On-line analysis of diaphragmatic EMG (EMGdi) should be useful in the weaning period, especially in newborns who have been shown to be at risk of respiratory muscle fatigue [1]. A previous study by Müller et al. [1] in newborns concerned only off-line analysis of the high over low frequencies ratio (H/L). In the present study we tested an on-line system of analysis in healthy preterm newborns. Furthermore, we compared the H/L ratio, the centroid frequency [2-4] and the modal frequency [5].

Methods and subjects

We studied seven healthy preterm newborns, free of respiratory disease, whose gestational age was 31 wks (range from 28-34 wks) and whose postnatal age was 16 days (range 2-75 days). Body weight at the time of the study was 1.660 g (range 1.350-2.190 g).

All subjects were tested whilst spontaneously breathing during sleep, in the supine position, inside an incubator. The EMGdi was recorded using two surface electrodes (Beckman) placed in the right 7th and 8th interspaces, between the mid-clavicular and mid-axillary lines. The inter-electrode distance was 20 mm and the inter-electrode impedance was lower than 10 kΩ. The signals were filtered to allow passage of frequencies between 10-1000 Hz [4-7] and amplified (preamplifier and amplifier Gould 13-4615-58). The signals were displayed on a Tektronix 5111A storage oscilloscope and processed using a microcomputer (Apple Ile), using two disc drives, a printer, a real time clock card (Nautic HC-1) and 12 bits A/D converter (SDM 837). Programs were written in machine code and Basic Microsoft (Beagle compiler-Beagle Bross Micro Software Inc.).

Data analysis

First step. The EMGdi signal was sampled during 4.65 s and monitored (fig. 1. panel a). The investigator placed horizontal lines on the screen of the computer. The vertical position of the lines determined the threshold for further QRS detection. The length of the lines corresponded to the time window during which the EMGdi signal would be digitized during the second step of the analysis. The QRS artifacts were automatically removed from the stored EMGdi signal (fig. 1. panel b); when the signal was greater than the QRS complex detection threshold, the 12 preceding and the 12 following data points of the EMGdi were set at zero. The residual artifact-free EMGdi signal was rectified. The mean amplitude (A) of the EMGdi was calculated (fig. 1. panel c). A would be the reference of mean amplitude value for detection of EMGdi inspiratory bursts during the second step of analysis.

Second step. After one QRS complex and during the time window, the EMGdi signal was digitized (256 data points and sampling frequency of 1024 Hz) (fig 2. upper panel), rectified and its mean amplitude (a) calculated. When a of the sample was less than the mean reference amplitude A, the signal was rejected, being presumably an expiratory signal. When a of the sample was greater than A X 3, the signal was also rejected being presumably modified by movement artifacts. Then the accepted
samples were analysed using: 1) auto-regressive model with calculation of the modal frequency (Fo) [5]; 2) power spectral analysis with determination of the centroid frequency (Fc) (fig. 2, lower panel) and of the H/L frequencies ratio (150–120/60–30 Hz).

For each subject all Fo and Fe data were compared using the paired t-test. The coefficient of variation and the percentage of rejected calculations between the H/L ratio, Fe and Fo were compared using the Wilcoxon test.

Results

Table 1 shows the mean individual values (±1 sd), the coefficient of variation and the percentage of rejected calculations for the H/L ratio, Fo and Fe. Mean individual Fe ranged from 46–62 Hz and mean individual Fo from 49–70 Hz. When all Fo and Fe calculations were compared for each subject, Fe was lower than Fo in six of the seven subjects, but the level of significance was reached in only four subjects (nos 2, 4, 6 and 7, table 1) (p<0.001). The coefficient of variation for Fo and Fe was not significantly different, whereas the coefficient of variation for the H/L ratio was significantly higher than for Fe, p<0.001. The percentage of EMGdi samples for which calculations were rejected was significantly higher for Fo than Fe, p<0.001. Figure 3 shows the relationship between all accepted calculations for Fo and Fe: Fe (Hz) = 11.8+0.71 Fo (Hz), r=0.81, p<0.001.

Conclusion

As in previous studies on EMGdi in the newborn we used surface electrodes [1, 6, 7]. Although there is a possibility of artifacts from surface electrodes, it has been shown that EMGdi recorded in infants from intercostal sites exhibit spectra which are very similar to those from subcostal diaphragm surface recordings [1] which in turn resemble EMGdi obtained from an oesophageal electrode [8]. However, contamination of diaphragmatic surface signals with EMG from other muscles cannot be excluded.

Different off-line techniques to remove QRS artifacts on the EMGdi have previously been proposed [4, 10]. In the present study we used an automatic gating technique. Another problem which arises is sampling inspiratory bursts for computer analysis of the EMGdi. A respiratory signal can be used to sample the EMG signal [1] during the inspiratory part of the respiratory cycle [5]. In the present study we did not use a respiratory signal. The aim of our investigation was to provide an on-line analysis which could be used in mechanically ventilated newborns in whom minimal apparatus is required. Our method of inspiratory burst determination was based on the mean reference amplitude A defined on the QRS free EMGdi.

As previously observed in adults [1], the coefficient of variation for the H/L ratio was significantly higher than for Fe in preterm newborns. Fe values (table 1) were close to the mean Fe observed in one full-term newborn by NuéRR and Finley [7]. As in adults, Fe and Fo were significantly related [5], however, Fe was significantly less than Fo in four of the seven preterm newborns. The
Relationship between the modal frequency (Fo) and the respiratory spectral spectra 1. Muller fatigue. early detection of the development of diaphragmatic EMGd analysis in sick newborns. percentage able coefficient of variation. Further investigations were significantly higher than for Fe. Thus, in our seven preterm newborns, Fe appears to be the best index of EMGdi analysis with a low percentage of rejection and a reasonable coefficient of variation. Further investigations are needed to justify the choice of Fe as the best index of EMGdi analysis in sick newborns.

In summary, an on-line analysis of EMGdi recorded using surface electrodes was tested in healthy preterm newborns. During the weaning period, our system should be useful for monitoring EMGdi in mechanically ventilated newborns. In addition to gas exchange monitoring, a decline of Fe in the EMGdi power spectrum may allow early detection of the development of diaphragmatic fatigue.

Acknowledgements: The authors are grateful to S. Rouchaville for typing the manuscript.

References


RÉSUMÉ: L'étude a été faite par des enregistrements électromyographiques au moyen d'électrodes de surface. Les signaux d'EMGdi ont été traités par un microprocesseur (Apple IIE). La fréquence contrôle (Fc) et le rapport des fréquences élevées sur les fréquences basses du spectre de puissance, ont été calculés. Par ailleurs, la fréquence modale (Fo) a été mesurée par le modèle auto-régressif du signal électromyographique. L'analyse EMGdi a été réalisée chez 7 nouveau-nés avant terme respirant spontanément. Fo s'étend de 46 à 62 Hz. Fo est significativement plus bas que Fo chez 4 des

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Table 1. - High-to-low frequency ratio, modal frequency and centroid frequency in seven health preterm newborns

<table>
<thead>
<tr>
<th>Subject</th>
<th>Number of EMGdi samplings</th>
<th>H/L mean</th>
<th>H/L std</th>
<th>H/L % failure</th>
<th>Fo mean</th>
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<th>Fo % failure</th>
<th>Fe mean</th>
<th>Fe std</th>
<th>Fe % failure</th>
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<td>0.13</td>
<td>10</td>
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EMGdi: diaphragmatic electromyogram; H/L: high low ratio of the power spectrum (150–120/60–30 Hz); Fo: modal frequency; Fe: centroid frequency; std/mean: coefficient of variation; failure %: percentage of EMG diaphragmatic samples for which Fo and Fe calculations were rejected, i.e. Fo or Fe <30 Hz or >150 Hz.

Fig. 3. - Relationship between the modal frequency (Fo) and the centroid frequency (Fe) (n=402).

Inclusion of rejected calculations for Fo was significantly higher than for Fe. Thus, in our seven preterm newborns, Fe appears to be the best index of EMGdi analysis with a low percentage of rejection and a reasonable coefficient of variation. Further investigations are needed to justify the choice of Fe as the best index of EMGdi analysis in sick newborns.

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7 nouveau-nés prématurés. Le coefficient de variation pour Fc est significativement plus bas que pour la relation H/L (p<0.001). Les coefficients de variation pour Fo et Fc ne sont pas significativement différents, mais le pourcentage de calculs rejettés pour Fo est significativement plus élevé que pour Fc (p<0.01). Pour cette raison, chez les nouveau-nés prématurés en bonne santé, Fc semble le meilleur index d'analyse d'EMGdi.

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