Sleep and Breathing at High Altitude

HIMANSHU WICKRAMASINGHE, M.D. and JAMES D. ANHOLM, M.D.

ABSTRACT
Sleep at high altitude is characterized by poor subjective quality, increased awakenings, frequent brief arousals, marked nocturnal hypoxemia, and periodic breathing. A change in sleep architecture with an increase in light sleep and decreasing slow-wave and REM sleep have been demonstrated. Periodic breathing with central apnea is almost universally seen amongst sojourners to high altitude, although it is far less common in long-standing high altitude dwellers. Hypobaric hypoxia in concert with periodic breathing appears to be the principal cause of sleep disruption at altitude. Increased sleep fragmentation accounts for the poor sleep quality and may account for some of the worsened daytime performance at high altitude. Hypoxic sleep disruption contributes to the symptoms of acute mountain sickness. Hypoxemia at high altitude is most severe during sleep. Acetazolamide improves sleep, AMS symptoms, and hypoxemia at high altitude. Low doses of a short acting benzodiazepine (temazepam) may also be useful in improving sleep in high altitude.

KEYWORDS: sleep, high altitude, periodic breathing, hypoxemia, sleep fragmentation, hypobaric hypoxia

I was unable to sleep and passed so bad a night that I would not wish it on my worst enemy.”
Dr. Jacottet on Mont Blanc, 1881

Climbers to high altitude frequently experience sleep disturbances, often reporting restless and sleepless nights. Others describe a feeling of suffocation on awakening from sleep. Anecdotal reports have noted worsening sleep as altitude increases, suggesting an inverse relationship between sleeping altitude and sleep quality. A characteristic waxing and waning breathing pattern known as periodic breathing accompanies sleep at high altitude. Periodic breathing during sleep was first described by Mosso in 1886 (Fig. 1) with further observations a few years later by Douglas and colleagues. This article will review high altitude sleep, focusing on sleep architecture, sleep continuity, arterial oxygen saturation, and on periodic breathing during sleep.

SLEEP ARCHITECTURE AND CONTINUITY

Sleep Stages
Observations from subjects working in the Antarctic provided some of the earliest information on sleep disturbance under conditions of hypobaric hypoxia. At the South Pole, barometric pressure is reduced both because of the elevation of the terrain and the effect of terrestrial spin. Major sleep disruption was noted on electroencephalographic studies (EEG) and a marked increase in slow wave sleep (stages 3 and 4) was seen. It is unclear to what extent these changes are attributable to hypobaric hypoxia alone because the isolation and change in the light-dark cycle seen at the South Pole could also have resulted in these changes.

Reite et al. studied normal subjects at sea level and following ascent to an altitude of 4300 m (Pike’s Peak, Colorado; barometric pressure /H11011 450 mm Hg). All subjects complained of sleeplessness following their first night at 4300 m altitude. Five of the 6 subjects demonstrated periodic breathing (PB) on the first night after ascent and PB occupied 54% of sleep time. A significant decrease in stage 3 and 4 sleep occurred along with an increase in stage 1 sleep. There was a significantly increased number of nighttime awakenings and less rapid eye movement (REM) sleep. Total sleep time, however, remained the same as at sea level. These sleep parameters all returned towards baseline values with acclimatization. This was accompanied by improvement in subjective reports of sleep quality.

Normand et al. studied sleep organization in normal subjects at sea level and after 3 weeks acclimatization at an altitude of 3800 m (La Paz, Bolivia). The subjects stated that they slept well both at sea level and at altitude. Sleep length, and the percent REM and stage 4 sleep were unchanged with altitude exposure. Sleep dis-
ruptions were the same after acclimatization at high altitude as at sea level.

Miller and Horvath studied the effects of simulated altitude where the subjects spent only the night under hypobaric conditions (barometric pressure \(P_B\) = 493 mm Hg; equivalent to an elevation of about 3500 m). They found an increase in stage 1 sleep and a decrease in stage 2 sleep, with total sleep time remaining unchanged. There was a significant increase in the time that the subjects spent awake.

At a somewhat higher simulated altitude (4330 m), Berssenbrugge, Dempsey, and Skatrud found similar results. They found the proportion of time spent in lighter sleep (stage 1 and 2) was increased while time spent in slow wave sleep (stages 3 and 4, [SWS]) and in REM sleep was significantly decreased. Likewise, during a French expedition to the Himalayas, Goldenberg et al. found increased wakefulness and a decrease in slow wave and REM sleep.

The Operation Everest II (OE II) simulated altitude study monitored sleep across increasing altitudes up to an altitude equivalent to that at the South Col of Mount Everest (8040 m, \(P_B = 282\) mm Hg). All subjects complained of poor sleep throughout the study. The main complaints were difficulty in falling asleep, frequent nighttime awakening, and feeling less refreshed in the morning than expected. Although some of these complaints were related to the monitoring equipment and conditions of the sleep studies, sleep difficulties persisted in some subjects even on nights when sleep studies were not performed. Sleep records were scored using standard criteria. Time awake increased from 9.5% ± 7.8% (mean ± SD) of the night at sea level to 45.8% ± 21.2% at the ICAO (International Civil Aviation Organization) altitude of 7620 m (\(P_B = 282\) mm Hg; equivalent to about 8040 m on Mount Everest). REM sleep was significantly reduced from 17.9% ± 6.0% of the night at sea level to 4.0% ± 3.3% at 7620 m. On return to sea level, REM sleep increased relative to that at high altitude. Slow wave sleep (stages 3 and 4) time was less than expected even at sea level and remained the same during high altitude exposure. Sleep continuity deteriorated at high altitude, as evidenced by a significant reduction in sleep efficiency (SE, equal to Total Sleep Time [TST] / Total time in Bed [TIB]) and a significant increase in the number of awakenings, compared with sea level. SE was 88.6% ± 8.2% at sea level and 55.5% ± 15% at an ICAO altitude of 4572 m (\(P_B = 429\) mm Hg). No significant differences in SE nor in the number of awakenings were noted in studies done beyond an altitude of 4572 m. Sleep architecture did not worsen on ascent above 4572 m (429 mm Hg). These data might indicate a ceiling effect beyond which there is no further deterioration in sleep; however, the sleep fragmentation data discussed below suggests otherwise.

The many settings, different altitudes, and durations for acclimatization in these studies of sleep architecture at high altitude make comparisons difficult. However, there is universal agreement that sleep is disrupted and that altitude sojourners feel less refreshed after a night at altitude, simulated or real. Most studies also indicate a reduction in slow wave sleep and REM sleep along with a concomitant increase in Stage 1 and Stage 2 sleep. In at least one study, the decrease in SWS may be important in decreasing symptoms of acute mountain sickness.

**Sleep Fragmentation**

Sleep studies done at high altitude support the conclusion that sleep at extreme altitude is quite unsatisfactory. However, neither nighttime awakenings nor sleep stage changes can account for the progressive worsening of sleep quality as altitude increases (e.g., in the OE II study, sleep stages at 7620 m were not markedly different from those at 4572 m). One explanation for this paradox is the sleep fragmentation caused by brief arousals that are not reflected in the traditional sleep stage scoring system. The effects of transient (3 to 5 second) arousals have been studied most thoroughly only during low altitude/sea level studies, but help explain the sleep disruption at high altitude.

Bonnet and Downey performed a series of studies comparing sleep quality with neurobehavioral performance. They found that consolidated sleep without