CHRONIC INTERMITTENT EXPOSURE TO HIGH ALTITUDE: THE VIEW FROM MAUNA KEA

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The summit of Mauna Kea is the highest point in the Pacific Basin. Rising over 30,000 feet from the ocean floor, this dormant volcano forms the bulk of the landmass of the Big Island of Hawaii and attains a summit elevation of 13,796 feet (4205 m). The summit is acknowledged as the world’s pre-eminent terrestrial site for optical, infrared and sub-millimeter astronomy: exceptionally sharp celestial images are obtained because the summit is above 40% of the earth’s atmosphere. A tropical inversion cloud layer below the summit isolates the observatories from interference by water vapour, which absorbs infra red and submillimeter radiation, and light and atmospheric pollution from sea level habitation. Rapid access to the mountaintop (one and a half-hour journey by road from sea level) facilitates the operation of the telescopes.

The summit area is operated as the Mauna Kea Science Reserve by the University of Hawaii’s Institute for Astronomy. In the late 1970’s, the Royal Observatory Edinburgh (R.O.E) constructed the United Kingdom Infrared Telescope (U.K.I.R.T), at 3.8m the largest infrared telescope in existence. As was the established practice with the existing observatories on Mauna Kea, the telescope was to be operated by staff resident at sea level. Following a case of high altitude pulmonary oedema (HAPO) on the mountain and an episode when workers were stranded at the summit by a snowstorm, concern was expressed by both the trade unions representing the work force and the R.O.E management regarding the safety and efficiency of operating a complex scientific facility at the summit altitude. Consequently, in 1980 the Science and Engineering Council of the United Kingdom commissioned a two-year study at the telescope (1). The study was supervised by the late Professor Donald Heath, author of Man at High Altitude (2) and High-Altitude Medicine and Pathology (3). This paper relates to that study and the experience of chronic intermittent exposure to hypoxia in the community of workers on Mauna Kea.

Study Details

The reduction in the optical thickness of the atmosphere at high altitude occurs concomitantly with falls in the atmospheric pressure and in the partial pressure of oxygen in the ambient air. At the summit of Mauna Kea, barometric pressure is 465 Torr (611 mbar), 61% of the sea level value, and the partial pressure of oxygen in moist inspired gas in the lung (PiO_2) is reduced to 88 Torr (115 mbar) compared to the sea level value of 149 Torr (196 mbar) (4).

By 1980, two patterns of work had evolved on the mountain. The UKIRT was operated on a shift schedule: the shift workers' schedule involved 40 days mountain work followed by 40 days office work at sea level. Mountain work comprised four shifts on the mountain with each shift lasting 5 working days plus an initial night of acclimatisation at 3000m. Whilst on the mountain workers ate and slept at the mid level facility of Hale Pohaku (3000m; 9300ft) which is the present day location of the Onizaku Center. Mountain shifts were interspersed by five days rest at sea level.

(Forty-one “shift workers” were studied during a total of 134 shifts.)
Staff manning the NASA infra red telescope (IRTF) commuted daily leaving sea-level at 0800 and arriving at the summit at 10.00 allowing for 30minutes respite at 3000m; the summit was vacated at 1600 hours. (Data were collected from nineteen “commuters” during 44 visits to the summit).

Study Findings
The majority (80%) of UKIRT shift workers experienced altitude sickness symptoms on the first day at the summit. Headache and breathlessness were the commonest complaints followed by insomnia, lethargy, poor concentration and impairment of memory. By the fifth day, 60% of shift workers were free of symptoms whilst the remainder reported minimal exertional dyspnoea or headache. Day commuters fared better; 60% were asymptomatic on arrival at the summit. However after a 5 hours work at 4200m, 35% of commuters experienced dyspnoea and 25% suffered headaches. Cerebral symptoms (poor concentration, lethargy and confusion) were reported by 10% of commuters.

On Mauna Kea, one case of HAPO was diagnosed during the 2-year study. Calculated in terms of the 2000 ascents per annum to the UKIRT, this low incidence of HAPO may reflect the lack of physical exertion involved in ascent to 4200m. A single episode of high altitude cerebral oedema (HACO) occurred during the Mauna Kea study.

Arterialised capillary blood samples were collected from 28 IRTF commuters during 35 ascents after approximately 3 hours at the summit; the mean arterial oxygen tension (PaO_2) was 39.9 mmHg (5.3 kPa). On the first day of the UKIRT shift on Mauna Kea, the mean PaO_2 was 42 mmHg (5.6 kPa) measured in 27 shift workers on 40 ascents. Mean PaO_2 rose significantly to 44.4 mmHg (5.9 kPa) by the fifth day. Thus mean PaO_2 levels were higher in the shift workers (day 1) than in the commuters: a night of acclimatisation at 3000m appears to confer benefit in this regard. The benefits of the shift schedule persisted and after five days on the mountain, shift workers had a significantly higher PaO_2 compared to commuters and fewer symptoms were reported.

Psychometric tests of numerate memory (Wechsler digit span tests), a skill much prized by the scientific staff members, and of motor speed and processing of information were studied. In shift workers, performance of one of the digit span tests was impaired on the first day however by the end of the 5-day shift there was no difference between the test results on the mountain and at sea level. Deterioration in the performance of both sets of tests occurred amongst the commuters. Thus although the commuters were less affected clinically than shift-workers, commuters were only at an advantage if their exposure to 4200m altitude was limited to less than 6 hours. The disadvantage of the commuters work schedule was that the commuters did not acclimatise.

Anecdotal accounts from the UKIRT personnel suggested that tolerance of hypoxia improved sequentially through the series of shifts i.e. more discomfort was experienced during the first shift of mountain work, following a sojourn of 40 days at sea level, than in subsequent shifts after only 5 days break. An analysis of the data according to whether the shift was worked after 40 or 5 days at sea level, showed no difference in terms of symptom scores or a variety of physiological measurements (tests of pulmonary function, electrocardiographs, exercise tests, haematological indices.). The failure to substantiate the impression of a follow-on of acclimatisation between shifts could be because the parameters employed, which did not include blood gas analysis, were inappropriate or too insensitive to detect a difference.

Individual response to high altitude exposure

Experiments at simulated high altitude in decompression chambers (5) have substantiated the impression that people react to high altitude exposure in an inherently individual manner. The circumstances of the work on Mauna Kea, involving the same individuals ascending to the same altitude by the same route on different occasions, allowed a study of this phenomenon in the ‘field’ (6). On Mauna Kea, PaO_2 recorded in the shift worker group ranged from 33mmHg (4.4 kPa) to 57 mmHg (7.6 kPa) at the summit . The worker with the highest PaO_2 during the first ascent (52.5mmHg; 7.0 kPa) recorded the highest PaO_2 on a subsequent ascent (57 mmHg;7.6 kPa): similarly one subject recorded the lowest PaO_2 (33mmHg; 4.4 kPa : 38 mmHg; 5.1 kPa) on both ascents. Although some workers were symptom-free, whilst others suffered altitude sickness, there was a significant correlation in the order of subjects ranked according to symptom scores in the first day of two shifts: 5 subjects were symptom-free on both occasions. Performance in memory and psychomotor tests were similar within each individual on the two ascents. Anomalies did occur - the sufferer of the documented case of HAPO had performed well on all previous occasions and continued to do so subsequently. Nevertheless, individual workers were remarkably constant in their response. One individual was so consistently affected by acute mountain sickness symptoms despite various strategies to ameliorate his distress (e.g. prolonged period of acclimatisation at Hale Pohaku, abbreviated periods at the summit) and prescription of acetazolamide prophylaxis that he was eventually excused mountain duties. In the 2 year study this was the only occasion when acetazolamide was prescribed for one of the staff: there was a reluctance to medicate the staff to facilitate work at high altitude which was shared by individual members of the staff and the managers of the telescope.

Conclusion

In June 1970 astronomical observations commenced at the University of Hawaii 2.2m optical telescope, the first major telescope built on the site. At the time of the completion of this study in 1982, there were four major telescopes at the summit. The success of these telescopes and the recognition by the scientific community, and various national grant-awarding bodies, of the excellence of the site has led to the construction of further observatories. In 1999, there are ten major telescopes, two of which are in an engineering phase, and an eleventh is under construction. No facility, including the most recently constructed, employ oxygen enrichment of the working environment although the capability exists at the Canada-France-Hawaii and the Keck telescopes; neither is this provision available at the dormitory and living facilities at Hale Pohaku.

In 1982, when the results of the study were published in medical and astronomical journals (7,8), the calculation was made that assuming a complement of 3 day staff and 3 night observers approximately 2,000 “man-days” were spent each year at

UKIRT: on average, each man-day constituted 9 hours at the summit. Observing practices change as technology advances nevertheless, in 1999 staffing requirements for UKIRT still necessitate 2000 man-days per annum. Overall, 30,000 man-days per annum are spent at the major telescopes on Mauna Kea, the increased numbers reflecting the demands of engineering and construction at the three new facilities. There has been a single cardiac death at the summit amongst the telescope personnel. A 37 year old astronomer, a smoker and diabetic, suffered a myocardial infarction after staying at the summit all night and working through the days. Post mortem examination revealed extensive coronary artery disease. Following this fatality, revised health and safety screening protocols were established. All UKIRT mountain personnel undergo a medical evaluation at sea level, which includes physical examination, comprehensive blood screen, resting ECG, chest X-ray, pulmonary function tests and a maximal treadmill stress test. The studies are recommended yearly for individuals above age 40, every two years for those between the ages of 30-39 and every three years for those younger than age 30. Two years ago a 40 year old construction worker suffered a fatal cardiopulmonary arrest at the summit: construction company employees are not required to undergo the rigorous screening programme described. (Dr D.I Lim. F.A.C.P. Cardiologist, Hilo. personal communication).

Confidence in the safety and effectiveness of the Mauna Kea site as a major astronomical facility has grown since the first observations in 1970. The initial trepidation of the telescope staff at the prospect of working in a hypoxic and hypobaric environment has been supplanted by knowledge of the consequences of altitude exposure, and the awareness that problems can be predicted and coping strategies developed. The converse 'machismo' attitude of denial of the hazards of altitude has been replaced by respect for the mountain site and acceptance that people react to altitude exposure in an individual manner irrespective of age, fitness, 'toughness' or gender. Inevitably, the confidence of the workforce – technical, scientific and managerial – in operating the telescopes on Mauna Kea has been greatly facilitated by ready access to high quality medical care in the event of an emergency. Within 2 hours of leaving the summit by road, a victim of HAPO or HACO could be undergoing MRI or CT scanning at sea level in Hilo: two other CT scanners are available on the leeward side of the Big Island and a second MRI scanner is planned. The availability of a high standard of clinical medical practice has been a great reassurance to the visiting scientists and permanent telescope staff, both those who originate from the United States and from farther afield in Europe and Asia.

Ambitious plans are afoot to construct a telescope at an altitude of 16,400 (5000m) in the Atacama Desert in northern Chile. The Atacama Large Millimeter Array (ALMA) will image the universe at millimeter wavelengths between radio and infrared spectral regions and will consist of thirty–six 12-meter antennas arranged in a circular configuration. The telescope will be a major development for astronomical science furthering investigation of the origins of galaxies and stars and 'imaging cosmic dawn"(9). At the proposed location of ALMA (barometric pressure 419 Torr) the PiO_2 is 78 Torr (102 mbar) compared with approximately 88 Torr (115mbar) at 4200m: workers at ALMA will be exposed to 11% less oxygen than the Mauna Kea telescope operators. (4). The ALMA project will reopen all the questions posed by the construction of telescopes at high altitudes – the best work schedules for the safety of the staff and the efficient operation of the facility, access to the site, rapid evacuation from the site in the event of an emergency, provision for staff in the event of a stranding , the availability of adequate medical services and the need or not for supplemental oxygen in living and working quarters etc. The success of the project will depend on the solutions to these problems as the resounding success in Hawaii has depended on the solutions that have evolved on the summit on Mauna Kea.

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1. Forster PJG. Work at High Altitude: a Clinical and Physiological Study at the United Kingdom Infrared Telescope, Mauna Kea, Hawaii. Edinburgh: Royal Observatory. 1983.
2. Heath D, Williams DR. Man at High Altitude. Edinburgh: Churchill Livingstone.1977.
3. Heath D, Williams DR. High – Altitude Medicine and Pathology. Oxford: Oxford University Press. 1995.
4. Napier PJ, West JB. High altitude medical and operations problems and solutions for the Millimeter Array. http://www.mma.nrao.edu
5. Robinson SM, King AB, Aoki V. Acute mountain sickness : reproducibility of its severity and duration in an individual. Aerospace Medicine. 1971; 42:706-8.
6. Forster PJG. Reproducibility of individual response to exposure to high altitude. Brit Med J.1984; 289: 1269.
7. Forster PJG. Effect of different ascent profiles on performance at 4,200m elevation. Aviat Space Environ Med. 1985; 56: 758-64.
8. Forster PJG. Health and work at high altitude : a study at the Mauna Kea Observatories. Proc Astro Soc Pacific. 1984; 96: 478-87.
9. Atacama Large Millimeter Array Web site. http://www.mma.nrao.edu/

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