Do lung volumes change with sleep state in the neonate?


1 Department of Child Health and 2 Department of Clinical Neurophysiology, Queen's Medical Centre, Nottingham, NG7 2UH, United Kingdom
3 Department of Medical Physics & Clinical Engineering, Royal Hallamshire Hospital, Sheffield, United Kingdom

Abstract. We have studied 12 healthy full-term babies, mean age 3.2 days, using physiological criteria — EEG, electro-oculogram, electromyogram, respiratory regularity and visible movement — to assess sleep state, and a respiratory jacket to record changes in functional residual capacity (FRC). A total of 593 min of sleep data were analysed. Of the recordings, 39% were scored as quiet sleep, 40% as active and 21% as indeterminate sleep. The mean maximum variation in FRC overall was 29 ml (SD ± 15.4 ml). Examination of these figures showed that FRC variations during sleep state changes were smaller than those seen within a defined sleep state. We conclude that changes in sleep state are not associated with variations in FRC.

Key words: Sleep state — Lung volumes — neonates

Introduction

If functional residual capacity (FRC) were to alter by a significant amount in the transition from quiet to active sleep, this would have profound implications on our concepts of respiratory physiology. A study by Henderson-Smart and Read [6] using occlusion plethysmography in six normal babies during active and quiet sleep suggested that the FRC fell by an average of 31% in active sleep. These data were challenged by Moriette et al. [7] who, using a helium dilution technique to study 10 premature babies, found that the FRC in active sleep rose in three babies, was unchanged in two and fell in only five. These results were in turn challenged on methodological grounds by Bryan and England [2].

Previous work in this Unit, using a plethysmograph in nine full-term babies, also showed a fall in FRC in active sleep but of only 12% [11]. At the same time, a parallel study on seven full-term babies, using observational criteria to assess sleep state and a respiratory jacket to measure changes in end-tidal baseline, showed no alteration at all in FRC transitions from active to quiet sleep. When the babies moved from quiet to active sleep the FRC variations were small (average 7 ml; range 3–15 ml) and associated with sighs, pauses and movements. They were also transient with re-establishment of the original FRC in less than 30 s. We suggested therefore that changes in sleep state were not associated with alterations in FRC, and that the apparent falls in FRC in active sleep demonstrated in plethysmographic studies could be artefactual and possibly related to a reduction in muscle tone in the upper airway. We also postulated that the variation between our results — a fall of 12% — and those of Henderson-Smart and Read — a fall of 31% — was in some way due to the differing effects of a seal obtained from a face mask, which gave some support to the checks, and a seal obtained solely around the nose, which gave no such support [11]. A criticism of our previous work was that sleep was staged purely on observational criteria. We therefore set up the present study to repeat the respiratory jacket measurements whilst using additional physiological criteria to assess sleep state.

Method

Twelve healthy full-term babies were included in the study. Their average age at time of study was 3.2 days (range 2–6 days). The assessments were carried out approximately 30 min after a feed with the babies lying in the right lateral position, and were of an average duration of 49 min (range 30–85 min). The room temperature was between 21°C and 24°C.

We wished to record FRC changes together with physiological data which would be adequate to score sleep state. The following recordings were made and subsequent analysis followed the methods described by Anders et al. [1] which are summarised in Table 1.

### Table 1. Polygraphic recordings used to define sleep stages

<table>
<thead>
<tr>
<th>Physiological variable</th>
<th>Active sleep</th>
<th>Quiet sleep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye movement (EOG)</td>
<td>Present</td>
<td>Absent</td>
</tr>
<tr>
<td>Cerebral activity (EEG)</td>
<td>LVI</td>
<td>TA</td>
</tr>
<tr>
<td>Low voltage irregular (LVI)</td>
<td>HVS</td>
<td>or M</td>
</tr>
<tr>
<td>Tracé alternant (TA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High voltage slow (HVS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed (M)</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Muscle tone (EMG)</td>
<td>Irregular</td>
<td>Regular</td>
</tr>
<tr>
<td>Respiration</td>
<td>Present</td>
<td>Absent</td>
</tr>
<tr>
<td>Body movement (observation)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Offprint requests to: A. D. Milner

Abbreviations: EMG = electromyogram; EOG = electro-oculogram; FRC = functional residual capacity
**Electroencephalogram**

The 6 mm silver/silver chloride electrodes secured with “Blen-derm” tape were positioned according to the International 10-20 System [1]. The three channels recorded were F4-P4, F3-P3, and P4-P3. Recordings were classified as one of four patterns — low voltage irregular, trace alternant, high voltage slow or mixed.

**Electro-oculogram**

Four electrodes, secured with double-sided sticky discs, were positioned immediately above and below the outer canthus of each eye. One channel connected ‘top right’ and ‘bottom left’ and the second channel ‘top left’ and ‘bottom right’. In this way eye movements in any direction could be recorded and, since they appeared out of phase in the two channels, could be more easily distinguished from high amplitude EEG signals, which in any case were maximally attenuated by this arrangement.

**Electromyogram**

Two sub-mandibular electrodes were used; the traces were scored as high or low voltage.

**Respiratory regularity**

Respiratory regularity was recorded from the abdominal transducer of a locally constructed respiratory inductive plethysmograph (Respivest), and scored per 20 s epoch as either regular or irregular. An epoch was scored as irregular if the respiratory rate varied by more than 20 breaths per min, and as regular if the rate varied by fewer than 20 per min.

**Visible movements**

The presence or absence of movement was noted by close observation and recorded on each 20 s page.

These data were recorded on a ten-channel EEG machine (Dantec DISA 26A10) at a paper speed of 1.5 cm/s. Active or quiet sleep was scored by standard techniques if three or more of the parameters recorded were positive for the state [1]. Indeterminate sleep was scored if only two positive features were present for any one state and were accompanied by an EEG of indeterminate pattern, i.e. M or HVS. Changes which persisted for less than one minute were ignored. The records were classified by two independent observers who agreed on the classification of 90% of the epochs, and were able to reconcile any differing scores on the remaining 10%.

**FRC changes**

FRC changes were assessed by respiratory jacket. The jacket is made from soft rubber and on the baby encompasses the chest and abdomen and fits snugly up to the neck. When inflated to an internal pressure of approximately 2 cm H2O, 1–2 mm H2O pressure changes occur within the jacket as a result of normal respiration. These changes are calibrated to measure tidal volume by injecting and withdrawing known volumes of air from a syringe [10]. In a similar manner, the fluctuations in FRC were monitored by measuring the variations in end-tidal baseline at 15–20 s intervals. Independent observations of patient movement were also recorded.

These data were recorded on tape (Racal, Store 4) and reproduced onto EEG paper for analysis. An electronic marker common to both systems was recorded on both chart recorder and the analogue tape to ensure the correct alignment of the records.

---

**Figure 1.** Sleep scored as quiet. No eye movements are seen, the EEG is trace alternant, a high EMG is present and respiration is regular.