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Occupational Rheumatic Diseases

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Locomotor problems of supersonic aviation and astronautics

PETER REMES

It is a platitude, but nevertheless a truth, that advances in modern science and technology not only bring advantages but also disadvantages. The latter are particularly evident with modern aviation and astronautics. A number of medical problems have emerged, such as those caused by long-term weightlessness in astronauts, which can now be regarded as occupational hazards. The purpose of this chapter is to review the musculoskeletal problems associated with modern aviation and astronautics.

UNFAVOURABLE PHYSIOLOGICAL EFFECTS OF AVIATION AND ASTRONAUTICS

The weak link in supersonic flying and space flight is undoubtedly the limitation of human ability to cope with both the psychological and physical stresses. According to Garney (1986), some 50–60% of catastrophes happen as a result of human error. Calvin and Gazenko (1975) and Hideg (1983) have outlined the requirements for modern fighter pilots and astronauts.

The hazards of supersonic flight are varied and numerous and include both hypoxia and hyperoxia, low atmospheric pressure, pressure breathing ejection decompression, noise, vibration, heat effects, acceleration, gravitation (G) loads, increased emotional tension, abnormal sensorimotor activity, illusions, the pressure of time constraints on the work performed, frequent changes in work–rest–nutrition rhythm, injuries, e.g. fractures after ejection, etc. The problems of long-term space flight include, in addition, exposure to cosmic radiation over months and even years, emotional reactions to weightlessness and limitations of artificial living space, and weightlessness.

The aim of aviation and aerospace medicine is not only to diagnose manifest illness but to detect latent problems which, under extreme conditions, may restrict a pilot's or astronaut's working ability.

The demands of civil aviation and on civilian scientists participating in space flight are not, of course, as stringent.

SPINAL DISEASE

Spinal disease has a prominent place among the medical problems of supersonic aviation and astronautics. The spine is not only the supporting structure to carry the weight of the pilot's trunk but also forms part of his personal equipment.

According to Leverett and Whinnery (1985), during high G manoeuvres the G load may increase some two- to nine-fold and, in the case of ejection or landing, up to 20-fold (Sharp, 1978). This increased load frequently leads to injuries such as fractures and dislocations. One of the factors leading to spinal problems among pilots and astronauts is the forced position in which the pilot is required to work for long periods of time. This may cause increased pressure on the intervertebral discs and strain on the spinal muscles. As a result, low back pain is a common complaint and conditions such as osteochondritis, spondylolisthesis, wedge-shaped vertebral body fractures, etc. occur. Indeed, spinal problems are second only to cardiovascular disease in causing a pilot to be considered unfit for flying duties (McNish, 1983). Spinal disorders develop mainly in fighter pilots (0.28%) compared to 0.05% for other types of pilots (Whitton, 1984).

Vertebral fracture

The most serious injury to the spine is undoubtedly vertebral fracture. This is due to high G forces, especially those encountered in ejections from fighter aircraft and hard landings (Figures 1 and 2). From Table 1 it can be seen that

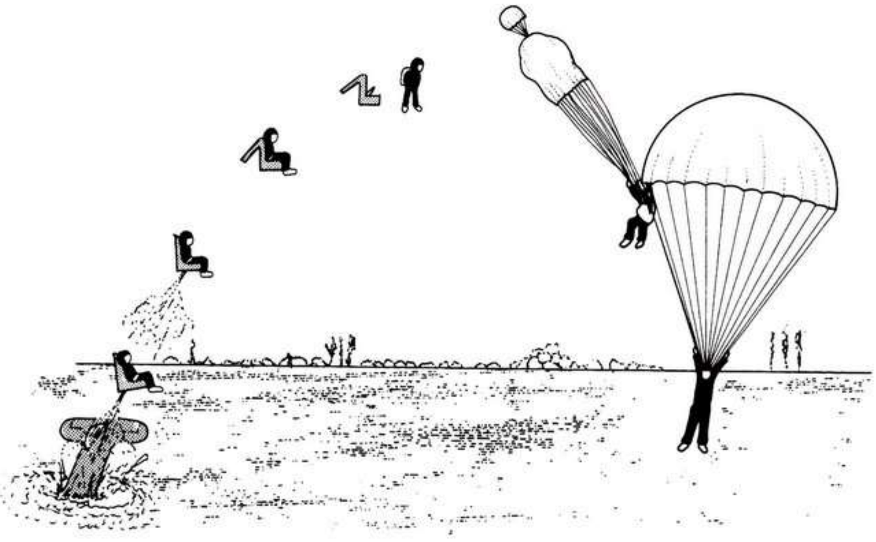

Figure 1. Ejection of pilot from high-speed aircraft. The seat separates from the aircraft and obtains the height required for parachuting with the aid of booster rockets. Abrupt overload during the booster rocket operation or during the opening of the parachute or on landing may cause spinal injury.

the incidence of vertebral fractures reported from different countries after ejection varies from 5.3% in a USA study to 50% in a report from Great Britain. These differences can be largely explained by differences in ejection appliances (Kozeikin and Moiseiev, 1986). The latest American ejection seat (ACES II) has an incidence of vertebral fracture of 6.25% (Delgado, 1981).

Fractures of the spine may also occur when the pilot's head hits the overhead canopy at the time of ejection. The characteristic feature of these lesions is that they occur in the mid-spine and often result in serious neuro-

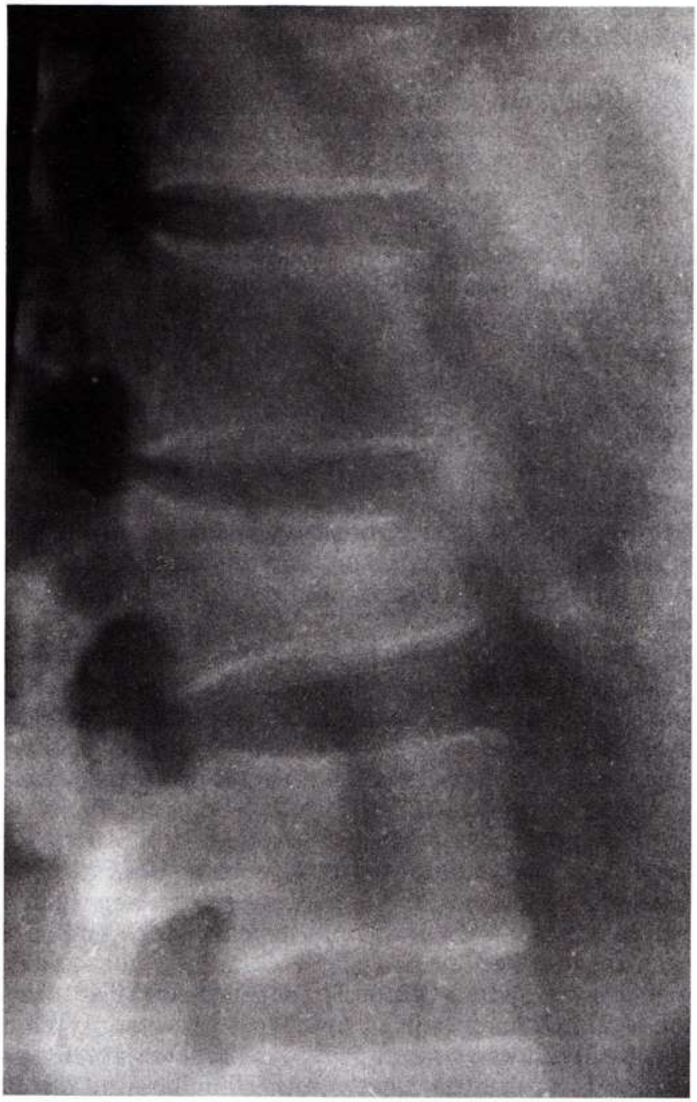

Figure 2. Compression of L-II vertebra can be seen. Vertical diameter of vertebral body diminished and superior laminae indented. The supersonic pilot has been injured during ejection.

Table 1. Statistics of pilot ejection reported from different countries.

Country	Period analysed	Number of pilots: Died*	Survived	With vertebral fracture*
Canada	1952–61	53 (24)	165	22 (13.3)
Canada	1962–66	9	65	14 (21.5)
France	1951–63	No data	No data	(9)
France	1951–69	71	295	26 (11.6)
France	1963–65	8 (25)	32	6 (15.6)
France	No data	11 (10.6)	92	(21.7)
German Federal Republic	No data	34 (19.3)	137	(10.2)
Great Britain	1949–60	No data	200	41 (19)
Great Britain	1961–73	4	14	7 (50)
Italy	No data	11 (11)	89	(16.8)
Sweden	1957–60	–	55	14 (25.5)
Sweden	No data	–	29	12 (41)
Sweden	–	–	23	4 (17)
USA	1948–55	174 (23)	583	(14.6)
USA	1953–63	–	165	34 (21)
USA	No data	No data	55	13 (25)
USA	No data	No data	49	7 (14.3)
USA	No data	No data	51	3 (5.3)
USA	No data	–	218	25 (11.5)
USA	1967–68	59	390	40 (12.1)
USA	1978–80	2 (12.5)	14	1 (6.25)

* Percentage in parentheses.

logical complications. To prevent such injuries, canopy-releasing devices have been developed and have been installed in the Tornado, Harrier and Hawk fighter aircraft, with a significant reduction in the incidence of such injuries.

Injuries to the cervical vertebrae have occurred during aerobatic exercises. Schall (1983) reported the case of a pilot instructor who fractured three of his cervical vertebrae after impacting the overhead canopy during a negative G defensive manoeuvre. The injuries resulted from the fact that the pilot was not wearing his seat-belt tightly enough. Aircrew frequently make head-to-canopy contact as a result of wearing their seat-belts and shoulder harnesses incorrectly.

The present new generation of aircraft, such as the F15, F16 and F18, which are able to manoeuvre at 9 G, puts severe strain on a pilot's thoracic and lumbar spine. Medical fitness requirements in the United States Air Force are stringent, and even a single Schmorl's herniation or spinal deformity (such as spondylolisthesis, degenerative disc disease, etc.) disqualifies a pilot from flying the new types of aircraft (Whinnery and Gillingham, 1983). Pilots who experience backache, especially if recurrent, during flying are instructed to interrupt their flight, since further loading may lead to injuries of the cervical vertebrae, Schmorl's node herniation or even vertebral compression fracture. The heavy helmet worn by pilots is another factor predisposing to cervical spine injuries. Efforts are currently being made to improve these helmets, and oxygen masks, in order to diminish the risk of damage.

The effects of repeated ejection have been studied in 132 United States Air Force pilots. On the first ejection six fractures were found, but only one on the second occasion. In the pilot with fractures on both occasions it was of interest that they occurred at different sites. This suggests regeneration of bone after a fracture may result in the vertebra becoming more compacted and more able to resist pressure. Recovery from a vertebral fracture is often slow, on average between 60 and 120 days, and the pilot may not be able to resume his flying for an even longer time. Late complications are not infrequent and the injury often results in total disqualification from further flying.

Considering the costs of training a modern fighter pilot, the economic losses due to vertebral fractures are considerable.

Spondylolysis and spondylolisthesis

Helicopter aircrew have been found to develop degenerative lytic changes in the intervertebral discs and adjacent vertebral bone. This has been attributed to vibration (Wilder et al, 1982) and to lumbar flexion while operating the helicopter (Delahaye and Auffret, 1982).

Lytic spondylolisthesis has also been recognized as an occupational hazard of helicopter pilots. Spondylolisthesis is, however, more often caused by fatigue fractures of the neural arches due to vibration. A high percentage (38%) of helicopter aircrew who develop spondylolisthesis complain of lumbar pain. In contrast, Froom et al (1984) found only 8% of pilots who did not have the disorder complain of lumbar pain. Reduction in spondylolisthesis as a result of vibration has been achieved using amortized equipment for the surface of the pilot's seat.

Back pain

One of the common problems of modern flyers is back pain. This is aggravated by prolonged sitting in seats without properly designed supports, wearing parachutes, and being strapped into place during a long flight. Some patients may have intervertebral disc disease and some may consciously or subconsciously use the complaint to avoid unpleasant duties. The astute physician may be able to demonstrate an emotional or malingering basis for the complaint but often this requires several consultations.

Scoliosis

Change in the curvature of the spine makes it more vulnerable to static and dynamic loads. Moser (1985) describes the case of a pilot with scoliosis who developed severe back pain while experiencing 6.5 G. The pain was localized at the point of maximum curvature of the spine where advanced degenerative changes were present. For this reason, current United States Air Force directives preclude flying duties for an individual with scoliosis.

Klippel–Feil syndrome

Patients with Klippel–Feil syndrome have fusion and deformities of the cervical vertebrae resulting in restricted cervical movement and, on occasion, symptoms of nerve involvement. This deformity has been found in crew members experiencing pain after high G manoeuvres (Kazarian and Belk, 1979). The spine of patients with this condition is thought to be susceptible to fracture with relatively low G loads. Individuals with this disorder should therefore not be accepted for flying.

Scheuermann's disease

This is the most frequent disorder of the spine in young people (Brocher and Willert, 1980). Its prevalence in the general population has been estimated at between 20 and 40%. According to Swiss aviation medicine data, 10% of candidates have clinical symptoms as a result of the disease, although it occurs in an asymptomatic form in 30% of candidates.

The aetiology of Scheuermann's disease is still largely unknown. Studies in twins suggest a genetic factor and a developmental disorder appears likely. The disease usually begins around the age of 10 years and progresses slowly, so that by the age of 18 some 20% complain of spinal pain and have limitation of spinal movement and kyphosis. At this age the X-ray findings are usually typical. Later, when the disease is fully established, some 80% of patients are symptomatic, complaining of thoracic and lumbar pain, brachalgia and having kyphoscoliosis. From the point of view of fitness for high-speed flying it is imperative that diagnosis in the early asymptomatic stage be made and the candidate not accepted.

BONE AND MUSCLE CHANGES IN WEIGHTLESSNESS

The loss of normal gravitational loads during weightlessness produces anatomical and functional changes in a number of organs by a number of different and complex mechanisms (Gazenko and Jegorov, 1983). Animal and manned space flight experiments have confirmed the seriousness of bone loss and have given some hints as to its pathogenesis (Biriukov, 1967; Biriukov and Krasnykh, 1970; Berry, 1967).

In 1965, Basetti published his hypothesis about osteoporosis developing during weightlessness. The structural substances of bone function as piezoelectric transformers, that is, mechanical tensions are converted into electrical tension. Within the bone tissue there is a close structural connection between the electron-plentiful hydroxyapatite crystals and collagen fibres. The primary stimulus of bone formation is mechanical force, which acts as a stimulus to produce piezoelectric manifestations. Electrical potential differences appearing in bones are proportional to the magnitude of mechanical deformation. This electric potential difference (charge difference) regulates osteoclast and osteoblast functions. Those bone sections which are exposed to the biggest deformation have the biggest negative polarity and are the sites of increased osteoblast activity. At sites without deformation, the osteoclast activity prevails and, because of the positive charge of bone sections, results in bone absorption. Thus, according to Basetti (1965), the electrical potential engendered by the mechanical load regulates the orientation of bone structure.

In weightlessness there is no deforming gravitational force having an effect on the bones, and muscular activity decreases. In addition, the electrical activity of the bones and the electric pump mechanism significantly decrease, which in turn affect oxygenation of bone. The blood calcium concentration increases and there is an increase in urinary calcium excretion. These changes also occur with prolonged bed-rest and immobility.

Muscles show atrophic changes following weightlessness. These changes have been shown to be frequently irreversible (Kovalenko and Kasian, 1983). They can be prevented, or at least their severity decreased, with regular static and dynamic exercises during the time the astronaut is weightless. On board Soviet space stations two hours of steady physical exercise have been found necessary to avoid irreversible damage (Kovalenko and Kasian, 1983).

SUMMARY

Modern high-speed aviation and space flight are fraught with many problems and require a high standard of health and fitness. Those responsible for the health of pilots must appreciate the importance of early diagnosis even before symptoms appear. This is particularly true in terms of preventing spinal injuries where even a single Schmorl's node may make a pilot unfit for high-speed flying. Spinal fractures are frequent during emergency ejection and landing.

Helicopter crews are particularly prone to spinal disc degeneration due to vibration. By effective lowering of vibration by changes in the seats, a reduction in such lesions is possible. The osteoporosis and muscle atrophy occurring among astronauts subjected to prolonged weightlessness can be prevented by regular physical exercises.

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