who are often difficult to evaluate clinically. As a result of sedation and assisted respiration and circulation, these patients often lack focal signs even when there are severe complications.

The incidence of significant CT findings in our patients was high (Fig. 5). In 57% of the CT occasions, pathology that affected treatment or prognosis of the patient was revealed. The demonstrated pathology often necessitated surgical treatment or percutaneous invasive procedures. In other patients the findings motivated rapid weaning from ECMO or withdrawal of treatment. Slightly more than half (32 of 59) of the findings were neurological complications, either intracranial haemorrhage or ischaemic injury. This could be expected, as CT is the only alternative for cranial examination in adults and older children on ECMO. Thoracic findings were most often haemorrhagic complications, often needing interventional treatment. Abdominal pathology was also mostly haemorrhagic complications, dominating in neonates after repair of CDH.

The pathology demonstrated on CT was often unsuspected. This was especially common in the group of patients with unexplained delay in clinical improvement. In one patient the indication for CT was delayed improvement after 40 days on ECMO without any clinical signs of complications. The CT examination showed unexpected pericardial effusion affecting the function of the right ventricle and a left-sided cerebellar haemorrhage with hydrocephalus. Both findings needed surgical intervention and the patient survived.

The CT protocols were no different in ECMO patients than for other patient groups and the ECMO equipment, including wired cannulae, did not adversely influence the quality of the CT examinations. Administration of IV contrast medium during ECMO, however, is different and has to be through the arterial line after the membrane oxygenator to prevent dilution of contrast medium in the ECMO system.

There were no complications directly related to 104 transports, 238 CT examinations or the use of IV contrast medium on 54 occasions during the study period of 80 months. Our study shows that CT can add important information about patients with ARF on ECMO and complements radiography and US. The role of CT is primarily in suspected complications, not for routine monitoring. CT can also add information in patients with lack of improvement during long-term ECMO. The transport and CT examination of the patients can be managed safely and within acceptable time limits. As this is a retrospective study, it has limitations, with sometimes brief medical records. In an extended study we are planning to study more closely the benefit of CT compared to bedside imaging studies.

References

1. Bartlett RH, Roloff DW, Custer RJ, et al (2000) Extracorporeal life support. The University of Michigan experience. JAMA 283:904–908
2. Bartlett RH, Roloff DW, Cornell RG, et al (1985) Extracorporeal circulation in neonatal respiratory failure: a prospective randomized study. Pediatrics 76:479–487
3. UK collaborative ECMO trial group (1996) UK collaborative randomized trial of neonatal extracorporeal membrane oxygenation. Lancet 348:75–82
4. Peek GJ, Sosnowski AW (1997) Extracorporeal membrane oxygenation for pediatric respiratory failure. Br Med Bull 53:745–756
5. Swaniker F, Kolla S, Moler F, et al (2000) Extracorporeal life support outcome for 123 pediatric patients with respiratory failure. J Pediatr Surg 35:197–202
6. Kolla S, Sarnir SA, Preston BR, et al (1997) Extracorporeal life support for 100 adult patients with severe respiratory failure. Ann Surg 226:544–566
7. Lewandowski K, Roissant R, Pappert D, et al (1997) High survival in 122 ARDS patients managed according to a clinical algorithm including extracorporeal membrane oxygenation. Intensive Care Med 23:819–835
8. Lindén V, Palmer K, Reinhard J, et al (2000) High survival in adult patients with acute respiratory distress treated by extracorporeal membrane oxygenation, minimal sedation, and pressure supported ventilation. Intensive Care Med 26:1630–1637
9. Gross GW, Cullen J, Kornhauser MS, et al (1992) Thoracic complications of extracorporeal membrane oxygenation: Findings on chest radiographs and sonograms. AJR 158:353–358
10. Taylor GA, Short BL, Kriesmer P (1986) Extracorporeal membrane oxygenation: Radiographic appearance of the neonatal chest. AJR 146:1257–1260
11. Taylor GA, Fitz CR, Miller MK, et al (1987) Intracranial abnormalities in infants treated with extracorporeal membrane oxygenation: Imaging with US and CT. Radiology 165:675–678
12. Zwischenberger JB, Steinhorn RH, Bartlett RH (eds) (2000) Extracorporeal cardiopulmonary support in critical care. Extracorporeal Life Support Organization, Ann Arbor
13. Bulas DI, Taylor GA, Fitz CR, et al (1991) Posterior fossa intracranial hemorrhage in infants treated with ECMO: sonographic findings. AJR 156:571–575
14. Zwischenberg JB, Upp JR (1995) Emergencies during extracorporeal membrane oxygenation and their management. In: Zwischenberger JB, Steinhorn RH, Bartlett RH (eds) ECMO. Extracorporeal cardiopulmonary support in critical care. Extracorporeal Life Support Organization, Ann Arbor, pp 221–249
15. Zwischenberg JB, Nguyen TT, Upp JR, et al (1994) Complications of neonatal extracorporeal membrane oxygenation. Collective experiences from the extracorporeal life support organization. J Thorac Cardiovasc Surg 107:838–848; discussion 848–849
16. Bowerman RA, Zwischenberger JB, Andrews AF, et al (1985) Cranial sonography of the infant treated with extracorporeal membrane oxygenation. AJNR 6:377–382
17. Jamadar DA, Kazerooni EA, Cascade PN (1996) Extracorporeal membrane oxygenation in adults: radiographic findings and correlation of lung opacity with patient mortality. Radiology 198:693–698
18. Gross GW, Dougherty CH (1995) Pleural hemorrhage in neonates on extracorporeal membrane oxygenation and after repair of congenital diaphragmatic hernia. Imaging findings. AJR 164:951–955
19. Matamoros A, Anderson JC, McConell J, et al (1989) Neurosonographic findings in infants treated by extracorporeal membrane oxygenation (ECMO). J Child Neurol [Suppl] 4:S52–61