Respiration during sleep in neuromuscular and thoracic cage disorders

J.M. Shneerson

ABSTRACT: Respiration during sleep in neuromuscular and thoracic cage disorders. J.M. Shneerson.

Many of the neuromuscular and thoracic cage disorders are associated with disorders of breathing during sleep. The abnormal mechanics of the chest wall impairs respiratory muscle function and this is compounded if there is underlying muscle weakness.

Respiratory abnormalities appear during REM sleep before NREM or wakefulness. Central sleep apnoeas are characteristic, but obstructive apnoeas are also occur because of loss of tone in the upper airway dilator muscles. Arousals from sleep return the blood gases towards normal, but cause fragmentation of sleep, leading to daytime sleepiness.

Ventilatory failure occurs particularly if the vital capacity is less than 1.0-1.5 litres or if the maximal inspiratory mouth pressure is less than 20-25cmH2O. Non-invasive ventilation effectively prevents both central and obstructive apnoeas and improves the sleep architecture and daytime blood gases.

Keywords: Non-invasive ventilation, scoliosis, thoracoplasty, neuromuscular disorders, respiratory failure.

Neuromuscular and thoracic cage disorders are individually uncommon, but together form an important group of conditions which often lead to respiratory abnormalities during sleep and to ventilatory failure during wakefulness.

Types of Disorder

It is important to recognise which of these disorders is likely to lead these complications and which form a low risk (table 1). Sternal abnormalities, particularly the depression deformities (pectus excavatum) and protrusion deformities (pectus carinatum) do not cause any significant respiratory abnormalities. Rib disorders also rarely interfere with respiration with the exception of a flail chest, usually due to trauma, and following a thoracoplasty. This procedure was performed in order to treat tuberculosis before chemotherapy was available and up to 11 ribs were resected. Many of this cohort of patients now developing respiratory failure due to the combination of the restrictive defect, paradoxical movement of the thoracic cage, pleural thickening, degenerative changes in the joints of the ribs and spine, a scoliosis and impaired diaphragmatic function [1].

Scoliosis, which is a lateral curvature of the spine associated with rotation, causes respiratory abnormalities during sleep due to the asymmetrical configuration of the rib cage and impaired respiratory muscle function, including the diaphragm. It may be secondary to an underlying neuromuscular disorder in which case the weakness of the respiratory muscles is an additional risk factor [2]. Thoracic kyphosis, an antero-posterior deformity, only leads to respiratory abnormalities during sleep if it occurs in the middle or upper thoracic spine [3].

Pathophysiology

Most of the thoracic wall deformities have similar pathophysiological features:

1. Alveolar Development: The formation of the normal number of alveoli is impaired if the thoracic wall deformity develops before the age of around 4 years by which time the normal number of alveoli has developed. Congenital and infantile idiopathic scoliosis, early onset kyphosis and asphyxiating thoracic dystrophy may all impede alveolar development [4].

Table 1. - Risk of developing ventilatory failure

<table>
<thead>
<tr>
<th>Low Risk</th>
<th>High Risk</th>
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<tbody>
<tr>
<td>Pectus Carinatum</td>
<td>Thoracoplasty</td>
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<tr>
<td>Pectus Excavatum</td>
<td>Scoliosis</td>
</tr>
<tr>
<td>Ankylosing Spondylitis</td>
<td>Poliomyelitis</td>
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<tr>
<td>Myasthenia Gravis</td>
<td>Motor Neurone Disease</td>
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<tr>
<td>Syringomyelia</td>
<td>Multiple System Atrophy</td>
</tr>
<tr>
<td>Dystrophia Myotonica</td>
<td>Duchennes Muscular Dystrophy</td>
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</table>
2. Lung volumes. Thoracic wall deformities almost invariably cause a restrictive defect with reduction in total lung capacity (TLC), functional residual capacity (FRC), residual volume and vital capacity. The exception is ankylosing spondylitis in which TLC and FRC are not reduced [5].

3. Chest wall and lung compliance. The abnormal configuration of the thoracic cage reduces the compliance of the chest wall, and the lung compliance falls mainly because of the small lung volume. These changes lead to a pattern of rapid shallow breathing which minimises the work of breathing, but increases the dead space ventilation and reduces alveolar ventilation.

4. Respiratory muscle function. The contractility of the respiratory muscles is normal in thoracic wall deformities unless there is an underlying neuromuscular disorder. The force of contraction of the muscles is reduced when they operate at less than their optimal length. Distortion of the rib cage also puts both the inspiratory and expiratory muscles at a mechanical disadvantage, particularly in scoliosis and after a thoracoplasty.

5. Ventilatory drive. The central ventilatory drive is normal in thoracic wall deformities, but this can not be translated into a normal degree of alveolar ventilation because of impaired respiratory mechanics and respiratory muscle function. Once chronic hypercapnia develops, the increase in cerebrospinal fluid bicarbonate concentration blunts the sensitivity to hypercapnia, and this can be further impaired by the effects of sleep deprivation (see below).

6. Blood gases. Mild hypoxia is common in thoracic wall deformities due to ventilation-perfusion mismatching, but hypoventilation occurs later, initially during sleep. It may develop insidiously or suddenly during an intercurrent illness such as a chest infection.

7. Exercise. During exercise the tidal volume increases initially and this is then followed by a rapid increase in respiratory rate. This increases the dead space to tidal volume ratio with a risk of alveolar hypoventilation. The arterial PO2 may be maintained during exercise, but the pulmonary artery pressure rises rapidly and in proportion to the reduction in pulmonary vascular bed. This is in turn related to the degree of the restrictive defect caused by the thoracic wall deformity [6].

8. Right Heart Failure and Polycythaemia. Right heart failure develops as a result of pulmonary hypertension due to hypoxic pulmonary vasoconstriction and to reduction in the pulmonary vascular bed, both of which increase the pulmonary vascular resistance. Hypoxia increases the sympathetic activity leading to renal vasoconstriction, activation of the renin-angiotensin-aldosterone system and thereby causes sodium and water retention. The acidosis associated with hypercapnia increases the excretion of hydrogen ions by the renal tubules through absorption of sodium and bicarbonate. The increased erythropoietin secretion in response to renal hypoxia increases the blood viscosity and consequently the pulmonary and systemic vascular resistance.

### Respiratory Abnormalities During Sleep

Oxygen desaturation during sleep is accompanied by a rise in the pCO2 [7, 8]. This indicates that hypoxia is not simply due to impairment of ventilation perfusion matching due to a reduction in lung volume as a result of the supine position or loss of respiratory muscle tone during sleep, but that there is alveolar hypoventilation. The extent of the hypoventilation depends partly on the respiratory mechanics. If the lung or chest wall compliance is reduced due to the thoracic cage deformity, hypercapnia during sleep is more likely [9]. Nevertheless the most important factor in determining whether or not alveolar hypoventilation occurs is the stage of sleep. Hypercapnia is more common in rapid eye movement (REM) than in non rapid eye movement (NREM) sleep [7, 8] and rarely occurs in NREM sleep without also being present in REM sleep, except in central alveolar hypoventilation and after cervical cordotomy.

#### a) REM Sleep

In REM sleep there is a reduction in the tone of the skeletal muscles and in reflex responses. Activity of the skeletal muscles is irregular. These changes are particularly important for the respiratory muscles. The respiratory drive is reduced and there is loss of activity in all the chest wall muscles except the diaphragm and to a lesser extent the parasternal intercostal muscles. Respiration therefore becomes virtually dependent on diaphragmatic function [10]. As a result, ‘central’ sleep apnoeas are common. They are particularly likely in the presence of bilateral diaphragmatic paralysis, in which situation none of the chest wall muscles are active during respiration. The commonest causes of bilateral diaphragmatic weakness are shown in table 2. It causes apnoeas which are best regarded as ‘peripheral’ or ‘pseudocentral’ since the respiratory drive is intact, but cannot be translated into respiratory movements because of the absence of any functioning chest wall muscles [11].

The action of the upper airway muscles during sleep is complex. The dilators and constrictors are reciprocally inhibited and the dilators and the diaphragm are activated together. There is a sequence of activation from the alae nasi to the diaphragm so that the upper airway is stabilised a few milliseconds before the negative pressure is developed in the airways through diaphragmatic

#### Table 2. - Causes of bilateral diaphragm weakness

<table>
<thead>
<tr>
<th>Trauma</th>
<th>High cervical cord lesions</th>
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<tr>
<td>Motor neurone disease</td>
<td>Poliomyelitis</td>
</tr>
<tr>
<td>Peripheral neuropathy</td>
<td>Acute idiopathic polyneuropathy</td>
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<tr>
<td>Congenital myopathies</td>
<td>Muscular dystrophies</td>
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Muscle strength and endurance appear to be im-
pressed by hypercapnia is reduced and both respiratory
for sleepiness, but also influences the respiratory dri-
fragmentation not only leads to excessive daytime
this occurs in NREM sleep as well. This sleep
has the disadvantage that the micro-arousals,
dilation rapidly increases. This defence mechanism
the chest wall muscles increases, the upper airway
cause of arousal is the increase in chest wall mus-
cell activity generated in response to the upper air-
way occlusion. Hypoxia and hypercapnia play a
lesser role, unless the apnoea is particularly pro-
longed as may occur in REM rather than in NREM
sleep.
An additional non respiratory factor determin-
ing whether or not arousal occurs is the cyclic al-
ternating pattern (CAP). This reflects an intrinsic
instability in the maintenance of NREM sleep
which has a cycle length of 20-40 seconds [19]. An
arousal is most likely to occur when a respiratory
abnormality, such as an apnoea, coincides with a
lighter phase of sleep.
In summary, alveolar hypventilation is most
common in REM sleep and it leads to sleep frag-
mentation which then reduces the respiratory drive
and muscle function. These in turn predispose to
hypventilation in NREM sleep, which further
fragments the sleep architecture. The effects on
respiratory drive and muscles can be sufficiently
severe to cause hypventilation during wakeful-
ness. At this stage metabolic and endocrine
changes, together with the increased pulmonary
artery pressure, lead to right heart failure.

**When to Suspect Ventilatory Failure**

Symptoms of respiratory abnormalities during
sleep such as awakenings from sleep, early morn-
ing headaches due to carbon dioxide retention, ex-
cessive daytime sleepiness as a result of sleep frag-
mentation and worsening breathlessness and ankle
swelling are important indicators of nocturnal res-
piratory abnormalities. Nocturnal respiratory ab-
normalities are likely when these are present in a
high risk disorder, particularly following a thora-
coplasty, or if there is an early onset kyphosis or
scoliosis or the presence of a neuromuscular disor-
der affecting respiration, such as previous po-
lomyelitis or Duchenne’s muscular dystrophy.
In general the vital capacity is less than 1.0-1.5
litres in subjects who are at risk of developing noc-
turnal respiratory failure and the maximum inspira-
atory mouth pressure is usually less than 20-
25cmH2O [20]. The oxygen saturation during
wakefulness correlates moderately well with the
mean oxygen saturation during sleep [7, 21], but it
is not sufficiently precise in the individual subject
to guide the management of the respiratory abnor-
malities. A sleep study is required to demonstrate
the respiratory-related changes, their type and
severity.
The importance of assessing respiration at
night in neuromuscular and thoracic cage disorders
has increased with the availability of effective
non-invasive ventilation [22]. Failure to accurately
assess the sleep related respiratory abnormalities
in these patients prevents them from receiving

### Table 3 - Neur muscular causes of obstructive sleep

<table>
<thead>
<tr>
<th>Condition</th>
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<tbody>
<tr>
<td>Multiple system atrophy</td>
</tr>
<tr>
<td>Syringobulbia</td>
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<tr>
<td>Motor neurone disease</td>
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<tr>
<td>Arnold-Chiari malformation</td>
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<tr>
<td>Poliomyelitis</td>
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<tr>
<td>Muscular dystrophies</td>
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<tr>
<td>Myopathies</td>
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treatment which can both improve their quality of life and increase their life expectancy.

**Ventilatory Support During Sleep**

Ventilatory support is usually provided non-invasively during sleep, and occasionally also during wakefulness. Negative pressure techniques have been used in the past, but positive pressure ventilation with a nasal or full face mask has largely superseded this. There have not been any randomised controlled trials of its effectiveness in the long term, but nasal ventilation has been shown to improve sleep architecture [23] as well as arterial blood gases during the day (figure 1) in a wide variety of neuromuscular and thoracic cage disorders [24]. There are also minor changes in vital capacity and respiratory muscle function [25] and improvement in daytime symptoms, such as excessive sleepiness and early morning headaches [26, 27].

The mechanism of these effects is still uncertain, but ventilatory support appears to reduce the degree of sleep fragmentation due to apnoeas and thereby improves respiratory drive and respiratory muscle function [28]. The cerebrospinal fluid bicarbonate concentration falls as the arterial pCO2 is normalised and this further increases the hypercapnic respiratory drive. The greater range of rib cage movements due to the ventilator may also increase the chest wall compliance. The lung compliance and the ventilation perfusion matching may improve at least temporarily during ventilatory support. Interestingly, some of these changes which are seen during the application of ventilation are retained during wakefulness. The arterial blood gases during the day, for instance, are improved as well as the values during sleep [29]. Once ventilatory support is withdrawn, however, the respiratory related abnormalities during sleep return, indicating that although it is very effective, ventilatory support does not resolve the underlying pathophysiological abnormalities of neuromuscular and thoracic cage disorders during sleep.

**References**


