Development of peripheral chemoreceptor function in infants with chronic lung disease and initially lacking hyperoxic response

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Abstract
Ten preterm infants with chronic lung disease (CLD) and undeveloped peripheral chemoreceptor function, described as ventilatory response to hyperoxia, were investigated, according to an individual protocol. Each infant was followed up until the response to hyperoxic inhalation had been observed on two occasions. Each examination consisted of overnight recording of saturation, testing of lung compliance and airway resistance, and the hyperoxic test.

The hyperoxic response appeared at a mean postnatal age of 14 weeks (range 9-33 weeks). This response, which was independent of the infant’s lung mechanics, appeared much later in infants with the severe form of CLD.

As undeveloped peripheral chemoreceptor function has been suggested to be a key factor in sudden infant death syndrome (SIDS), the delayed development of their chemosensitivity leaves some infants with CLD unprotected against hypoxia at the age at which the risk for SIDS is highest.

(Keywords: peripheral chemoreceptors, CLD, SIDS)

Infants with chronic lung disease (CLD) usually exhibit frequent episodes of hypoxaemia, due to episodes of desaturation, increased lung compliance, and increased airways resistance. Furthermore, when exposed to hypoxia, these infants often respond with initial arousal, followed by prolonged apnoea and bradycardia. Desaturations may adversely affect the sensitivity of peripheral chemoreceptors and, as shown in animal models, result in severe disturbances in respiratory control mechanisms, in the absence of arousal from hypoxia or in sudden death. It has been suggested that absent or attenuated peripheral chemoreceptor function may, at least partially, explain the significantly increased incidence of sudden infant death syndrome (SIDS) in these infants.

In previous studies we have shown that prolonged oxygen treatment attenuates the sensitivity of peripheral chemoreceptors, and that most infants with CLD had defective function of peripheral chemoreceptors. This prompted us to investigate whether adequate responsiveness of these receptors in infants with CLD develops subsequently during recovery from the disease or whether the observed dysfunction is permanent.

Because exposure to hyperoxic gas mixtures causes an almost immediate suppression of the action of peripheral chemoreceptors, an oxygen induced decrease in ventilation has been used as an indirect measure of the sensitivity of these receptors.

Methods
Ten infants treated at Karolinska Hospital were included in this study on the basis of two criteria: they were diagnosed as having CLD; and they displayed an initial absence of the response to hyperoxia.

CLD was diagnosed on the basis of the following criteria: (1) an acute lung injury during the first week of life; (2) clinical signs of chronic respiratory disease; (3) a requirement for supplemental oxygen in order to maintain a PaO2 of over 50 mm Hg for more than 28 days; (4) a chest radiograph showing persistent strands of density in both lungs.

CLD was divided into stages according to the criteria described by Toce et al. In addition to the criteria mentioned above, the respiratory status of the infants was also determined with regard to the amount, duration, and depth of spontaneous desaturations during the night preceding the test, and by lung compliance and airways resistance at the time of the test.

Informed consent from the parents was obtained and the examination was often performed in the presence of at least one parent. This study was approved by the local ethics committee at the Karolinska Hospital.

Respiratory recordings
Ventilatory measurements were performed using a neonatal/infant pulmonary monitor (Bicore, CP-100) which provides continuous pulmonary monitoring of airway flow and pressure through a flow transducer. The
Chemoreceptor function in infants with CLD

Experimental procedure – timing and structure

Supplemental O₂ decreased by 2–3% or 2 days after discontinuation
With one week intervals
2–3 weeks after establishment of the hyperoxic response

Figure 1 Timing and structure of experimental protocol. The timing of measurements was based on the infant’s requirement for supplemental oxygen. All measurements, except for the final test, included overnight recording of the saturation and daytime recording of respiratory mechanics and administration of the hyperoxic test.

Table 1 Patient data

<table>
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<th>Case No</th>
<th>Gestational age at birth (weeks)</th>
<th>Birth weight (g)</th>
<th>Ventilator treatment (days)</th>
<th>CPAP</th>
<th>O₂ treatment (days)</th>
<th>CLD grade</th>
<th>Diuretic treatment (Salbutamol)</th>
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*Yes/No = treatment interrupted during the course of study.
† Receiving supplemental oxygen at time of discharge home.

sampling frequency of the system for pressure and flow is 100 Hz and the response time 13.5 ms. By using a flow transducer together with an occlusion valve, airway pressure, compliance, and respiratory resistance could be measured. During the hyperoxic test, the flow head was connected via a T-tube to a stream of 4 l/minute humidified, warmed air that could be rapidly switched to 4 l/minute 100% humidified, warmed oxygen. The dead space of the mask, flow head, and tubing was 2–3 ml and their total resistance was 7.1 cm H₂O/l/s. The respiratory parameters—that is, minute ventilation, inspiratory/expiratory tidal vol-
Hyperoxic test
The infants were loosely wrapped in blankets in their cots. All examinations were performed during behavioural quiet sleep, characterised by the absence of eye and body movements and by regular respiration. The face mask was gently placed on the infant’s face. The test was initiated by three to five minutes of stable breathing with warmed, humidified air. Thereafter, the inspiratory line was rapidly switched and the infant breathed 100% humidified oxygen for 30 seconds, followed by re-administration of air. This test was repeated five to 10 minutes later. During every session, two to four tests were performed.

Pulmonary mechanics
Infants breathed through the face mask into the flow transducer connected to the occlusion valve. The airways were occluded automatically at the end of inspiration and the accompanying volume/pressure and pressure/flow correlations described respiratory system compliance ($C_R$) and resistance ($R_T$). All data were stored on the computer.

ANALYSIS OF THE RESULTS
Recordings were considered satisfactory for analysis only if the baby remained in the same position without sudden movement, in continuous behavioural quiet sleep.

Saturation
Box and whisker plots were used to describe desaturations. This analysis provides the range and median and is useful for studying symmetry and detecting out of range data.

Response to hyperoxia
Tidal volume, breath duration, and minute ventilation were analysed on a breath by breath basis for each individual. Ventilatory variables were calculated for the 30 seconds of air breathing immediately preceding the hyperoxic test, during the 30 seconds of oxygen administration, and during the first minute of recovery by breathing air. The mean values from three to four trials were calculated and used for analysis. Percentage changes in the tidal volume, breath duration, and minute ventilation on going from normoxic to hyperoxic conditions were determined for each infant and tested for significance by analysis of variance.

Clinical status and hyperoxic response
Possible correlations between the age at which the hyperoxic response developed and grade of CLD, postconceptional age at birth, birthweight, days on a ventilator and on continuous positive airway pressure (CPAP), duration of supplemental O$_2$ treatment, and the number, duration, and depth of desaturations were examined using multiple regression analysis.

Possible relationships between the grade of CLD and respiratory system compliance ($C_R$), airway resistance ($R_T$), and the strength of the hyperoxic response were evaluated using the Spearman Rank correlation.

The time dependent changes in $C_R$ and $R_T$ in all patients were evaluated using the analysis
of variance test for homogeneity, which examines the differences between several subgroups of data.

Results
The patient data are presented in table 1. The mean postconceptional age at birth and mean (SD) birthweight were 26.3 (2.4) weeks and 965 (332) g, respectively. The length of time on ventilator support varied between 0 (one infant) and 21 days, while the number of days on CPAP ranged between 11 and 159 days. Supplemental oxygen was provided for a mean period of 120 days (range from 49 to > 352 days). Two infants (cases 3 and 9), were still receiving oxygen at the time of discharge home. Five infants had grade I CLD, three grade II, and two grade III.

The median number of desaturations per night decreased with increasing age from 5.5 at the time of the first test to 0 at the last test (the mean decreased from 10 to 0.6 desaturations per night). At the same time, the duration and depth of the desaturations decreased (fig 2).

All infants developed sensitivity to hyperoxia before being discharged, at the times indicated by the arrows in fig 3. Once established, this response either remained unchanged (in seven infants), or became even stronger (in three infants). The median postnatal and postconceptional age at which the hyperoxic response was established were 14 weeks (range 9-33 weeks) and 41 weeks (range 37-58 weeks), respectively (table 2).

The more severe cases of CLD showed delayed appearance of the hyperoxic response (fig 4). There was a significant correlation (P=0.02) between the postnatal age at which the response appeared and the grade of CLD; postconceptional age was not associated with the time for establishment of this response (P=0.057). Three of the infants were still receiving supplemental oxygen when they developed the hyperoxic response (table 2). Two of these had the highest postnatal and postconceptional ages. On the other hand, the strength of the response was related neither to the postconceptional or postnatal age of the infant, nor the grade of CLD. The response time was not correlated with the CLD grade or strength of the response.

The repeated measurements of $C_r$ on the same test, varied by a mean of 7.3% (range 4-10%), which was significantly lower than the differences between individuals (ANOVA; P < 0.000). The measurements of $R_s$ showed much higher variations (mean of 17.2% and range of 11-25%).

The two infants with grade III CLD had significantly lower $C_r$ (P=0.001) and lower $R_s$ (P=0.002) then the other infants (fig 5). The time dependent changes in $C_r$ and $R_s$ are shown in figs 6 and 7. The stars denote a significant difference from the first test (using the Mann-Whitney U test). In two infants the
Discussion

In previous studies, we have shown that most infants with impaired or inhibited peripheral chemoreceptor function, as indicated by the response to hyperoxia, were very low birthweight (VLBW) infants with CLD. It has been suggested that attenuated action of these chemoreceptors is a key factor in SIDS. The hypothesis that there is a connection between SIDS and peripheral chemoreceptor dysfunction seems to be strengthened by our data, and the high incidence of sudden infant death among this group might at least be partially explained. However, our present results show that all infants with CLD and an initially absent hyperoxic response, with the exception of two infants with the most severe grade of CLD, developed this response at a mean postnatal age of 13 weeks (range 9-16)—that is, at the age where the risk for SIDS is highest. The two infants with grade III CLD also developed the response to hyperoxia, but at a much later postnatal age (6 and 8 months). This is particularly interesting, because postnatal age is significantly correlated with the development of peripheral chemoreceptor function (present study) and has been associated with the time period for increased risk of SIDS.

The delayed development of chemoreceptor function at the age where the susceptibility to SIDS is highest suggests that some infants with more severe CLD lack the ability to defend themselves when subjected to hypoxia. Although only a small number of patients were investigated in the present study, our findings support the hypothesis that defective peripheral chemoreceptor function is a contributory factor to SIDS. Therefore, an effort should be made to identify additional risk factors that might predispose infants with CLD to SIDS.

On the basis of an epidemiological study of very preterm and small for postconceptual age infants in the Netherlands, maternal smoking, hypothermia on the first day of life, and a decreased number of white cells and thrombocytes at birth were proposed as perinatal risk factors for SIDS. Intrauterine hypoxia was suggested as the common denominator for these risk factors. Similarly, postnatal hypoxia was suggested as a risk factor for SIDS, because a substantial proportion of SIDS babies have chronic pulmonary hypoventilation, respiratory distress syndrome, and hypoaxaemia. Short hypoxaemic episodes in the form of frequent desaturations have recently been observed in infants with CLD. In our study group the infants also initially sustained desaturations during sleep, despite treatment with supplemental oxygen. The decrease in the frequency and duration of night time desaturations, which was not paralleled by an improvement in respiratory mechanics, might be explained by maturation of the ventilatory control mechanisms. The possible connection between the desaturations and impaired lung mechanics is particularly important, as in infants with CLD the hypoxic episodes might be potentiated by obstruction in the airways and by the inability to compensate for this kind of respiratory loading. Surprisingly, the infants in our study who had the most severe CLD (grade III) showed the lowest arterial resistance. However, the explanation for this could be simple. The examination of the infants was performed within 2 to 3 hours of treatment with bronchodilators administered to alleviate severe initial obstruction.

The preceding hypoxaemia in SIDS babies is associated with pathological changes in the glomus of carotic bodies. Hypoxaemic episodes also result in histological and chemical changes in the brain, and might therefore even affect the respiratory control centres localised in the brain stem. The negative effect of hypoxaemia on peripheral, as well as on central, structures might contribute to an increased susceptibility to SIDS.

Even though this hypothesis does not provide an aetiological explanation for SIDS, it might shed light on the mechanisms underlying susceptibility to SIDS among very low birthweight infants who often experience both perinatal and postnatal hypoxia. The importance of precluding hypoxic episodes as a pre-

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**Figure 7** Time related changes in $R_s$ for each infant. *indicates significant change from first measurement.

The table and diagram show the time-related changes in $R_s$ (cm H2O/second) for each infant. The asterisk indicates a significant change from the first measurement.
ventive measure against SIDS has recently been emphasised by Gray and Rogers, who showed that treatment of infants with CLD with supplemental oxygen once they had returned home lowered their risk for SIDS to normal levels.

Most infants with CLD who had the initial absence of a peripheral chemoreceptor response to hypoxia subsequently develop this at about 14 weeks after birth. However, most severely affected infants still lack the response at the age at which the strongest susceptibility to SIDS occurs, and so must be carefully monitored.

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monary mechanics and small arteries in infants and