Intensive Care Med (2000) 26: 934–941

L. Desfrere
PH. Jarreau
M. Dommergues
A. Brunhes
P. Hubert
C. Nihoul-Fekete
P. Mussat
G. Moriette

Impact of delayed repair and elective high-frequency oscillatory ventilation on survival of antenatally diagnosed congenital diaphragmatic hernia: first application of these strategies in the more "severe" subgroup of antenatally diagnosed newborns

Received: 7 October 1999
Final revision received: 14 February 2000
Accepted: 25 February 2000

L. Desfrere (✉) · PH. Jarreau · A. Brunhes · P. Mussat · G. Moriette
Services de Médecine Néonatale,
UFR Cochin-Port Royal,
123 Bd. de Port Royal,
74679 Paris Cedex 14, France
e-mail: luc.desfrere@cch.ap-hop-paris.fr
Tel.: + 33-1-42 34 12 60
Fax: + 33-1-43 29 03 38

M. Dommergues
Médecine Foetale,
UFR Cochin-Port Royal,
123 Bd. de Port Royal,
74679 Paris Cedex 14, France

P. Hubert
Services de Réanimation
Pédiatrique Polyvalente,
Hôpital Necker-Enfants Malades, Paris,
France

C. Nihoul-Fekete
Chirurgie Pédiatrique,
Hôpital Necker-Enfants Malades, Paris,
France

Abstract *Objective:* a) To analyze the influence of a new management strategy on the outcome of neonates with antenatally diagnosed congenital diaphragmatic hernia (CDH); b) to determine early prognosis respiratory factors with the new strategy. *Design:* Retrospective study. *Setting:* Level III perinatal center. *Patients and method:* Between 1985 and 1997, 51 consecutive neonates with antenatally diagnosed CDH were admitted to our level III neonatal intensive care unit. Before 1992 (period 1; $n = 19$), we used conventional mechanical ventilation and early surgery requiring transfer. Since 1992 (period 2; $n = 32$), we prospectively tested a new approach including (a) systematically use of high-frequency oscillatory ventilation (HFOV) regardless of the initial clinical severity, (b) delayed surgery following stabilization requiring transfer to a different surgical unit, but (c) no transfer of unstable patients with surgery under HFOV in our neonatal intensive care unit ($n = 10$). The two cohorts were comparable in terms of potential ante and postnatal prognostic indicators. *Results:* Survival was improved with the new strategy: 21/32 (66 %) vs. 5/19 (26 %); $P < 0.02$. This improvement between periods 1 and 2 was due to a decrease in both preoperative and postoperative deaths in the later period. The better survival during period 2 was associated with the appearance of very late deaths, frequent pleural effusions, and the survival of more severe forms having evolved to a chronic respiratory insufficiency. Survivors were ventilated for longer time with longer duration of oxygen supplementation. The best oxygenation index (OI), alveolar arterial difference and oscillation amplitude (P/P) during the first 24 h, but not the best $PaCO_2$, were the most reliable prognostic indicators during period 2. An OI ≤ 10 with a P/P ≤ 55 cmH_2O was associated with a very good prognosis (94 % survival). *Conclusions:* The prognosis of antenatally diagnosed CDH was improved by systematic HFOV on admission, no systematic transfer, and delayed surgery. This improvement is associated with modification of postnatal outcome.

Key words Congenital diaphragmatic hernia · Antenatal diagnosis · Postnatal management · High-frequency oscillatory ventilation · Intensive care unit · Neonate

Introduction

Despite improvements in neonatal and surgical care of neonates with congenital diaphragmatic hernia (CDH), the prognosis still remains poor, particularly in the case of antenatal diagnosis, as the survival rate in infants with antenatally diagnosed CDH is less than 50 % [1, 2, 3, 4], lower than that of infants with postnatally diagnosed CDH. This poor prognosis is attributed to the association of severe lung hypoplasia and a higher incidence of associated anomalies [4, 5].

CDH has long been considered to require immediate operative repair. Following the reports of Cartlidge et al. [6] and Hazebroek et al. [7], preoperative stabilization and delayed surgery have been widely used. In addition to conventional mechanical ventilation (CMV), new strategies have been developed, including extracorporeal lung support [8], high-frequency oscillatory ventilation (HFOV) [9], exogenous surfactant [10], and inhaled nitric oxide [11]. However, there is no clear evidence that any of these alternative approaches provide a significant survival benefit.

In our level III neonatal intensive care unit (NICU) newborns with antenatally diagnosed CDH were managed until 1992 by a "classical" approach using CMV and referral to a surgical unit for emergency repair. Because of the high mortality observed with this management and the introduction of HFOV in our unit, we decided to change our postnatal management of these neonates and use: (a) HFOV on admission, (b) delayed surgery after stabilization, (c) no transfer and surgery in our NICU for unstable patients. The purpose of our study was (a) to evaluate the possible influence of this new strategy on outcome, and (b) to review respiratory parameters to identify prognosis-related factors with this new strategy.

Materials and methods

Patients

From January 1985 to June 1997, 51 consecutive neonates with antenatal diagnosis of congenital diaphragmatic hernia were managed in our level III perinatal center. Nineteen patients were treated before 1992 (period 1) and 32 after 1992 (period 2). These two periods correspond to the two different strategies.

For the 51 neonates, the antenatal diagnosis was established by routine ultrasound and was confirmed at our referral fetal medicine unit. Potential indicators of poor prognosis [12], including ultrasound diagnosis before 25 weeks [3, 13, 14], polyhydramnios [15], intrathoracic stomach for left-sided defects and major mediastinal shift (i. e., absence of identification of contralateral lung between the fetal heart and chest wall on a four-chamber view [12]) were collected prospectively. No significant difference in the distribution of antenatal or postnatal indicators was observed between the two periods (Table 1).

Postnatal management

All neonates were nasally intubated in the delivery room. They were immediately admitted to the NICU, close to the delivery room. They were sedated by continuous infusion of fentanyl and 45/51 were paralyzed with pancuronium bromide. Pulse oximetry, pre- and postductal $PtcO_2$/$PtcCO_2$ were continuously monitored. Inotropic infusions and volume infusion were designed to maintain mean blood pressure over 40 mmHg.

During period 1 surgical repair was performed on an emergency basis and neonates were rapidly referred to the pediatric surgery unit of the Necker–Enfants Malades Hospital (NEM), situated 1 km from our center, at a median age of 2 h (range: 0.5–5). All patients were ventilated exclusively by CMV. Postoperative care was performed in the NEM intensive care unit. CMV was adjusted to obtain PCO_2 between 30 and 40 mmHg using high respiratory rate ($\geq$ 60/min) and low peak inspiratory pressure ($\leq$ 30 cmH_2O) whenever possible.

During period 2 a new preoperative and postoperative management strategy was designed. The main changes were: (a) immediate ventilatory support with HFOV only, (b) delayed CDH repair, and (c) no transfer of unstable infants, who were consequently operated in our NICU. HFOV using a piston oscillator (OHF1; Dufour) was started in all neonates on admission to our NICU (< 30 min of life), regardless of initial clinical severity. A fixed frequency of 15 Hz was chosen based on the recommendations of Bohn et al. [16]. Initially, the mean airway pressure was usually set between 12 and 15 cmH_2O, and the inspired fraction of oxygen (FiO_2) was set to maintain preductal saturation above 95 %. Mean airway pressure was subsequently adjusted according to FiO_2 and pulmonary inflation on chest X-rays. The peak to peak pressure (P/P) was adapted to obtain chest vibration and PCO_2 between 30 and 40 mmHg (range used for Dufour OHF1 is 25–100 cmH_2O).

Inhaled NO was delivered in cases of severe pulmonary hypertension on echocardiography with a pre-/postductal saturation difference greater than 10 %. Rescue surfactant replacement (Curosurf) was used in the most severe cases with "refractory" hypoxemia.

Stabilization was defined by the following criteria: (a) normal hemodynamic variables without inotropic agents; (b) disappearance of pre-/postductal saturation difference and of signs of pulmonary hypertension on echocardiography; (c) adequate oxygenation achieved under HFOV with $FiO_2 \leq 0.3$ and mean airway pressure $\leq$ 8 cmH_2O; and (d) adequate CO_2 clearance with P/P level lower than 50 cmH_20. When this level of assistance on HFOV was obtained after a short period, a trial of switching to CMV was performed. When well tolerated, with moderate values of peak inspiratory pressure (15–20 cmH_2O), the infants were then transferred on CMV to the "NEM" NCIU for surgery. This was possible in 15 of 32 cases, at a median age of 70 h (range: 48–144). In the 10 cases in which stabilization was difficult to obtain, surgery was performed in our NICU on HFOV to avoid all factors likely further to impair the condition of these unstable patients.

For period 2, oxygenation indices were calculated thus: oxygenation index (OI) = FiO_2 × mean airway pressure/postductal PaO_2 and alveolar arterial difference (A-aDO_2) = (barometric pressure–47) × FiO_2–$PaCO_2$ (FiO_2 + 1–FiO_2/0.8)–preductal PaO_2).

Survival was defined at the time of hospital discharge. Postmortem examination was performed when the parents' consent was obtained. The diagnosis of pulmonary hypoplasia was based on a lung weight to body weight ratio less than 0.018 or a radial alveolar count less than 3.1 [17].

Table 1 Comparison of pre and postnatal prognostic factors between the two periods (means ± SD; *in parentheses* percentages/95 % confidence intervals, *AGPAR* appearance-pulse-grimace-activity-respiration)

	Characteristics	Period 1 n = 19	Period 2 n = 32	*p*
Prenatal	Age at Diagnosis	7	16	NS
Data	< 25 weeks	36.8 % [16.3 %–61.6 %]	50 % [31.9 %–68.1 %]	
	Polyhydramnios	11	14	NS
		57.9 % [33.5 %–79.7 %]	43.7 % [26.4 %–62.3 %]	
	Intrathoracic Stomach	16	22	NS
	for left CDH	94.1 % [71.3 %–99.8 %]	91.7 % [73 %–100 %]	
	Médiastinal Shift	10	14	NS
		52.6 % [28.9 %–75.5 %]	43.7 % [26.4 %–62.3 %]	
Postnatal	Gestational age [wk]	37.6 ± 2.7	37.9 ± 1.9	NS
Data	Birth weight [g]	2940 ± 800	2980 ± 600	NS
	Right-side defect	2	8	NS
		10.5 % [1.3 %–33.1 %]	25 % [11.5 %–43.4 %]	
	Associated anomalies	8[a]	12[b]	NS
		42.1 % [20.2 %–66.5 %]	37.5 % [21.1 %–56.3 %]	
	5 minute APGAR score	7.2 ± 1.9	8 ± 1.9	NS
	Surgery	10	15	
	after transport	52 %	47 %	
	Surgery in our NCIU	0	10	
			31 %	

[a] Moderate cerebral ventriculomegaly ($n = 1$), anomaly of the external ear and other dysmorphic features ($n = 2$), unilateral hypoplastic kidney ($n = 1$), minor costal anomalies ($n = 1$), labial split + hydrops ($n = 1$), and minor gastrointestinal anomaly ($n = 2$)

[b] Esophageal atresia ($n = 1$), coarctation of the aorta ($n = 1$), extralobar pulmonary sequestration ($n = 2$), unilateral multicystic kidney dysplasia ($n = 1$), minor costal anomalies ($n = 3$), minor ventricular septal defect ($n = 1$), minor atrial septal defect ($n = 1$), cerebral anomaly ($n = 1$), and minor gastrointestinal anomaly ($n = 1$)

Statistical analysis

Results are expressed as means and 95 % confidence intervals for normal distribution and median and range otherwise. For categorical data, the standard error of the difference between two proportions and a chi-square test were used to determine the significance of the difference between two independent groups. A nonparametric test (Mann-Whitney U test) was used to compare continuous data between groups. A probability (p) of less than 0.05 was considered significant. Receiver operating characteristic (ROC) curves were generated to determine the most powerful test for predicting outcome.

Results

Outcome and postnatal management

Survival was increased from 26.3 % (95 % IC: 9.2–51.2 %] during period 1 to 65.6 % (46.8–81.4 %) during period 2 with an observed difference of 2.7 SE ($P < 0.02$). Survival in patients with isolated CDH rose from 36.3 % (95 % IC: 10.9–69.2 %] to 80 % (56.3–94.3 %) with an observed difference of 2.4 SE ($P < 0.05$). The clinical courses are described in Table 2. OI calculated on the first blood gases, frequency of pneumothorax, and primary vs. patch repair were similar for the two periods. Surgery was performed later during period 2 than during period 1 ($P < 0.0001$) and after a very variable duration, depending on severity. The decreased mortality was related to a reduction in the number of both preoperative and postoperative deaths. Preoperative deaths occurred later in period 2 than during period 1 ($P < 0.002$). During period 2 two infants died after 8 and 16 days, respectively, due to the inability to obtain the respiratory and hemodynamic conditions required for surgery. Postoperative deaths also occurred much later with the new management strategy. Three of four neonates died in our NCIU after surgery.

Postmortem examination was performed in 13 of 25 cases. Pulmonary hypoplasia was confirmed in 12 patients. Pulmonary hypoplasia could not be confirmed in one case, as the lung weight to body weight ratio was 0.023 and the radial alveolar count was not determined. In this case, death occurred very late (50 days) in a context of respiratory infection and chronic lung disease.

In period 2, inhaled NO therapy was used during the stabilization period in 11 patients. It was considered to be effective in only two surviving patients. “Rescue” surfactant replacement was used in six neonates with no apparent efficacy.

Survivors were ventilated for longer times during period 2 than during period 1 ($P < 0.02$), with longer duration of oxygen supplementation ($P < 0.05$). Two postoperative respiratory complications were observed following surgery in the survivors during period 2: chronic lung disease and pleural effusion. Three patients with an

Table 2 Clinical courses (means; *in parentheses* percentages/95 % confidence intervals)

	Period 1 n = 19	Period 2 n = 32	*p*
OI on the first blood gases	27.3 ± 12.1	24.1 ± 22.3	NS
Preoperative pneumothorax	6 31.6 % [12.6 %–56.5 %]	6 18.8 % [7.2 %–36.4 %]	NS
Preoperative deaths	9 (47 %)	7 (22 %)	
Time of preoperative deaths (hours)	15 (0.8–32)	64 (29–384)	< 0.002
Time of surgery (hours)	6.5 (1–32)	96 (17–408)	< 0.0001
Primary repair n = 23 (66 %)	8 (80 %)	15 (60 %)	NS
Patch repair n = 12 (34 %)	2 (20 %)	10 (40 %)	
Postoperative deaths	5 (26 %)	4 (13 %)	
Time of postoperative deaths (hours)	48 (7–125)	540 (140–1200)	< 0.02
Ventilator days in survivors	5 (3.5–9)	14 (4–901)	< 0.02
Days of increased FiO_2 in survivors	5 (2–7)	7 (1–1100)	< 0.05
Length of hospital stay in survivors	33 (28–45)	38.5 (15–360)	NS

Values are reported as median and range or mean ± SD.
Numbers in [] represent the 95 % confidence interval of proportions for each period

Table 3 Oxygenation/ventilation results for the best blood gas results within the first 24 h of life with the new management (means; *in parentheses* percentages/95 % confidence intervals)

	Survivors n = 21	Deaths n = 11	*p*
Best post ductal PaO_2 (Torr)	69 [63.2–74.7]	53.2 [37.1–69.2]	0.01
Lowest post ductal $PaCO_2$ (Torr)	28.9 [27.0–30.7]	27.1 [23.2–31.0]	NS
Best OI	6.2 [2.7–9.8]	28.2 [17.3–39]	0.0001
Best $AaDO_2$	117.4 [56.0–178.9]	440.5 [330.6–550.3]	< 0.0001
Lowest peak to peak pressure	44.0 [38.5–49.4]	67.1 [60.9–73.3]	< 0.0001

Values are reported as mean and the 95 % confidence interval

associated malformation (esophageal atresia, costal anomalies and minor gastrointestinal anomaly) developed severe chronic lung disease. One died from right-sided heart failure in a context of lung infection at 3 months of age. The two survivors still required oxygen supplementation and/or nocturnal ventilator at about 3 years of age. A pleural effusion complicated the postoperative course in one infant before 1992 and in 11 of 21 survivors (53 %) after 1992 (NS). In 8 of 12 cases the lymphatic nature of the effusion was confirmed by a proportion of lymphocytes greater than 80 % or by the presence of chyle on pleural fluid examination.

Respiratory parameters during the first 24 h in period 2

Blood gas data were available for the 32 patients during period 2. Table 3 summarizes data calculated for four commonly used prognostic indicators derived from the best results of the arterial blood gases obtained within the first 24 h of life. The highest postductal PaO_2, lowest OI, and A-aDO_2 were all significantly correlated with outcome (Table 3). The lowest $PaCO_2$ during the first 24 h was similar in survivors and nonsurvivors, but the level of P/P required to obtain these results was significantly higher in nonsurvivors. To compare these indices, ROC were generated, and the ROC curves for A-aDO_2, OI, and P/P are show in Figs. 1 and 2. The best A-aDO_2, best OI, and lowest P/P were more powerful than the postductal PaO_2 in predicting survival. An A-$aDO_2 \leq 235$ predicted a good outcome (95 % survival rate) with a sensitivity of 95 % and specificity of 91 %. An OI ≤ 6 had a 94 % survival rate, with a sensitivity of 81 % and specificity of 91 %. A P/P ≤ 52 cmH_2O had a 94 % survival rate, with a sensitivity of 81 % and specificity of 91 %. Figure 3 shows the data when OI was plotted against P/P. A poor outcome (11 % survival) was predicted for all data points with OI above 10 and P/P above 55 cmH_2O. In contrast, a high survival rate (94 %) was observed with OI ≤ 10 and P/P ≤ 55 cmH_2O.

Discussion

This study evaluated the impact of postnatal management on the outcome of neonates with antenatally diagnosed congenital diaphragmatic hernia. The introduction of a new management strategy in 1992 was associated with a significant increase in survival from 26 % to 66 %. Because of the historical nature of the comparison

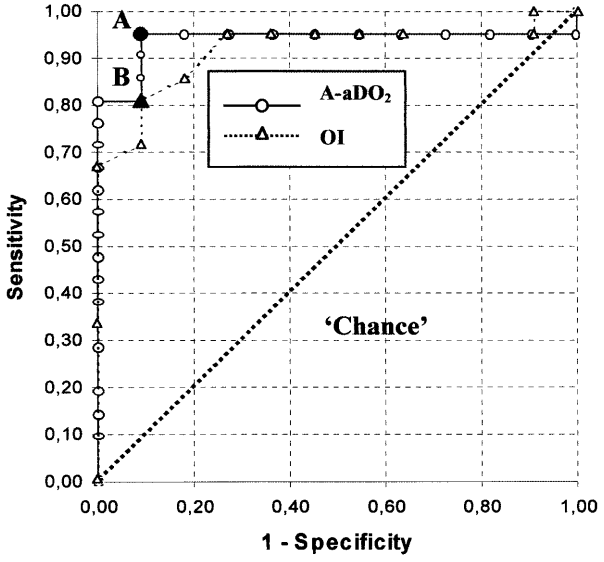

Fig. 1 ROC curves for best A-aDO_2 and OI. *Point A*: A-$aDO_2 \leq 235$, the value with the highest combination of sensitivity and specificity in predicting survival. *Point B*: OI ≤ 6, the value with the highest combination of sensitivity and specificity in predicting survival

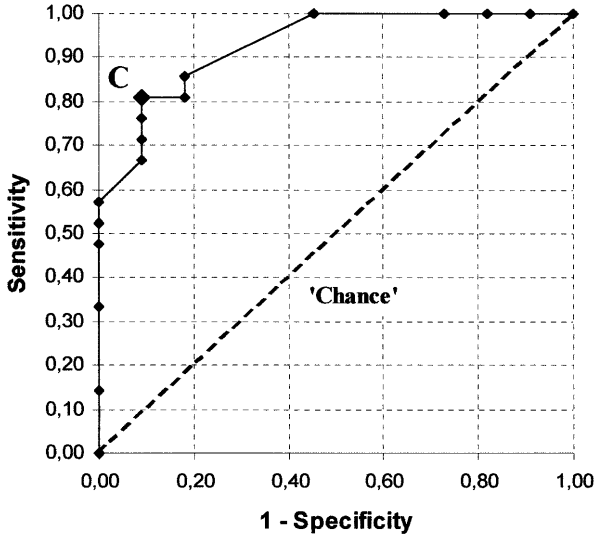

Fig. 2 ROC curve for lowest P/P pressure. *Point C* P/P ≤ 52, the value with the highest combination of sensitivity and specificity in predicting survival

of these two periods, factors other than modified postnatal management may be involved in this improved survival. However, careful comparison of antenatal prognostic factors in the patients of the two periods did not reveal any significant difference, suggesting that the change in postnatal management may have played a role.

All cases of CDH were considered to be isolated, and a similar frequency of antenatally missed malformations, which did not modify the management strategy, was observed during the two periods. The most severe malformations likely to interfere with cardiorespiratory function were observed during period 2.

Improvement in the capacities of antenatal diagnosis over the past 10 years may have resulted in the antenatal detection of less severe forms of CDH after 1992 than during period 1. Our observation of a small increase in the proportion of CDH diagnosed before 25 weeks of gestational age during period 2 compared with period 1 could be related to this technological improvement rather than to the diagnosis of more severe forms of CDH. Although antenatal prognostic factors do not predict survival with certainty [12], they provide an estimate of the severity of the malformation. A similar distribution of antenatal prognostic factors was observed during periods 1 and 2, suggesting that the 2 groups are comparable, despite a slight nonsignificant difference in the frequency of mediastinal shift and polyhydramnios during period 1. The two cohorts cannot be compared in terms of postnatal respiratory prognostic factors due to the major differences in clinical management between the two periods.

The management of CDH during period 2 was designed to avoid factors likely to precipitate ductal and preductal shunting and iatrogenic complications, during both the preoperative and postoperative periods. Delayed surgery is now widely accepted for the management of CDH, but its possible effect on mortality is still controversial [8, 9, 18, 19].

Hyperventilation and hypocapnia have been used in the management of persistent pulmonary hypertension of neonates, including CDH [20], but pulmonary injury can result from aggressive ventilatory strategy [21]. Several recent studies have reported both improved survival and decreased use of extracorporeal membrane oxygenation after stopping the use of hyperventilation with CMV in CDH [22, 23]. Compared to CMV, HFOV may minimize baro-/volotrauma due to much smaller alveolar pressure and volume variations. However, the place of HFOV in the management strategies for CDH is still uncertain, and neonates with CDH seem to be the least likely to respond to HFOV [24]. Reduction in PCO_2 and alkalosis can be obtained with HFOV in neonates with CDH, despite severe pulmonary hypoplasia, but no effect on survival has been demonstrated [25, 26, 27]. A recent review of the last 10-year experience of HFOV for CDH reports disappointing results, with only 11 % survival in neonates switched from CMV to HFOV [9]. The marked improvement in survival in the present study, however, is in contrast these reports. In these "rescue" strategies, however, HFOV may have been used too late, after onset of lung damage due to high pressure with CMV and supporting the concept of

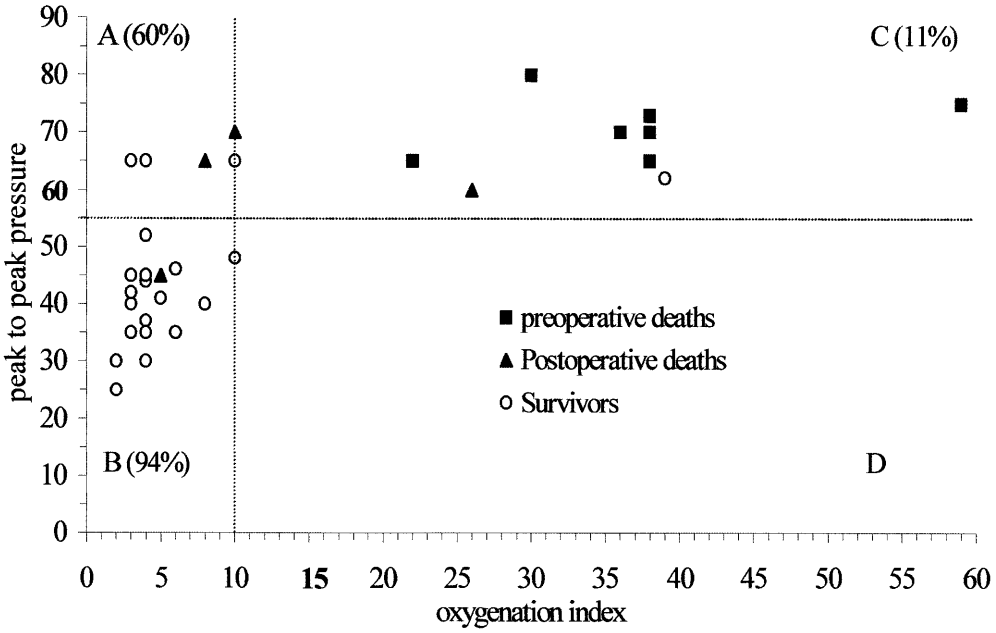

Fig. 3 The relationship between OI and P/P. *In parentheses* Survival rates in the respective quadrants. *A:* OI ≤ 10 and P/P > 55; *B:* OI ≤ 10 and P/P ≤ 55; *C:* IO > 10 and P/P > 55; *D:* IO > 10 and P/P ≤ 55

reduced volotrauma. In our study no attempt was made to induce permissive hypercapnia. Because of the remarkable capacity of purification of the CO_2 of the HFOV while minimizing the effects of baro-/volotrauma, the PCO_2 was maintained between 30 and 40 mmHg.

The results of early use of HFOV for CDH have been previously reported with good results but without evaluation of severity of CDH [26, 27]. The original feature of our study is the antenatal diagnosis of CDH in all cases. Antenatal diagnosis allowed a careful comparison of the severity of patients between the two periods and a very early use of HFOV. It eliminated the need for transfer of highly unstable patients, even for surgery. In the most severe cases, HFOV was continued during preoperative stabilization, surgery and the postoperative period.

Inhaled NO was considered to be effective in only two patients. The dramatic improvement reported with inhaled NO in other forms of persistent pulmonary hypertension of neonates is observed less frequently in patients with CDH [28]. We did not use surfactant prophylactically but rather as "rescue" therapy. Little or no improvement was observed in gas exchange and sometimes poor tolerance, with acute hypercapnia. Prophylactic surfactant therapy may be preferable, as demonstrated in the fetal lamb model of CDH [29].

The postoperative course during period 2 was quite different. With the new management, a "honeymoon" period followed by postoperative deterioration leading to death in the first postoperative days was no longer observed. On the contrary, probably in relation to survival of more severe cases, a prolonged course with severe chronic lung disease and pulmonary hypertension was recorded in some patients, as a late onset death at 3 months of age. During period 2, the postoperative period was more frequently marked by the development of lymphatic pleural effusion, unrelated to patch repair. This may have been due to the increased number of operated CDH and the survival of more severe forms. Two mechanisms could explain this previously reported finding [30, 31, 32]: a lesion of the thoracic duct during surgery or abnormal development of the lymphatic vessels. In the majority of cases rapid recovery (less than 1 month) was obtained with total parenteral nutrition or enteral feeding with a limited amount of long-chain fatty acid.

In contrast with CMV [9, 33], $PaCO_2$ levels were not an accurate early predictor of outcome on HFOV. This confirms the remarkable capacity of HFOV to eliminate CO_2. However, significantly higher P/P values were required in nonsurvivors. Nevertheless, P/P levels have no absolute value, as they vary considerably according to the ventilator used and the type of neonatal disease.

We have shown that OI, A-aDO_2, and P/P, when derived from an infant's best value, have predictive value in our institution. Although an A-aDO_2 at or below 235 is marginally the best predictor of survival in our population, it is calculated from an infant's PaO_2 and $PaCO_2$ without consideration of the ventilation required to achieve such values. An infant's OI and P/P provide more objective information because they include ventilatory data. An OI of ≤ 10 or less and a P/P value of ≤ 55 cmH_2O or less in the first 24 h of life were associated with a good prognosis (94% survival rate, 17/18). The only death observed in this group was related to an

accidental complication, unrelated to CDH. An OI higher than 10 with a P/P value higher than 55 cmH_2O were associated with poor prognosis (11 % survival rate, 1/9). The survivor in this category subsequently developed chronic respiratory insufficiency and pulmonary hypertension. These clinical predictors of survival, derived from retrospective data, should be tested prospectively.

Conclusions

HFOV soon after birth, delayed surgery, and no transfer of unstable patients allowed a survival rate of 66 % in infants with antenatally diagnosed CDH. Surgery was performed in the NICU on HFOV in the most severe cases. The survival rate was much better than in similar cases treated in the same unit several years previously using CMV and emergency transfer for surgery but perhaps with an increase in morbidity. Long-term morbidity has not yet been evaluated. An OI of ≤ 10 or lower with a P/P pressure of ≤ 55 cmH_2O or less in the first 24 h of life is associated with a good prognosis.

References

1. Manni M, Heydanus R, Den Hollander NS, Stewart PA, De Vogelaere C, Wladimiroff JW (1994) Prenatal diagnosis of congenital diaphragmatic hernia: a retrospective analysis of 28 cases. Prenatal Diagn 14: 187–190
2. Harrison MR, Adzick NS, Estes JM, Howell LJ (1994) A prospective study of the outcome for fetuses with diaphragmatic hernia. JAMA 271: 382–384
3. Sharland GK, Lockhart SM, Heward AJ, Allan LD (1992) Prognosis in fetal diaphragmatic hernia. Am J Obstet Gynecol 166: 9–13
4. Wilson JM, Fauza DO, Lund DP, Benacerraf BR, Hendren WH (1994) Antenatal diagnosis of isolated congenital diaphragmatic hernia is not an indicator of outcome. J Pediatr Surg 29: 815–819
5. George DK, Cooney TP, Chiu BK (1987) Hypoplasia and immaturity of the terminal lung unit (ascinus) in congenital diaphragmatic hernia. Am Rev Respir Dis 136: 947–950
6. Cartlidge PHT, Mann NP, Kapila L (1986) Perioperative stabilisation in congenital diaphragmatic hernia. Arch Dis Child 61: 1226–1228
7. Hazebroek FWJ, Tibboel D, Bos AP, Pattenier AW, Madern GC, Bergmeijer JH, et al (1988) Congenital diaphragmatic hernia: impact of preoperative stabilization. A prospective pilot study in 13 patients. J Pediatr Surg 23: 1139–1146
8. Wilson JM, Lund DP, Lillehei CW (1992) Delayed surgery and preoperative ECMO does not improve survival in high-risk congenital diaphragmatic hernia. J Pediatr Surg 27: 368–372
9. Azarow K, Messineo A, Pearl R, Filler R, Barker G, Bohn D (1997) Congenital diaphragmatic hernia-A tale of two cities: the Toronto experience. J Pediatr Surg 32: 395–400
10. Glick PL, Leach CL, Besner GE, Egan EA, Morin FC, Malanowska-Kantoch A, et al (1994) Pathophysiology of congenital diaphragmatic hernia. III. Exogenous surfactant therapy for the high-risk neonate with CDH. J Pediatr Surg 27: 866–869
11. Shah N, Jacob T, Exler R, Morrow S, Ford H, Albanese C, et al (1994) Inhaled nitric oxide in congenital diaphragmatic hernia. J Pediatr Surg 29: 1010–1015
12. Dommergues M, Louis-Sylvestre C, Mandelbrot L, Oury JF, Herlicoviez M, Body G, et al (1996) Congenital diaphragmatic hernia: can prenatal ultrasonography predict outcome? Am J Obstet Gynecol 174: 1377–1381
13. Adzick NS, Harrison MR, Glick PL, Nakayama DK, Manning FK, de Lorimier AA (1985) Diaphragmatic hernia in the fetus: prenatal diagnosis and outcome in 94 cases. J Pediatr Surg 20: 357–361
14. Crawford DC, Wright VM, Drake DP, Allan LD (1989) Fetal diaphragmatic hernia: the value of fetal echography in the prediction of postnatal outcome. Br J Obstet Gynaecol 96: 705–710
15. Adzick NS, Vacanti JP, Lillehei CW, O'Rourke PP, Crone RK, Wilson JM (1989) Fetal diaphragmatic hernia: ultrasound diagnosis and clinical outcome in 38 cases. J Pediatr Surg 24: 654–658
16. Bohn DJ, Miyasaka K, Marchak E, Rtytr NB, Yuiuy LM, Hgfrtr HJ (1980) Ventilation by high frequency oscillation. J Appl Physiol 48: 710–716
17. Askenasi SS, Perelman M (1979) Pulmonary hypoplasia: lung weight and radial alveolar count as criteria of diagnosis. Arch Dis Child 54: 614–618
18. Nio M, Haase G, Kennaugh J, Bui K, Atkinson JB (1994) A prospective randomized trial of delayed versus immediate repair of congenital diaphragmatic hernia. J Pediatr Surg 29: 618–621
19. Langer JC, Filler RM, Bohn DJ (1988) Timing of surgery for congenital diaphragmatic hernia: is emergency operation necessary? J Pediatr Surg 23: 731
20. Drummond WH, Gregory GA, Heymann MA (1981) The independent effects of hyperventilation, talazoline, and dopamine on infants with persistent pulmonary hypertension. J Pediatr 98: 603–611
21. Kolobow T, Moretti MP, Fumagalli R (1987) Severe impairment of lung function induced by high peak airway pressure during mechanical ventilation. Am Rev Respir Dis 135: 312–315
22. Wilson JM, Lund DP, Lillehei CW, Vacanti JP (1997) Congenital diaphragmatic hernia-A tale of two cities: the Boston experience. J Pediatr Surg 32: 401–405
23. Wung JT, R. Sahni, Moffitt ST, Lipsitz E, Stolar CJ (1995) Congenital diaphragmatic hernia: survival treated with very delayed surgery, spontaneous respiration, and no chest tube. J Pediatr Surg 30: 406–409
24. Paranka MS, Clark RH, Yoder BA, Null DM Jr (1995) Predictors of failure of high-frequency oscillatory ventilation in term infants with severe respiratory failure. Pediatrics 95: 400–404
25. Tamura M, Tsuchida Y, Kawano T (1988) Piston-pump-type high frequency oscillatory ventilation for neonates with congenital diaphragmatic hernia: a new protocol. J Pediatr Surg 23: 478–482

26. Miguet D, Claris O, Lapillonne A, Bakr A, Chappuis JP, Salle BL (1994) Preoperative stabilization using high-frequency oscillatory ventilation in the management of congenital diaphragmatic hernia. Crit Care Med 22 [Suppl 22]:S77–S82
27. Reyes C, Chang LK, waffarn F, Mir H, Warden J, Sills J (1998) Delayed repair of congenital diaphragmatic hernia with early high-frequency oscillatory ventilation during preoperative stabilization. J Pediatr Surg 33: 1010–1016
28. Mercier JC, Lacaze T, Storme L, Rozé JC, Dinh-Xuan TA, Dehan M, et al (1998) Disease-related response to inhaled nitric oxide in newborns with severe hypoxaemic respiratory failure. Eur J Pediatr 157: 747–752
29. Wilcox DT, Glick PL, Karamanoukian H, Rossman J, Morin FC 3rd, Holm BA (1994) Pathophysiology of congenital diaphragmatic hernia. V. Effect of exogenous surfactant therapy on gas exchange and lung mechanics in the lamb congenital diaphragmatic hernia model. J Pediatr 124: 289–293
30. Tilmont P, Alessandri JL, Duthoit G, Rossi-Farrer C, Roge-Wolter M (1993) Epanchement chyleux après cure chirurgicale d'une hernie diaphragmatique chez 2 nouveau-nés. Arch Fr Pediatr 50: 783–786
31. Wiener ES, Owens L, Salzberg AM (1973) Chylothorax after Bochdalek herniorrhaphy in a neonate. Treatment with intra-veinous alimentation. J Thorac Cardiovasc Surg 65: 200–206
32. Oshio T, Matsumara C (1983) Chylothorax following Bochdalek herniorrhaphy in a infant. J Pediatr Surg 18: 298–299
33. Bohn DJ, James I, Filler RM (1984) The relationship between PaCO2 and ventilation parameters in predicting survival in congenital diaphragmatic hernia. J Pediatr Surg 19: 666