Asynchronous breathing during sleep

J Kohyama, T Shiiki, M Shimohira, T Hasegawa

Abstract

Background—Children rarely complain of symptoms associated with sleep disordered breathing (SDB). Paradoxical inward rib cage movement (PIRCM) during sleep might prove useful for detecting SDB.

Aims—(1) To determine the correlation between the degree of PIRCM and other measures of disordered breathing during sleep. PIRCM occurs physiologically throughout rapid eye movement sleep in neonates, while no PIRCM has been reported during sleep in adolescents. (2) To determine the chronological changes in the degree of PIRCM.

Methods—PIRCM was quantified by means of the laboured breathing index (LBI). LBI was determined by respiratory inductive plethysmography; PIRCM accompanies a high LBI. Sleep recordings obtained for 101 subjects for various reasons (aged from 3.5 months to 19 years) were analysed.

Results—In 22 records, the minimum Sao value was 90% or more and no obstructive apnoea of more than 10 seconds was observed. In these 22 records, LBI during rapid eye movement sleep decreased significantly with age, reaching the mature low level at 3.3 years of age. In the other 79 records, LBI correlated well with measures of obstructed breathing during sleep.

Conclusions—By paying more attention to PIRCM, more obstructed breathing during sleep might be found among children aged 3 years or more.

Keywords: asynchronous breathing; sleep disordered breathing; obstructive sleep apnoea; laboured breathing index

Sleep disordered breathing (SDB) occurs in about 1–3% of children. Children with SDB show more behaviour problems than controls. However, children rarely complain of symptoms associated with SDB, making diagnosis difficult. Paradoxical inward rib cage movement (PIRCM) or asynchronous breathing occurs in patients with obstructive sleep apnoea or SDB. We considered that PIRCM might be useful for detecting SDB.

One of our aims was to determine the correlation between the degree of PIRCM and other measures of disordered breathing during sleep. PIRCM is known to occur physiologically throughout rapid eye movement sleep (REMS) in neonates, while PIRCM has not been seen during REMS in adolescents. Although PIRCM during REMS is widely believed to disappear by 3 years of age, this age dependency has been examined quantitatively only by Gaultier et al. Our other aim was to determine chronological changes in the degree of PIRCM.

For these purposes, we needed an index to quantify PIRCM. The laboured breathing index (LBI), determined on respiratory inductive plethysmography (RIP), is the sum of the integrals of the absolute values of the derivatives of the inspiratory limbs of the rib cage and abdomen divided by the corresponding integral of the derivative of the inspiratory limb of the tidal volume. LBI equals 1.0 when the chest and abdominal motions are in perfect synchrony. Any lack of synchrony between them will increase LBI. Qualitative diagnostic calibration performed before each RIP recording allowed us to determine the absolute tidal volume value by RIP. After qualitative diagnostic calibration, LBI has been reported to be stable regardless of a change in body position.

Unfortunately, as our cohort was not a normal healthy population, we have not obtained normative data. However, the results regarding chronological changes of LBI obtained for subjects without desaturation and obstructive apnoea during sleep corresponded well with previously accepted views on normal subjects (for example, PIRCM during REMS disappears by age 3).

Materials and methods

We analysed 101 all night polysomnographical recordings with complete RIP (RESPSOMNOGRAPH, nims. Inc.) together with percutaneous arterial oxygen saturation (Sao) monitoring obtained between October 1992 and September 1999. All recordings were performed in an isolated semisoundproof recording room with an air conditioner (temperature range, 22–24°C). Each recording included electroencephalography, electro-oculography, electromyography of the chin and trunk muscles, Sao monitoring (Ohmeda Biox 3740; averaging time, six seconds), and video monitoring. Oxygen desaturation obtained when the averaging time was set to six seconds on this equipment showed no significant difference from that obtained with the control oximeter. We did not measure end tidal or transcutaneous carbon dioxide. Sleep stages were determined according to the standard criteria depending on the age at the time of recording.

The 101 recordings were obtained for 101 subjects, for various reasons: 57 subjects had respiratory problems during sleep (irregular
Asynchronous breathing during sleep

Results

The minimum SaO₂ value in the whole night recordings was observed exclusively during non-REMS in 33 records, during REMS in 56, and during both non-REMS and REMS in the remaining 12. The average minimum SaO₂ value in 56 cases who exhibited the minimum SaO₂ value during REMS was significantly lower than in the 33 cases who exhibited the minimum SaO₂ value during non-REMS (81.6% vs 87.0%, p < 0.05). LBI-R was higher than LBI-NR in 74 subjects, equal to LBI-NR in 14, and lower than LBI-NR in the remaining 13. Eighteen of the 101 subjects had a central apnoea index exceeding 1.0. However, desaturation below 90% did not accompany their central sleep apnoea.

We classified the recordings into two types according to the minimum SaO₂ value and obstructive apnoea index: 22 without obvious desaturation (minimum SaO₂ > 90%) and obstructive apnoea (obstructive apnoea index = 0)²; and 79 with desaturation or obstructive apnoea. The maximum change of SaO₂ in the 22 records without desaturation and obstructive apnoea was less than 4%.

Records without desaturation and obstructive apnoea

Table 1 shows the profiles and sleep variables of the 22 records without desaturation and obstructive apnoea. The correlation between age in months and LBIs was statistically significant for REMS (LBI-R, r = −0.67, p < 0.001), but not significant for non-REMS (LBI-NR, r = −0.37, p > 0.05). The regression curve for the age in months (X) and LBI-R was as follows: LBI-R = 1.41X−0.065 (R = 0.78, p < 0.001). The upper range (mean + 2.0 SD) for LBI-R in the 11 subjects aged more than 100 months was 1.11. The regression curve crossed this value at 39.7 (3.3 years).

Records with desaturation or obstructive apnoea

In the other 79 records we calculated correlations between LBIs and the age in months, DT, obstructive apnoea index, minimum SaO₂ value, and central apnoea index (table 2). The indices other than the age and central apnoea index showed statistically significant correlations with LBIs.

However, some subjects were exceptional. A 13 year old boy (patient A) who complained of nocturnal seizures exhibited no desaturation (minimum SaO₂ > 90%) and a low obstructive apnoea index (0.3), but showed high LBI values (LBI-NR, 1.42; LBI-R, 2.06). In contrast, an 8 month old boy (patient B) with the complaint of irregular respiration during sleep had a high DT (8.2%), a high obstructive apnoea index (7.5), and a low minimum SaO₂ value (69%), but showed low LBI values (LBI-NR, 1.04; LBI-R, 1.24).

Obesity index

The obesity index ranged from 72.4% to 58.0% with a mean value of 2.0. The correlation coefficient between the obesity index and

www.archdischild.com
LBIs calculated for the total 101 recordings was less than 0.1 (not significant).

**Discussion**

Obstructive apnoea of more than 10 seconds is not observed in normal subjects aged 3 months or more. The minimum age of our subjects was 3.5 months. Twenty two of our subjects satisfied this criterion and also exhibited no desaturation (minimum SaO2 > 90%), although these 22 subjects did not belong to a healthy population.

In these 22 records (mean SaO2 during REMS ranged from 96.0% to 98.5%; mean 97.1%, SD 0.6%), LBI-R calculated on whole night RIP recording decreased to the mature low level at age 3.3 years. Interestingly, this result was similar to the report of Gaultier et al. They assessed PIRCM by visual coding in 13 normal subjects aged from 7 to 31 months (the mean truncatable partial pressure of O2 during REMS ranged from 68.7 to 84.8 mm Hg; mean 76.5; SD 5.5), and concluded that PIRCM in REMS decreased significantly with age. The general notion that PIRCM during REMS disappears by age 3 years is based on this report. In our study, we found this notion true for subjects without desaturation and obstructive apnoea during sleep, though these subjects were not completely healthy.

**REMS atonia** is one of the factors that produce PIRCM (that is, elevation of LBI), and facilitate the occurrence of SDB. Although the minimum SaO2 value was observed during REMS in most of our records, it was also seen during non-REMS. Similarly, LBI-R was higher than LBI-NR in most records, but some exceptional cases were noted. REMS is a state in which desaturation and PIRCM (elevation of LBI) tend to occur. However, REMS atonia is not a single determinant of SDB but PIRCM (or LBI). The degree of REMS atonia increases with age. Other factors that overcome this age related development of REMS atonia function to decrease PIRCM with age. As proposed by Gaultier et al, a reduction in chest wall compliance is one of the candidate factors explaining the age related disappearance of PIRCM during REMS.

In contrast to the current results, we found a significant decrease in LBI-NR with age in a larger number of subjects without notable desaturation and obstructive apnoea (n = 51). In that preliminary study, we used milder criteria for desaturation and obstructive apnoea than those in the current study. According to these criteria, some young infants who had a high LBI-NR value were included. Studies on factors that affect LBI during non-REMS should also be performed.

Respiratory effort is a factor that could produce PIRCM or increase LBI. To measure respiratory effort, monitoring of oesophageal pressure is the standard method. However, no absolute level of oesophageal pressure is known to be abnormal. In contrast to the measurement of oesophageal pressure, PIRCM is easily observed even by caretakers. The correlation between the degree of PIRCM (or the LBI) and oesophageal pressure as well as the reliability of the caretakers’ observation of PIRCM are the next important issues to be examined. Moreover, we have to confirm that PIRCM (elevation of LBI) does not occur even with notable respiratory effort when muscle

---

**Table 2 Correlations between LBI and other indices in the 79 subjects with desaturation or obstructive apnoea**

<table>
<thead>
<tr>
<th>Age</th>
<th>DT</th>
<th>OAI</th>
<th>Min. SaO2</th>
<th>CAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBI-NR</td>
<td>-0.16</td>
<td>0.27</td>
<td>0.57</td>
<td>-0.50</td>
</tr>
<tr>
<td>p value</td>
<td>&gt;0.05 (ns)</td>
<td>&lt;0.05</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LBI-R</td>
<td>-0.03</td>
<td>0.32</td>
<td>0.65</td>
<td>-0.57</td>
</tr>
<tr>
<td>p value</td>
<td>&gt;0.05 (ns)</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**Table 1 Profiles and sleep parameters of the 22 subjects without desaturation and obstructive apnoea**

<table>
<thead>
<tr>
<th>Age</th>
<th>Sex</th>
<th>Cause of PSG</th>
<th>% REMS</th>
<th>Mean SaO2 non-REMS/REMS</th>
<th>Min. SaO2 (%)</th>
<th>LBI-NR</th>
<th>LBI-R</th>
<th>CAI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 y 11 mth</td>
<td>F</td>
<td>Epi</td>
<td>18.9</td>
<td>96.3 / 96.9</td>
<td>93</td>
<td>1.01</td>
<td>1.02</td>
<td>0.54</td>
</tr>
<tr>
<td>6 y 7 mth</td>
<td>F</td>
<td>XP</td>
<td>16.4</td>
<td>97.8 / 98.5</td>
<td>90</td>
<td>1.01</td>
<td>1.00</td>
<td>0.20</td>
</tr>
<tr>
<td>7 y 1 mth</td>
<td>F</td>
<td>Double cortex</td>
<td>14.1</td>
<td>96.9 / 97.0</td>
<td>91</td>
<td>1.23</td>
<td>1.19</td>
<td>0.12</td>
</tr>
<tr>
<td>7 y 2 mth</td>
<td>M</td>
<td>DMD</td>
<td>16.4</td>
<td>96.6 / 96.9</td>
<td>91</td>
<td>1.01</td>
<td>1.01</td>
<td>0.13</td>
</tr>
<tr>
<td>8 y 6 mth</td>
<td>M</td>
<td>XP</td>
<td>17.0</td>
<td>95.7 / 96.0</td>
<td>90</td>
<td>1.02</td>
<td>1.03</td>
<td>0.12</td>
</tr>
<tr>
<td>8 y 7 mth</td>
<td>M</td>
<td>CRS</td>
<td>23.1</td>
<td>96.6 / 96.4</td>
<td>91</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>9 y 0 mth</td>
<td>F</td>
<td>XP</td>
<td>19.4</td>
<td>97.4 / 97.8</td>
<td>94</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>9 y 3 mth</td>
<td>F</td>
<td>AN</td>
<td>8.5</td>
<td>96.4 / 96.3</td>
<td>94</td>
<td>1.00</td>
<td>1.00</td>
<td>0.44</td>
</tr>
<tr>
<td>9 y 5 mth</td>
<td>F</td>
<td>Epi</td>
<td>26.5</td>
<td>96.5 / 96.7</td>
<td>91</td>
<td>1.00</td>
<td>1.01</td>
<td>0.00</td>
</tr>
<tr>
<td>10 y 10 mth</td>
<td>M</td>
<td>Epi</td>
<td>24.7</td>
<td>96.6 / 96.7</td>
<td>91</td>
<td>1.01</td>
<td>1.01</td>
<td>0.17</td>
</tr>
<tr>
<td>11 y 11 mth</td>
<td>F</td>
<td>Hypersomnia</td>
<td>15.3</td>
<td>97.5 / 96.7</td>
<td>92</td>
<td>1.05</td>
<td>1.10</td>
<td>1.10</td>
</tr>
<tr>
<td>12 y 11 mth</td>
<td>F</td>
<td>Epi</td>
<td>20.0</td>
<td>97.1 / 96.7</td>
<td>90</td>
<td>1.03</td>
<td>1.06</td>
<td>0.27</td>
</tr>
<tr>
<td>13 y 5 mth</td>
<td>F</td>
<td>OD</td>
<td>21.8</td>
<td>96.9 / 97.3</td>
<td>93</td>
<td>1.01</td>
<td>1.00</td>
<td>0.13</td>
</tr>
<tr>
<td>14 y 11 mth</td>
<td>M</td>
<td>DSPS</td>
<td>16.8</td>
<td>97.8 / 97.0</td>
<td>95</td>
<td>1.02</td>
<td>1.02</td>
<td>0.00</td>
</tr>
<tr>
<td>15 y 10 mth</td>
<td>M</td>
<td>Epi</td>
<td>26.8</td>
<td>97.1 / 97.3</td>
<td>93</td>
<td>1.03</td>
<td>1.01</td>
<td>0.75</td>
</tr>
<tr>
<td>16 y 1 mth</td>
<td>F</td>
<td>Double cortex</td>
<td>14.1</td>
<td>96.9 / 96.7</td>
<td>91</td>
<td>0.98</td>
<td>0.98</td>
<td>0.27</td>
</tr>
<tr>
<td>17 y 2 mth</td>
<td>M</td>
<td>Epi</td>
<td>27.0</td>
<td>96.6 / 97.0</td>
<td>93</td>
<td>1.01</td>
<td>1.01</td>
<td>0.86</td>
</tr>
</tbody>
</table>
Asynchronous breathing during sleep

177

resistance syndrome.25 In contrast, patient B
us from diagnosing him as having upper aiway
duce PIRCM and increase LBI. Unfortunately,
pressure against the upper airway obstruction.
PIRCM.

distortion which could cause cardiorespiratory
quently. PIRCM might also produce a thoracic
during sleep might be detected more fre-
children aged 3 or more. By paying more
detecting obstructed breathing during sleep in
PIRCM has not yet been studied, but PIRCM
value and the degree of clinically observed
measures of obstructed breathing during sleep.
Consistently, the correlation between the obes-
severity of SDB.

weakness is present. Although these limitations
exist, we wondered whether the quantification of
PIRCM through LBI could be used to assess the
severity of SDB.

In the 79 records with desaturation or
obstructive apnoea, we observed statistically
significant correlations between LBI and DT;
the obstructive apnoea index, and the mini-
mum SaO2 value. However, we found no corre-
lation between LBI and the central apnoea
index. We concluded LBI correlated well with
measures of obstructed breathing during sleep.
In patient A, airflow enough to maintain the
SaO2 value might have been maintained by the
action of increasing negative intrathoracic
pressure against the upper airway obstruction.
This negative intrathoracic pressure could pro-
duce PIRCM and increase LBI. Unfortunately,
unlike the obstruction of the SaO2 value and a
high obstructive apnoea index without distur-
ance of LBI. Mechanisms that cause
airway obstruction but do not affect LBI might
be involved in this patient.

Obesity is an important factor in causing
sleep apnoea in adults, and is also a predispos-
ing factor in children. However, most children
with obstructive sleep apnoea are not obese,
and abnormal polysomnographical findings
were reported to have been obtained in patients
who had an obesity index of more than 200%.26
Consistently, the correlation between the obesity
index and LBI was not significant in our
study.

We have shown that LBI correlated with
measures of obstructed breathing during sleep.
The correlation between the absolute LBI value
and the degree of clinically observed
PIRCM has not yet been studied, but PIRCM
PIRCM might prove to be a useful tool in
detecting obstructed breathing during sleep in
children aged 3 or more. By paying more
attention to PIRCM, obstructed breathing
during sleep might be detected more fre-
quently. PIRCM might also produce a thoracic
deformity which could cause cardiorespiratory
problems. We should pay more attention to
PIRCM.

1 Ali NJ, Pitson DJ, Stradling JR. Snoring, sleep disturbance,
2 Golubin T, Benteliksdottir B. Snoring, apneic episodes,
and nocturnal hypoxemia among children 6 months to 6
3 Ali NJ, Pitson DJ, Stradling JR. Natural history of snoring
and related behaviour problems between the ages of 4 and
4 Rosen CL. Obstructive sleep apnea syndrome (OSAS) in
5 Curzi-Dascalova L. Thoraco-abdominal respiratory correla-
tions in infants: constancy and variability in different sleep
6 Tabachnick E, Muller NL, Bryan AC, et al. Changes in venti-
lation and chest wall mechanics in normal sleeping adoles-
7 Guitter C, Prasd JP, Canet E, et al. Paradoxical inward rib
cage motion during rapid eye movement sleep in infants
8 Warren RH, Horan SM, Robertson PK. Chest wall motion
in preterm infants using respiratory inductive plethysmo-
9 Krieger BP. Respiratory inductive plethysmography. Probl
Reprir Care 1989;2:156–75.
10 Chadbina TS, Watson H, Birch S, et al. Validation of respira-
tory inductive plethysmography using different calibration
piratory inductive plethysmograph during natural breath-
12 Färre R, Montserrat JM, Ballester E, et al. Importance of
the pulse oximeter averaging time when measuring oxygen
13 Anders T, Emre R, Parmelee A. A manual of standardised
terminology, techniques and criteria for scoring of states of
sleep and sleep-wakefulness in newborn infants. Los Angeles:
UCLA Brain Information Service/IBI Publications Office,
1971.
14 Guilleminault C, Souquet M. Sleep states and related
pathology. In: Kosek K, Guilleminault C, eds. Advances
in perinatal neurology. New York: Spectrum Publications,
1979;225–47.
15 Rechtschafer A, Kales A. A manual of standardised terminol-
y, techniques and scoring system for sleep stages of human sub-
1968.
16 Marcus CL, Omlin KJ, Basinho DJ, et al. Normal
polygraphic values for children and adolescents. Am Rev
17 Suckner MA. Non-invasive respiratory monitoring. Non-
18 Brouillette RT, Weese-Mayer DE, Hunt CE. Disorders of
breathing during sleep in the pediatric population. Semin
19 Carroll JL, Loughlin GM. Obstructive sleep apnea syn-
drome in infants and children: diagnosis and management.
In: Ferber R, Kryger M, eds. Principles and practice of sleep
medicine in the child. Philadelphia: WB Saunders, 1993:
193–216.
20 Issa FG, Sullivan CE. Upper airway closing pressures in
activity reduction occurring with horizontal rapid eye
movements during active sleep in human. Exp Brain Res
22 Kohyama J, Tachibana N, Taniguchi M. Development of
23 Kohyama J, Shida T, Sakuma H, Shimoizira M, Hasegawa T.
Age-related changes of paradoxical inward rib cage
movement during sleep. Sleep Res Online 1999;2(suppl
1):112.
24 American Academy of Sleep Medicine Task Force. Sleep-
related breathing disorders in adults: recommendation for
syndrome definition and measurement techniques in clini-
25 Guilleminault C, Pelzio R, Leger D, et al. Recognition of
sleep-disordered breathing in children. Pediatrics 1996;98:
871–82.
26 Carroll JL, Loughlin GM. Obstructive sleep apnea syn-
drome in infants and children: clinical features and patho-
physiology. In: Ferber R, Kryger M, eds. Principles and
practice of sleep medicine in the child. Philadelphia: WB Sau-
ders, 1995;163–91.
Asynchronous breathing during sleep

J Kohyama, T Shiiki, M Shimohira and T Hasegawa

Arch Dis Child 2001 84: 174-177
doi: 10.1136/adc.84.2.174

Updated information and services can be found at:
http://adc.bmj.com/content/84/2/174

These include:

References
This article cites 18 articles, 7 of which you can access for free at:
http://adc.bmj.com/content/84/2/174#BIBL

Email alerting service
Receive free email alerts when new articles cite this article. Sign up in the box at the top right corner of the online article.

Topic Collections
Articles on similar topics can be found in the following collections

Airway biology (228)
Child health (3922)
Sleep disorders (neurology) (68)
Sleep disorders (respiratory medicine) (68)
Sleep disorders (59)

Notes

To request permissions go to:
http://group.bmj.com/group/rights-licensing/permissions

To order reprints go to:
http://journals.bmj.com/cgi/reprintform

To subscribe to BMJ go to:
http://group.bmj.com/subscribe/