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Physiopathology and Pathology of Affections of the Spine in Aerospace Medicine

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

PHYSIOPATHOLOGY AND PATHOLOGY OF AFFECTIONS OF THE SPINE IN AEROSPACE MEDICINE

by

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PHYSIOPATHOLOGY AND PATHOLOGY OF AFFECTIONS OF THE SPINE IN AEROSPACE MEDICINE

Roland-Paul Delahaye, Roger Pannier, Henri Seris, Robert Auffret,
Raymond Carré, Henry Mangin and Marie-José Teyssandier

1. IMPORTANCE OF THE PROBLEM

To the practitioner o Aviation Medicine who daily encounters problems of spinal pathology in flying personnel, the contradictory opinions in the literature are not particularly helpful. There has furthermore been no recent synthesis of the problem to comment upon the new syndromes and special injuries that have been identified in the past fifteen years: for example, chronic pain in parachutists, spinal fractures in aircrew who have ejected and lumbothoracic pain in helicopter pilots.

The frequent occurrence of lumbar pain in the 1987 man, and the use of X-rays and tomographic techniques, have given a better understanding of spinal diseases and have been the subject of numerous communications in orthopaedic, radiological and rheumatological congresses. In addition, reports from Aviation Medicine Research Establishments and from clinical sources have stressed the pathogenesis and prophylaxis in accidents, and have also described the common clinical picture.

This report, produced under the direction of Professor Delahaye, is the work of a team from the Aviation Medicine and Electroradiology Departments of the Dominique-Larrey Army Teaching Hospital at Versailles; from the Principal Centre for Specialist Medical Examinations of Flying Personnel in Paris (15^{e}); from the Aerospace Medical Laboratory at the Flight Trials Centre at Bretigny-sur-Orge, and from the Group on Studies and Research in Radiology in Paris.

A brief statement of the factors of aggression in flight and a quick reminder of vertebral anatomy will be necessary to understand the various aspects of spinal conditions in aviation medicine. This study will consist of three parts of varying importance.

By reason of their frequency, different etiologies, symptomatology and their development, injuries merit special attention. We shall give particular attention to the affections of posture since this is a new problem with many unknown facets such as etiology and development. The acquired spinal conditions, especially in older pilots, also merit special consideration since they call for particular care in regard to investigation and treatment.

2. AGGRESSIVE FACTORS IN FLIGHT

These are many but can be grouped into two categories - first, the usual factors inherent in flight, for example, vibration and accelerations of long duration, and secondly, accident factors such as ejections or crash landings which subject the skeleton to considerable forces but of very short duration.

2.1 Inherent Factors in Flight

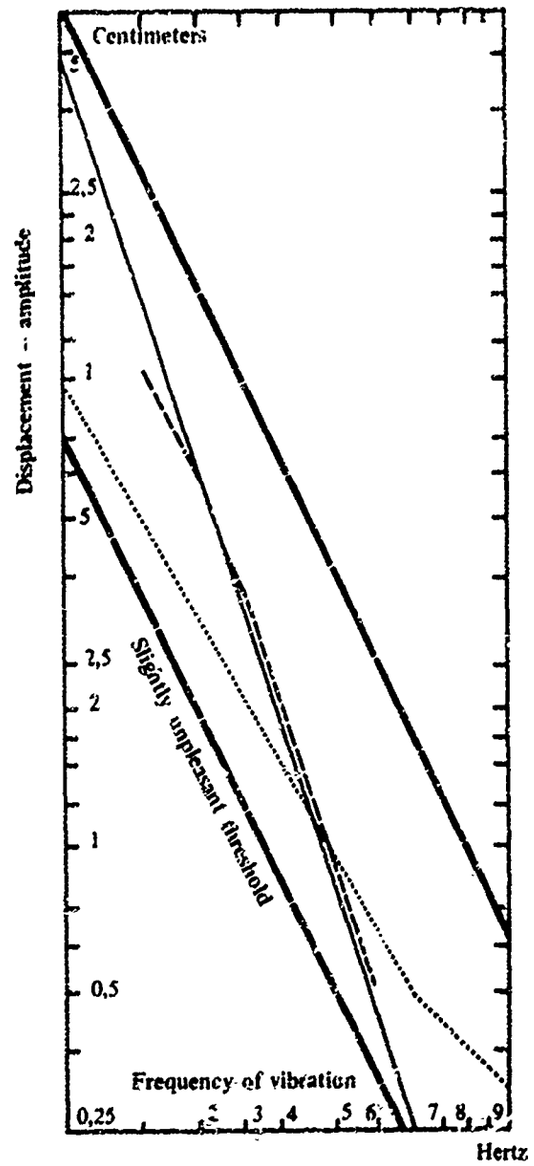
2.1.1 Vibration

Vibration is a constant factor to which the pilot is subjected from the starting up of his aircraft and throughout the flight. The highest frequencies have their origin in the aircraft engines or, in general, in any moving mechanical elements, while the very low frequency vibrations (below 20 Hz) are caused mostly by turbulence of aerodynamic origin. They are very difficult to eliminate (unlike those of high frequency) and are particularly dangerous. The subjective tolerance for short duration vertical vibration is shown in Figure 1.

2.1.2 The Accelerations

The accelerations are caused by changes in the speed or direction of the aircraft. Acceleration derived from speed is expressed in meters per second per second. However, in current practice the unit "g" is used, this being the acceleration due to gravity (9.81 m/sec^2).

The choice of expressions used to describe the direction of the vector having an influence on man, in a man-machine complex, depends upon the choice of reference point. AGARD has attempted to put some order into the many systems employed, some of which take the movement of the aircraft as reference, others that of the pilot, while others again note only the forces of inertia and their effects.



Burton Douglas. Threshold most unpleasant
Goldman. Mean threshold of discomfort
Dieckmann. Level to be exceeded only briefly
Janeway. Recommended safety level

Fig. 1 Subjective tolerance curves for short duration vertical sinusoidal vibration

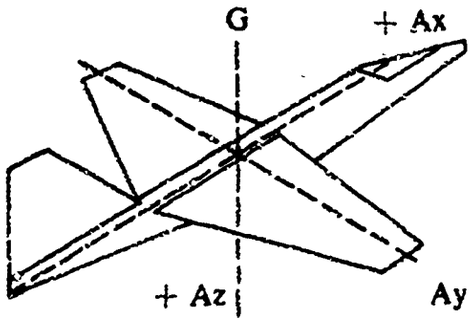


TABLE I

Aircraft acceleration		*Physiological acceleration*	*Inertial force*
Forward	+ Ax	+ Gx	Aft
aft	− Ax	− Gx	forward
up	− Az	+ Gz	down
down	+ Az	− Gz	up
to right	+ Ay	+ Gy	to left
to left	− Ay	− Gy	to right

Ta shows the relationship between aircraft and pilot axes according to AGARD. Note that the Z vector for a and for pilot are of opposite sign thus +Gz accelerations give rise to a force of inertia in the head t direction which tends to push the pilot into his seat and to compress the spine. It is possible that such repeated "microtrauma" may play a part in the deterioration of the vertebral axis. It is often when practicing aerobatics that there appear the first thoracic or lumbar pain of a vertebral arthrosis which had up till then been latent.

The transverse accelerations : at right angles to the vertebral axis, and are designated by the letters Gx. They are much less dangerous than the preceding accelerations.

Tolerance to these is high, and in astronautics it is to this type of acceleration that cosmonauts are subjected on blast-off and on re-entry into the atmosphere.

In aviation the accelerations reach high levels during certain manoeuvres such as tight turns, pull-out from a dive, catapult launching, and deck landing. In ejections, accelerations approach the limits of the human body's tolerance and unfortunately often exceed it in a crash landing. Some of the other hases of flight in which one encounters other problems of acceleration are:

(a) putting out airbrakes;

(b) lighting after-burners;

(c) low speed spins.

These various accelerations commonly encountered in flight can exist as combinations of longitudinal and of transverse types and are of moderate intensity but of long duration (greater than one second). Figures 2 to 6 give the tolerance levels for the various types of acceleration.

2.2 Accidental Factors

2.2.1 *Ejections*

Escape from an aircraft flying at high speed is possible only by means of an ejection seat which, as a result of the application of a force sufficient to give it a sharp acceleration, (greater than 15g but of short duration (200-400 milliseconds)) exerts a force initially in the longitudinal body axis in the foot to head direction. The force then becomes complex as a result of the turning of the seat in its trajectory.

After separation of the pilot from the seat it must not be forgotten that he becomes a parachutist and that he is then subjected first to the opening shock of the canopy (8 to 10 g for one second) and then to possible injury on landing. This is all the more frequent since, first, the pilot is not a trained parachutist, secondly the canopy area is reduced and thirdly the pilot weighs much more because of the survival pack dangling from his harness. A further hazard is of course introduced by the fact that unlike a parachutist the escaping or ejecting pilot cannot choose his jumping zone.

2.2.2 *Forced Landing*

In the course of a forc landing away from runways, the pilot is subjected to complex decelerations of very high intensity (100 g for ple) but of very short duration measured in milliseconds. It should be noted that a crash landing can no longer be attempted with modern fighter aircraft by reason of the high stalling speed. In the case of total engine failure the aircraft must therefore be put into a steep dive so as to keep flying.

In summary, the pilot's spine is subjected to two kinds of aggression - first that of relatively low intensity whose effects resemble those observed in metal fatigue (fatigue des matériaux), secondly unusual stress (ejection or crash landing) of very high intensity, which can hazard the mechanical resistance of the spine since it can cause fractures.

3. GENERAL FEATURES OF VERTEBRAL ANATOMY

Before tackling the clinical and radiological study of the spinal conditions in aerospace medicine, it is necessary to recall a few general anatomical features Some of the elementary facts however, such as morphological descriptions and variations according to level in the spine will, however, not be considered. We shall on the other hand stress three essential points:

the general appearance of the dorsolumbar spine;

the means of intravertebral union;

the vertebral structure.

3.1 General Appearance of the Lumbosacral Spine

The vertebral column which has an "S" shaped curvature adapted to the standing position, comprises a dorsal segment with a backward convexity and a cervical and lumbar segment with an anterior convexity.

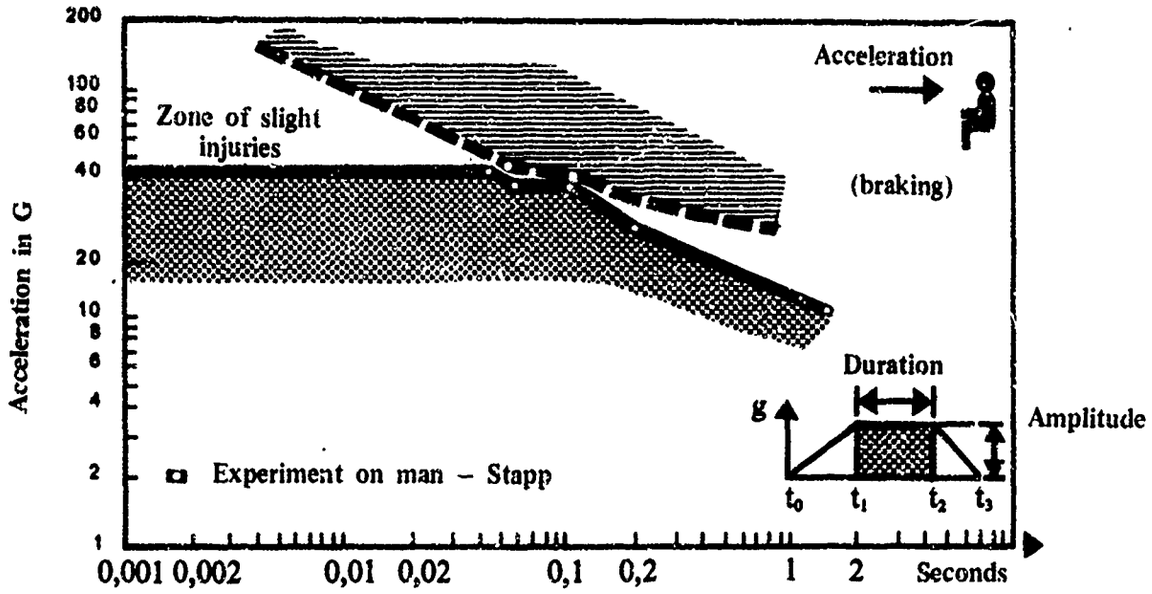


Fig. 2 Duration of acceleration

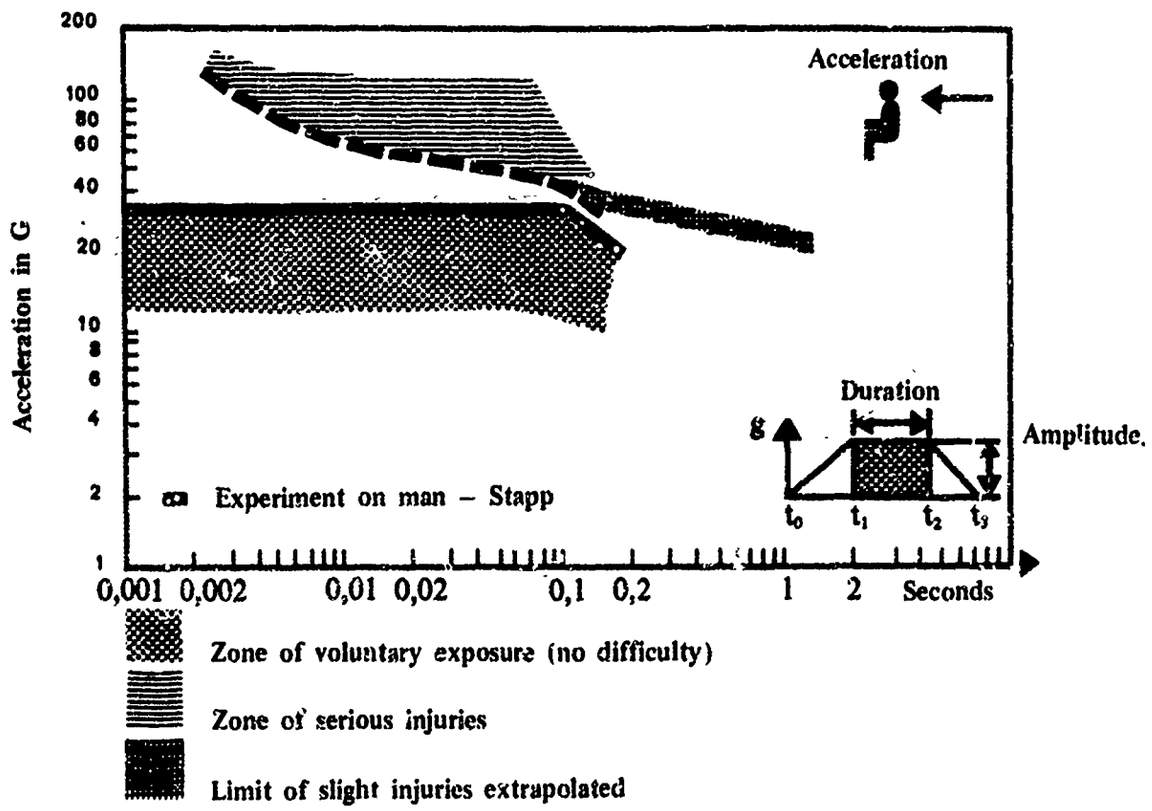


Fig. 3 Tolerance to acceleration

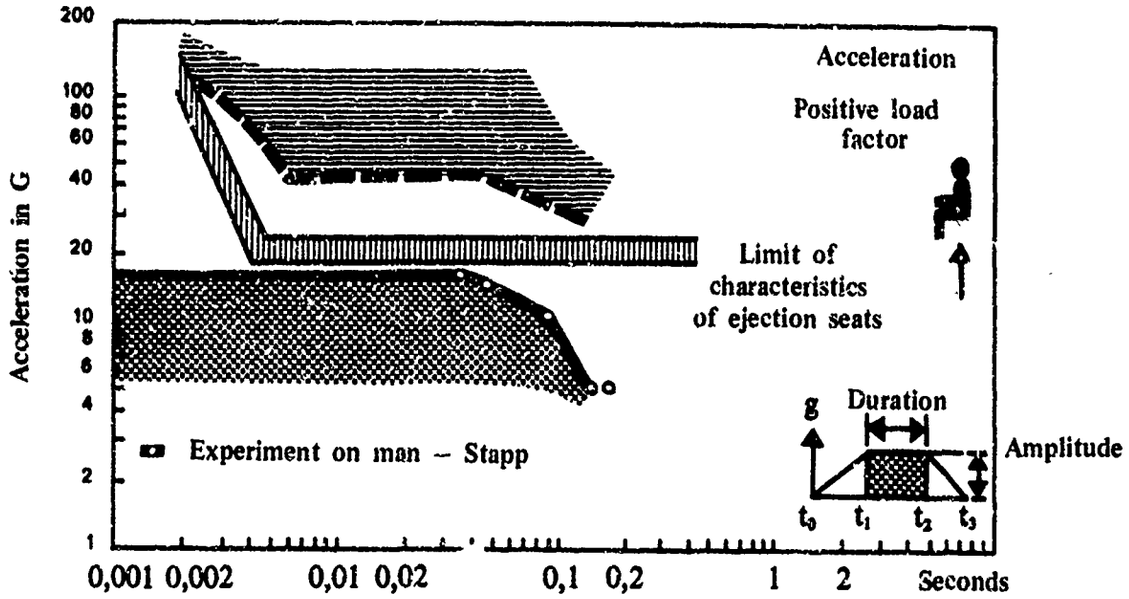


Fig. 4 Duration of acceleration plateau

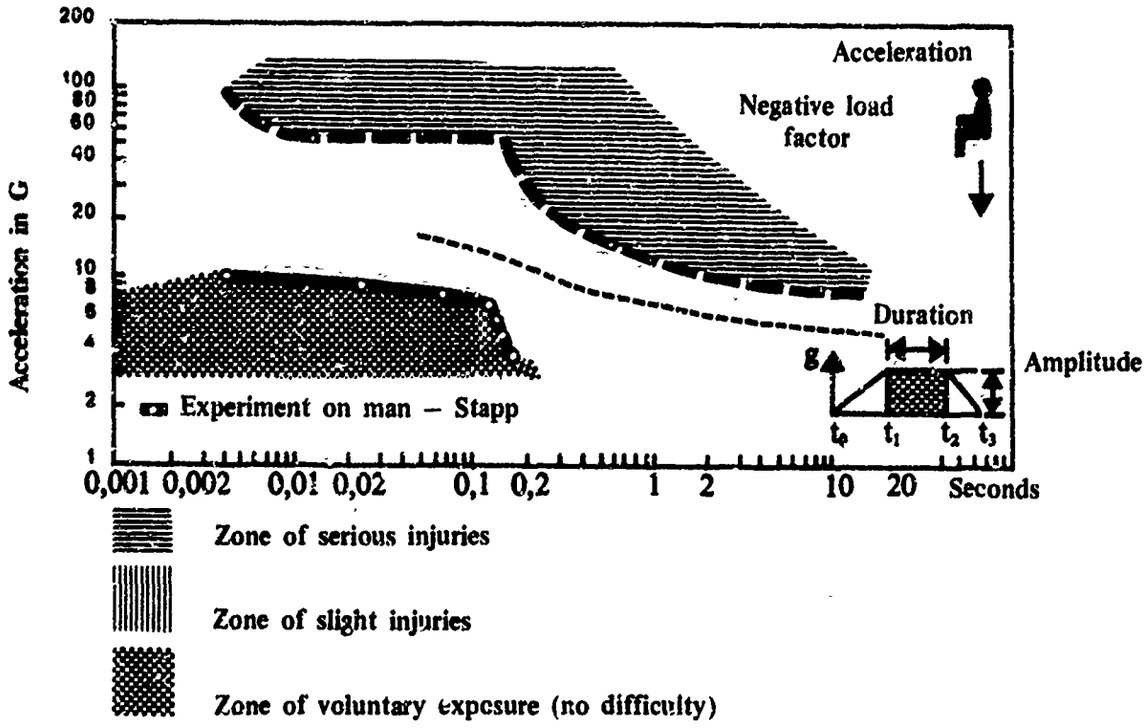


Fig. 5 Tolerance to accelerations

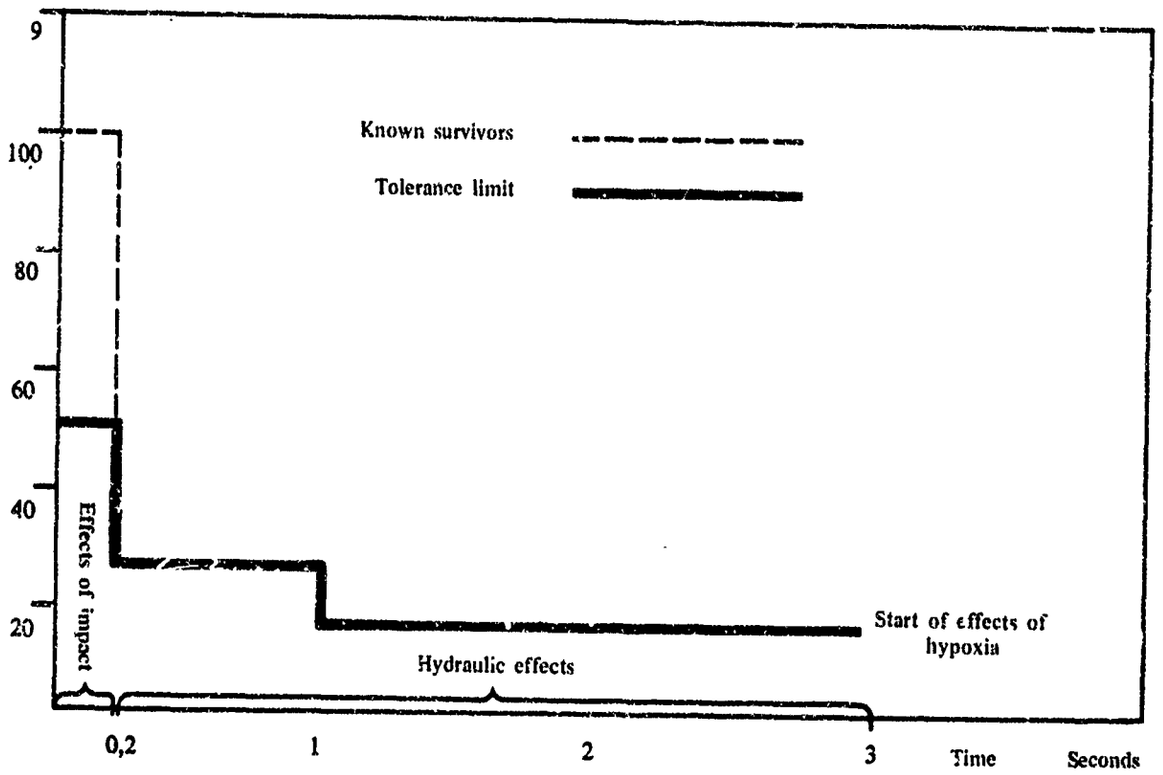


Fig. 6 Tolerance to acceleration (after J.S.Cook and H.V.Lund, Human Engineering Guide to equipment design 1963)

In man, one can distinguish both anatomically and physiologically, two segments separated by the twelth thoracic vertebra. The higher or cervico-thoracic segment and the lower or lumbosacral segment exhibit changes of a gradual nature. Thus, the vertebrae which are particularly characteristic of the middle part of the segments become less so towards the end of the segments. The twelth thoracic vertebra, virtually a sort of a vertebral hinge, has both thoracic and lumbar characteristics. The inferior articular process of T12 is similar to that of the lumbar vertebrae. At the most prominent point of the curvatures, the vertebral bodies of T6 - T12 and L1 exhibit an anterior wedge-shaped deformation. This appearance which constitutes a physiological variant of the vertebral morphology must be borne in mind in the interpretation of X-ray plates. The level of this vertebral deformation varies a little with individuals, and is responsible for the variations in curvature and modifications in the line of gravity.

In other respects the extent of cuneiformity of the vertebrae or discs is capable of modifying the usefulness of the posterior wall. (Delmas).

3.2 The Types of Union of Vertebrae

The thoracic and lumbar vertebrae are articulated in the same way - the posterior arches by means of articular processes, and the vertebral bodies by means of discs (Fig.8). The articular processes are virtually posterior bolts, while the discs play the part of shock absorbers. They are some 12 mm thick in the lumbar region and are composed essentially of two parts - first, a central nucleus pulposus which is a mass of mucoid tissue very rich in water, incompressible, but on the other hand very easily distorted. Peripherally there is the annulus fibrosis closely connected with the cartilaginous plate of the vertebral plateaux.

The vertebrae are furthermore united by a ligamentary system whose role is most important. The common anterior and posterior ligaments in particular, impart to the spine much of its unity by forming a continuous and strong sheath. These have an antagonistic action and contribute to give equilibrium to the movements of the spine.

Many intervertebral ligaments stretching between the spiky and the transverse processes, unite the spines very strongly and prevent the separation of the articul.. surfaces. The vertebral muscles play a part in maintaining physiological rigidity in which they act as antagonists to the passive reflex movements, and are at the same time capable of supporting pressures in excess of one ton. They are in fact active stays.

3.3 Structure of the Lumbo Thoracic Vertebrae (Fig.7)

The study of the lumbo thoracic verebral structure shows how vulnerable it is to injury. Covered only by a thin shell of compact tissue, the vertebral body is mostly composed of spongy tissue with ordered trabeculae which can be seen on section in the dried preparation or in X-rays. The spongy cross members cross one another in the vertebral body to form a complex lattice-work on which, in an adult, can be seen three trabecular systems (Fig.7):

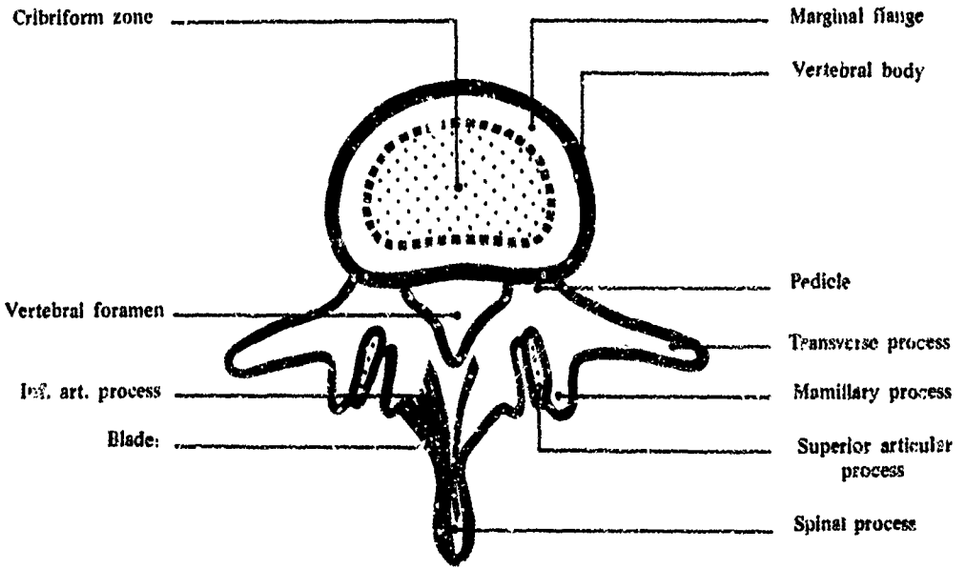
a radiating horizontal system (remains of the infantile r[illegible] system);

a vertical system made up of axial concave cross members spread out over the whole spine; and

an oblique system formed by an upper oblique and a lower oblique bundle continuing on the posterior arch.

The posterior arch of compact bone comprises some oblique bundles continuous with the vertebral body's oblique system; a transverse and a "U" shaped fasciculus.

The study of the vertebral structure shows us that the median and anterior parts of almost empty vertebral bodies, constitute a zone of least resistance, particularly predisposed to compression as a result of injury. On the other hand, the very tight crossing of the upper oblique and lower fasciculi at the level of the pedicular insertion strengthens that portion of vertebrae. The pedicular insertion on the posterior aspect of the vertebral body is termed by Rieunau, "the posterior wall" - a concept which is most important in the pathology of vertebral injury.



Thoracic or lumbar vertebra (after Paturet)

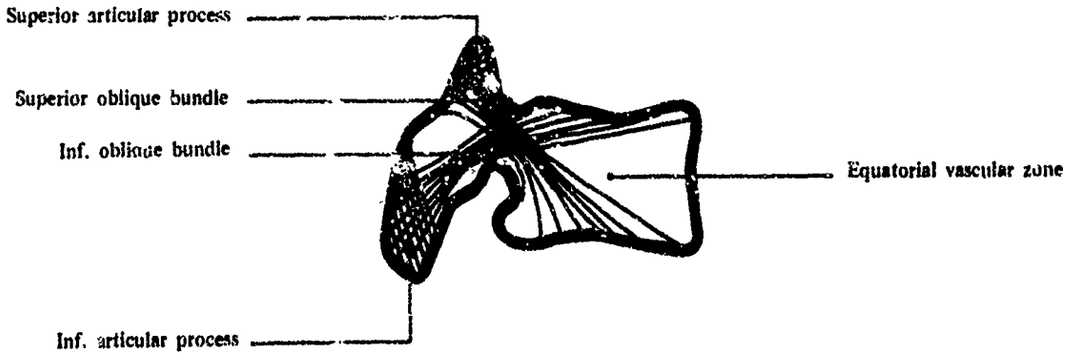


Fig.7 Morphology and architecture of a vertebra (after Paturet). Note the cross supports for the processes

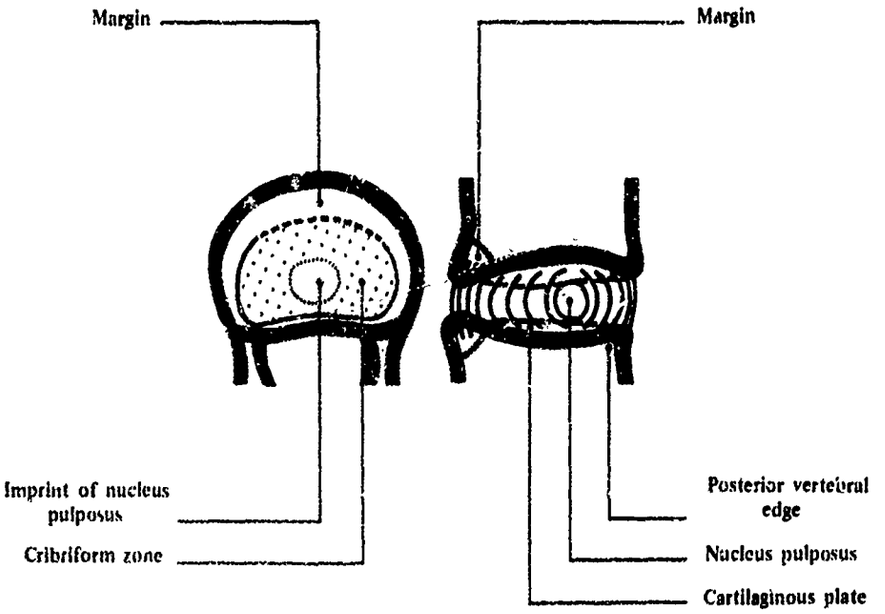


Fig.8 Intervertebral disc (after Schmorl)

PART I: THE INJURIES OF THE SPINE IN AEROSPACE MEDICINE

1. INTRODUCTION

Injuries of the spine are often encountered in aviation medicine and they always occur in association with a state of emergency in flight. Whatever the type of aircraft (propeller or jet) there are two possible methods of escape from an emergency situation. The first is the crash or forced landing (commercial aircraft, light private aircraft and some military aircraft). The second is escape by parachute. In the case of a generalised failure in a propeller aircraft the pilot can leave the cockpit by his own resources. On the other hand the high speeds reached in jet fighter aircraft call for the use of an ejection seat to assist escape from the aircraft.

After a review of the pathogenic theories of spinal fracture, we shall consider first the various etiological conditions in which fractures and other injuries may occur (crash landing, parachuting, ejection), then the clinical and radiological studies. The many traumatic sequelae deserve a detailed account for they involve a special symptomatology since they can be considered as an occupational disease. The risk of seeing an injury appear on a spinal cord rendered fragile by a congenital or acquired lesion justifies the systematic radiological examination on entry.

2. PATHOGENIC THEORIES OF SPINAL FRACTURES (Fig.9)

From all the pathogenic theories of lumbo dorsal fractures, we shall note Watson-Jones' classification which distinguishes three types of fracture according to the direction of impact.

(a) The vertical compression of the spine during slight flexing results in an anterior wedge-shaped compression fracture. One or several vertebrae bodies show an involvement only of the anterior portion without involvement of the posterior wall. If the trunk is deviated laterally at the time of impact an asymetric lateral compression can be observed on antero-posterior radiographs.

Discs are usually spared: the inter spinal ligaments can be, but are very seldom ruptured.

(b) The postero-superior force which acts suddenly from top to bottom and from back to front, puts the spine into hyperflexion. This results in a comminution fracture of the vertebral body.

(c) The posterior force which acts at right angles to the spine on the upper part of the trunk, puts the spine into hyperflexion and causes a fracture dislocation with injury of posterior wall of the vertebral body and a rupture of the interspinal ligament.

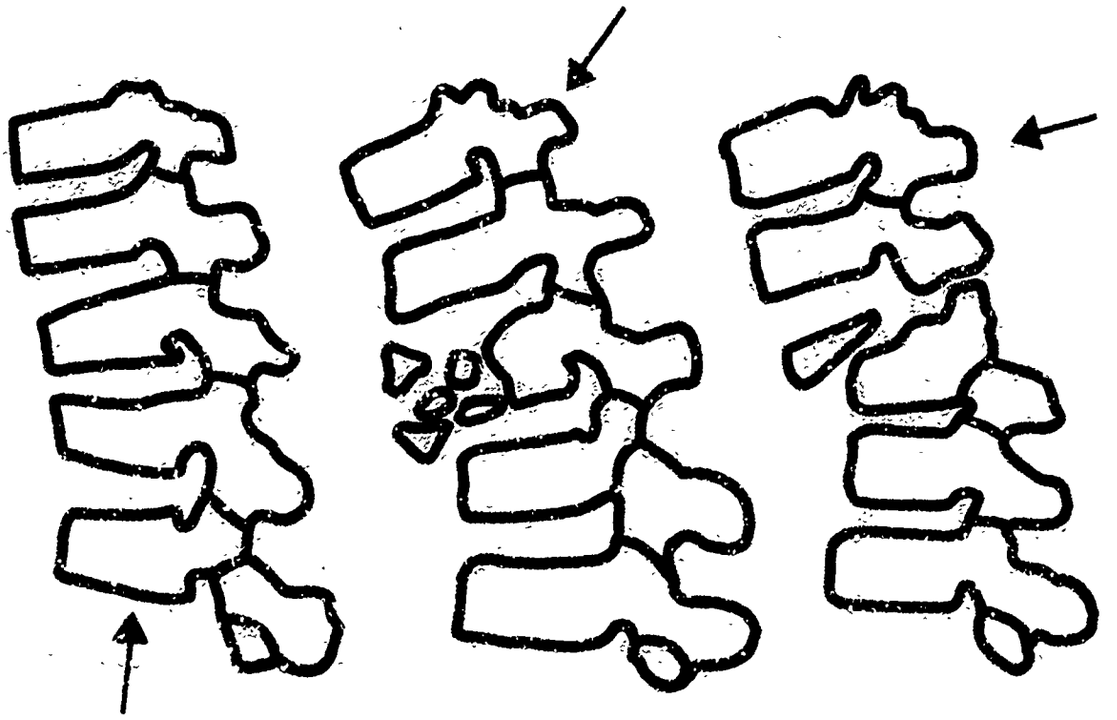


Fig.9 Mechanism of spinal fractures (after Watson-Jones)

3. STRENGTH OF VERTEBRAE

This problem has been particularly studied by Rieunau who is currently looking into the strength of a group of three vertebrae taken from nine young subjects and comprising the vertebral bodies, the soft tissues, and in particular the discs and the ligaments. The author has been particularly concerned with the force required to rupture the ligaments of the lumbo thoracic spine. X-rays (A.P., lateral and ¾, and tomograms) taken before and after compression enabled the lesions to be demonstrated. The first signs such as creakings, compression, and extravasation of blood appear at pressures of between 600 and 700 kg, while total rupture occurs at about 850 kg. The great strength of the vertebral column and its resistance to aggression can be deduced from this study.

These measurements which relate to experiments made on anatomical specimens are none the less valid, but one must also take into account the part played by the paravertebral muscle masses which do strengthen the resistance too impact. On a live subject it can be said that one vertebra can tolerate a compression of one ton.

4. ETIOPATHOGENESIS OF SPINAL FRACTURES IN AVIATION MEDICINE

These fractures can arise as a result of either crash landings (aircraft, gliders, helicopters), parachuting and ejection.

4.1 The Crash Landing

4.1.1 Military Aircraft

In military aviation thanks to development of personal escape systems (ejection seat and parachute), the crash or forced landing is not often attempted with most modern fighter aircraft.

4.1.1.1 French statistics

The appearance of vertebral fractures arising from crash landings has been reported by many authors (Watson-Jones, Grandpierre, Malmejac, etc). In France, one of the most recent and most documented works has been published in the Revue de Médecine Aéronautique (1963) by Grandpierre, Violette, Fabre, Marchesseau, Ginet and Cholin. In this report, most of the accidents occuring in the French Air Force from 1st January 1954 to 30th March 1961 have been studied. Out of 299 forced or faulty landings, 16 subjects have had one or several fractures of the spine (5.3%). Table II shows the distribution of injuries according to the type of aircraft which has been used.

Pilots of single and two-seater aircraft have sustained vertebral fractures whereas these have not been found in pilots of large transport aircraft (for instance, Nord 2501, C47) due to the greater structural strength of these aircraft and to the lower speed on impact. Grandpierre et al. note that all these fractures occur in accidents taking place away from the runway (crash on rough terrain, or aircraft leaving the runway immediately after touch-down).

4.1.1.2 Case histories

We have selected some typical histories from the work of Grandpierre.

Case No.1 – Pilot V on a Fouga comes in too short on finals. The starter orders him to open up throttle but the pilot does not react. All he does is to increase his nose-up attitude in an attempt to reach the runway. The under-carriage being out, the aircraft hits the ground in a marked nose-up attitude, bounces, touches down again this time striking the right wing. It whips round and strikes an embankment which it crosses as it disintegrates. The speed at the time of impact is 110 knots and the stopping distance 110 meters. The pilot sustains a fracture of T10.

Case No.2 – Pilot S and Pilot D on a T33. At an altitude of 200 feet and right after take off, thinking he is raising the under-carriage, the pupil stops the engine. The pilot puts the aircraft into a spiral descent to the right to avoid a village and with under-carriage down and flaps out the aircraft continues descending. Finally it stalls at a height of roughly 10 metres and on impact the starboard tank bursts, the right wing bends under impact and the aircraft tilts forward and strikes the ground violently with the nose-wheel and the under-part of the nose. After a bounce of 37 metres the aircraft falls back and skids over 45 metres. The speed on impact is 95 knots. X-rays show that one of the pilots has a fracture of L1.

Case No.3 – Pilot G on F84F. During aerobatics the right leg of the under-carriage comes out violently. Although the under-carriage is damaged, the pilot attempts to land away from the runway, with the under-carriage out. The aircraft comes into contact with the ground at an angle of about 20° nose down and after a bounce of about 100 metres, it then skids over 00 metres. The speed on impact has not been noted. The pilot sustains two fractures of T12 and L1.

Case No.4 – Pilot V on a Broussard. Owing to an engine failure the pilot has to make a crash landing in the bush in a swamp. The speed on impact is about 70 km/hr. The three members of the crew (pilot, navigator and photographer) each exhibit a fracture of L1. The deceleration has caused the seat backs to move forward.

TABLE II

Distribution of Fractures According to the Type of Aircraft after (Grandpierre et al.). The data relates only to Survivors

	Type of aircraft	*No. of accidents*	*No. of subjects showing vertebral lesions*
Propeller aircraft	T 6	73	1
	Broussard	12	3
	Sipa	2	-
	Jodel	1	-
	Marcel Dassault 315	15	-
	Marcel Dassault 312	5	-
	Marcel Dassault 311	1	-
	C 47	13	-
	Nord 2501	11	-
Jet aircraft (French construction)	Mystère 4	34	-
	SMB 2	11	-
	Fouga Magister	9	1
	Vautour	5	1
Jet aircraft (American construction)	T 33	12	5
	F 86 K	5	-
	F 84 G	20	2
	F 84 F	25	2
Other jet aircraft	Meteor	2	-
	Mistral-Vampire	47	1

Case No.5 - Pilot S on a T6. In the course of a low level turn there is an engine failure and the aircraft loses altitude and stalls when it is about 3 metres from the top of a rocky cliff. During the impact the aircraft loses its wings and its under-carriage, bounces about 10 metres and turns over on its left side. The speed on impact is about 80 knots. The pilot sustains a fracture of the antero-superior angle of L1.

4.1.1.3 Location of crash fractures

Table III gives the different locations for fractures according to the paper by Grandpierre and his colleagues. It represents a total of 24 fractures sustained by 16 pilots or other aircrew.

It will be seen that the fractures occur mostly at the level of T10 to L2 (eighteen times out of twenty-four). Over the past 20 years many reports have stressed the frequency with which fractures occur at the level of the dorsolumbar hinge (Fig. 11). This however is not an observation related specifically to crash landings since it is found in all injury statistics published in the last few years. The fractures in fact may involve T2, T3, T6 or T7. In one unusual accident the atlas (or first cervical vertebra) was fractured at the level of its anterior arch with a sublaxation of the atlanto-axial joint. Multiple locations are not unusual, occuring in fact 8 times out of 16 in Grandpierre's data and usually involving two vertebrae whose immediate neighbours show some slight impairment too.

TABLE III

Distribution of 24 Fractures Arising from Accidents

Vertebrae affected	*Number of fractures*
C1	1
T4	1
T6	1
T7	1
T10	2
T11	1
T12	1
L1	10
L2	4
L3	2

TABLE IV

(After Grandpierre et al.) Distribution of Multiple Lesions

Vertebrae affected	*Number of subjects*
T4 - L2 - L3	1
T6 - T7	1
T10 - T11	1
T12 - L1	1
L1 - L2	2
L2 - L3	1

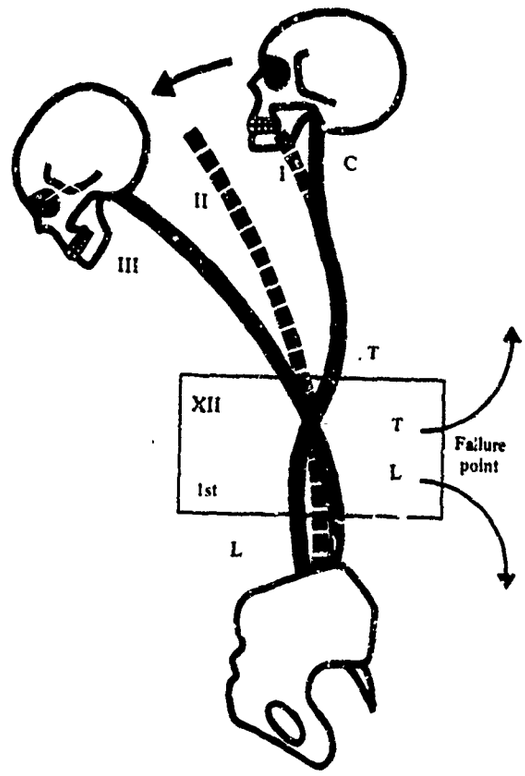


Fig. 10 Diagram showing straightening of lumbar curve during a forward flexion of the spine and the "hinge point" (after E. Forgue)

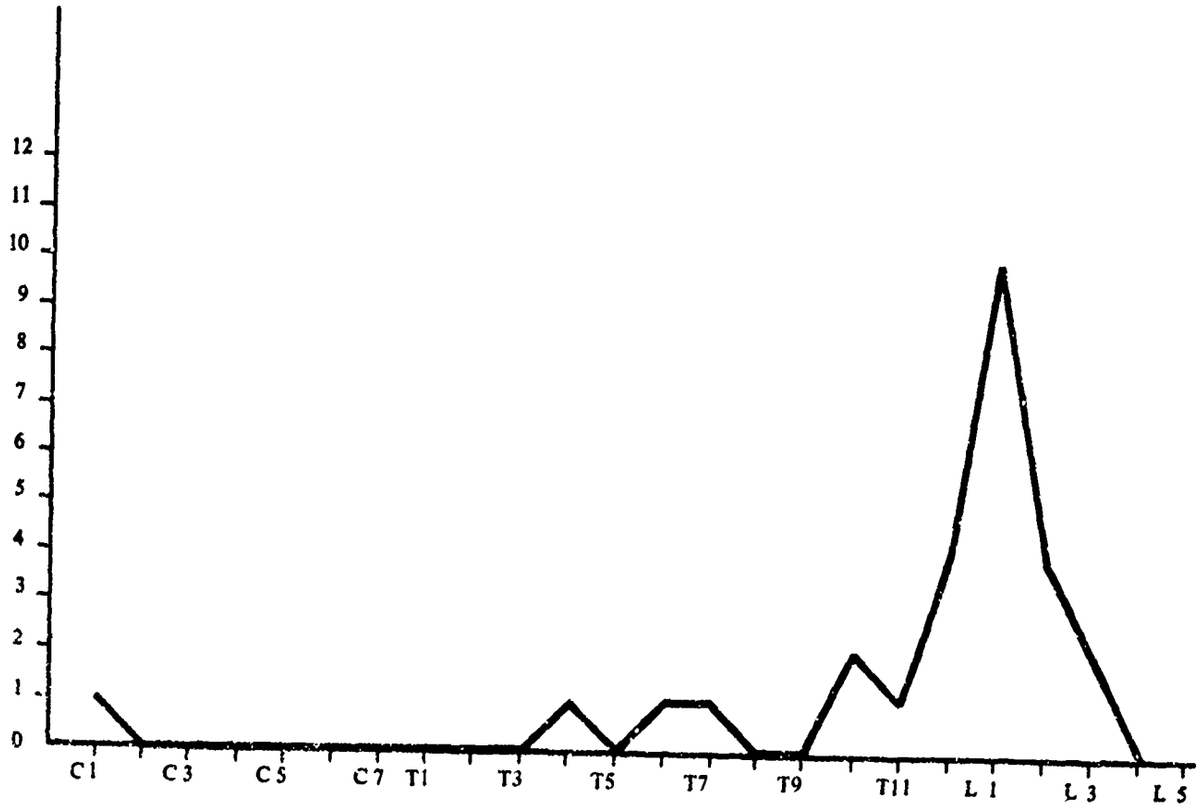


Fig. 11 Distribution of fractures in aircraft crashes

4.1.1.4 Pathogenicity of crash fractures

Watson-Jones in Great Britain was the first person to demonstrate that there was a relationship between the causal mechanism and the injuries, by making use of the data from 1,058 spinal fractures mostly amongst RAF personnel during the second World War. The fractures were considered to be associated with spinal flexion, the actual degree of which was associated with the position of the seat harness.

When a crash is imminent the pilot tightens his harness, rests his feet on the rudder bar and braces his back against the seat back rest. In the seated position this produces straightening of the lumbar curvature of the spine but the thoracic kyphosis is hardly altered at all.

We have been able to confirm these facts by radiography of the seated subject (Delahaye, Auffret, Mangin, and Seris, 1961). At the instant of the crash there occurs a violent deceleration which gives rise to a hyperflexion of the trunk which may occur at the hinging point between T12 to L1 or higher (T2 to T7) according to the position and tension in the seat harness. The type of fracture sustained in a crash is therefore consistent with the mechanisms described by Watson-Jones. Thus, one can draw attention to the fractures with comminution of an anterior corner (Mechanism 2). In fact these fractures can, in cases of hyperflexion (as, for example, with poor harness restraint) give rise to tearing of the inter-spinal ligaments and to fractures of the articular processes.

In the crash landing of aircraft damaged by warfare, multiple fractures are frequently encountered, the number of fractured vertebrae varying from two to ten. Indeed, Watson-Jones reported a case of one RAF pilot who sustained ten fractures of thoracic and lumbar vertebrae as a result of a crash landing. Isolated fractures of the articular processes and of the isthmus are not usually encountered as a result of crash landings, however when they do exist, they are almost always associated with fractures of the vertebral body.

Cervical fractures which are so frequently encountered in motor car accidents, occur in aircraft crashes only in special circumstances, e.g. rolling or tumbling after hitting the ground, or with a direct blow to the cervical spine or to the head. A typical accident giving rise to a cervical injury has been described by Grandpierre et al. as follows.

When his engine failed, the pilot of a Mistral had to make a forced landing with under-carriage retracted, into a wheat field. The entire front part of the aircraft disintegrated after a skid of 500 metres and the pilot sustained a fracture of the anterior arch of the atlas with a sublaxation of the atlanto axial joint.

A blow on the top of the head and transmitted down the axis of the spine to the vertebrae through the occipital condyles, tends to rupture the annulus of the atlas. If the pilot is thrown onto the forward part of the instrument panel (insufficient seat restraint) the hyperextension can give rise to fractures at the level of the odontoid process of the lower cervical vertebrae. In all these cases the skull injury is the predominant feature but a careful radiological examination has to be carried out on the entire vertebral axis. In practice such lesions of the cervical cord in aircraft accidents are rare.

4.1.2 Accidents to Gliders and to Light Private Aircraft

In regard to accidents involving light aircraft (forced landing in the countryside under difficult conditions) we were able in the four cases examined, to detect fractures of the spine at the level of T12 and of L1. Recently at Dominique-Larrey Hospital, we have seen a student pilot who had been involved in a glider accident (high tension cable strike followed by stall). He has fractures of L3, L4 and L5. The posterior walls of L3, L4 are affected and tomography reveals multiple signs involving the posterior arches of L3 and L4.

4.1.3 Commercial Aircraft

In the absence of personal escape systems, a forced landing is the only way out of an emergency situation. The accelerations involved can vary in amplitude and direction according to the type of terrain and according to the aircraft. Where high accelerations are involved, failure of the bolts holding the seats to the floor can result in a piling up of passengers still strapped in their seats, into the forward part of the aircraft. In these multiple injuries, spinal fractures which are usually lumbo thoracic, may be encountered.

4.1.4 Helicopter Crash

4.1.4.1 Different types of landing

Helicopter accidents can be considered under two headings according to whether or not there is loss of control, e.g. whether the main rotor and tail rotor are continuing to turn or not.

Emergency Landing with Auto-rotation

In this case the pilot retains a certain amount of control of the aircraft which he lands at a low forward speed and at a variable vertical velocity. This latter can vary from that of normal landing to the destructive impact produced by free fall. The force here is essentially in the vertical axis and any spinal fracture which occurs will be at the level of T11, T12, L1 or L2.

Crash Landing due to Loss of Control

With the loss of one or more blades of the main rotor and failure of the tail rotor, the helicopter may go into a spin and hit the ground at any angle of incidence. Accelerations increase in all axes and multiple injuries without any particular pattern are encountered.

4.1.4.2 Case histories - (light aircraft-Army and Air Force)

We shall describe some typical case histories.

Case No.1 - Pilot P on Alouette 2. Crash as a result of a down draught during an operational flight in difficult country (mountainous and wooded). The aircraft hits some trees and violently goes over onto its back. The pilot has an anterior cuneiform compression fracture of L1.

Case No.2 - Pilot C on Alouette 2. The loss of a tail rotor blade brings about an immediate tearing out of the tail rotor housing. The aircraft crashes onto flat ground from a height of 700 metres in auto-rotation but with the engine still switched on. The final phase takes place into wind with the aircraft falling flat from a height of 1 to 1½ metres; an error which was due to the fact that high corn misled the pilot into judgement of height above ground. On X-ray he was subsequently found to have sustained anterior cuneiform compression fractures of T10 and T11.

Case No.3 - Pilot F on Alouette 2. During cruising flight the transmission shaft to the tail rotor failed, giving rise to loss of the antitorque system. A crash landing in a spin with the engine still switched on, took place on particularly difficult mountainous terrain. The pilot sustained fractures of L2 and L3 and shortly afterwards exhibited a flaccid injury paraplegia.

Case No.4 - Pilot J on Bell 47 G2. During a test flight after servicing of the tail rotor system, the aircraft engine failed. The pilot did not react well, and the measures he took resulted in a reduction of revs in the main rotor. He belatedly put the aircraft in auto-rotation. X-rays showed an anterior cuneiform compression fracture of L3 (lateral view) whilst an AP plate demonstrated some right lateral compression.

Case No.5 - Pilot F on Bell 47 G2. During an attempted landing on a mountainous DZ at 2,115 metres, the helicopter came into violent contact with some rocks. The harness restraint system was cut through on impact and the pilot sustained two fractures (T3 and T4).

4.1.4.3 Location of fractures (Fig.12)

Spinal fractures are not often found in helicopter crashes, and of 113 helicopter accidents recorded in the French Air Force from 1961 to 1968 inclusive, 9 pilots were found to have a total of ten fractures (8.8%).

In Army light aircraft, in an unspecified number of accidents, 8 fractures were discovered by radiographic examination. Furthermore, Fabre records 8 fractures occurring before 1961 in Army Helicopter accidents.

Table V shows the distribution of fractures according to the vertebrae involved. It will be seen that fractures occur most frequently in the region of T10 to L2 but that the number of fractures involving L3, L4 and L5 is greater than in crashes of fixed-wing aircraft. Changes in the nervous system as a result of the involvement of the posterior wall (paraplegia cauda equina syndrome) were observed in 3 cases. As will be seen in Table VI, fractures involving several vertebrae are less frequent and are not typical of helicopter crashes.

4.1.4.4 Pathogenesis of fractures in helicopter accidents

G.Fabre who has extensively studied this problem, noted in 1963 that the almost exclusive injury to the dorso-lumber hinge was significant, in that it showed that the spine of helicopter pilots who were restrained by a seat harness, behaved as though the individual were not wearing a harness. Thus, with a sharp deceleration the vertebral column gave way at the level of its natural pivot - in other words at the dorsolumbar hinge. These fractures which ranged from T10 to L2 were particularly observed in crashes during auto-rotation at a variety of speeds.

In crashes with loss of control, the injuries may range from the level of T10 to L2. By a mechanism which has already been described, in a crash landing the deceleration can sometimes give rise to a hyperflexion at the mid-thoracic level, e.g. T5 to T8. The impact may be by the individual being directly thrown onto obstacles as in the fractures of T3, T4 of the pilot in case No.5 above. The fractures in the lower lumbar region - L3 to L5 are due to a vertical compression without the shock absorbing of the lower limbs, as for example may occur in parachuting where an individual lands on his buttocks.

4.2 Parachuting

4.2.1 Generalities

The parachute originally used as a means of saving aviators and balloonists was employed after 1935 in a new technique for infiltration behind enemy lines, and in the last War (1939-45) and in other conflicts (Indo China or Algeria) airborne and commando parachute troops played a most important role. The need to reduce to a minimum the occurrence of immobilising injuries has therefore resulted in the development of new techniques, particularly in regard to landing. In this chapter we shall be considering the jumps with automatic deployment of parachute which are most frequently made use of by the military.

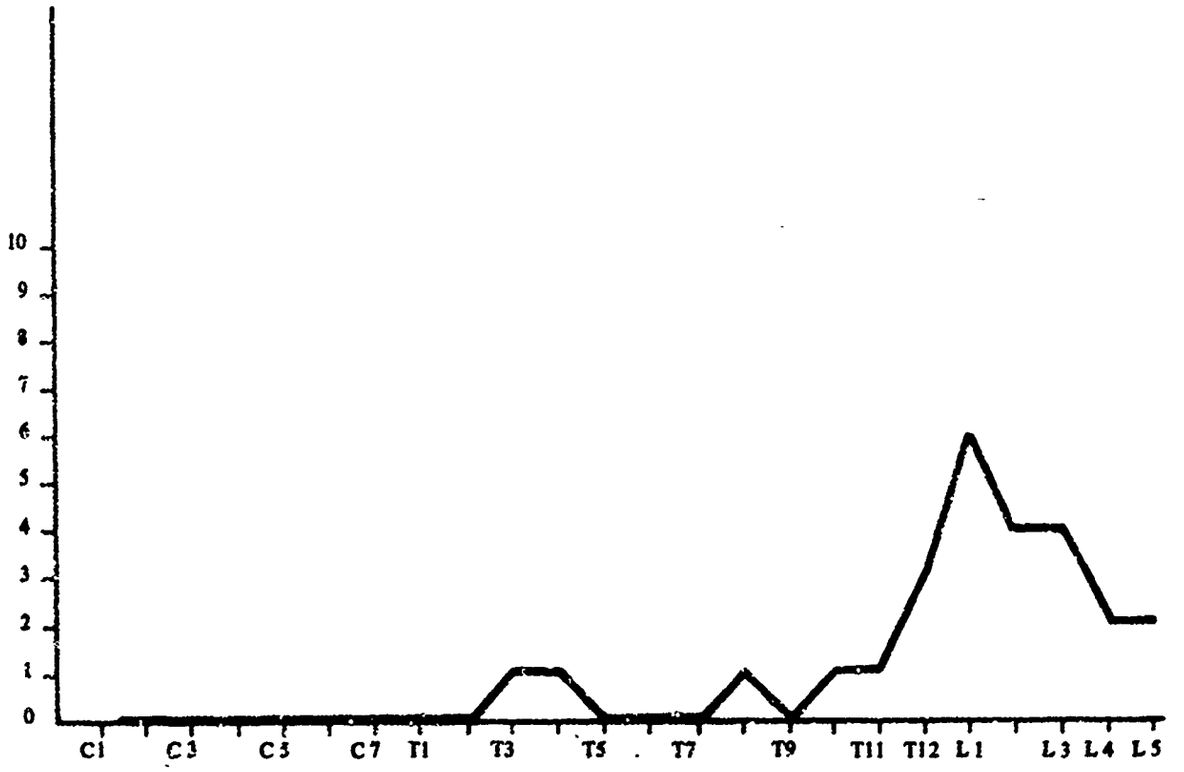


Fig. 12 Distribution of fractures in helicopter crashes

TABLE V

Fractures of the Spine after Helicopter Crash (French Statistics)

	Number of fractures observed			
	Air Force		*Army light aviation*	*Total*
	Before 1961	*1961-1966 inclusive*		
T3	–	–	1	2
T4	–	–	1	1
T8	1	–	–	1
T10	–	–	1	1
T11	–	–	1	1
T12	2	1	–	3
L1	4	1	1	6
L2	–	3	1	4
L3	1	1	2	4
L4	–	2	–	2
L5	–	2	–	2
Total	8	10	8	26

TABLE VI

Multiple Injuries in Helicopter Crashes

Vertebrae affected	*Number of pilots*
T3 - T4	1
T10 - T11	1
L1 - L3	1
L1 - L4	1

4.2.2 Parachuting - French Technique

4.2.2.1 The equipment of the military parachutist

The military parachutists' equipment comprises clothing weighing 7½ kilograms made up of a particularly light-weight combat suit, a steel helmet with chin strap and a pair of parachuting boots. The two parachutes weigh together 17 kilograms. They consist of first the back parachute (Type TAP 600) with automatic opening, and secondly the ventral emergency parachute (Type TAP 660) with manual opening. Impedimenta weighing between 25 and 40 kilograms (rations, armament, warm clothing) are carried on operations or on manoeuvres. The parachutist of 75 kilograms completely equipped therefore weighs some 125 to 140 kilograms.

4.2.2.2 The French back parachute

The French back parachute is composed of a nylon canopy 60 square metres surface, with a vent for the escape of air; a harness terminating in four lift webs and twenty-four shroud lines which join the lift webs to the canopy.

The complete parachute (except the harness) is folded into a bag or sack which is closed by three fine cords which break under a pull of 25 kilograms. The canopy is strengthened at the level of the vent by a cord which breaks under a pull of 15 kilograms on the static line 4.8 metres long and with a breaking strain of 1,500 kilograms (Fig. 13). The static line folded at the top of the pack, ends in a snap hook which is fixed to a cable in the aircraft shortly before the jump.

The harness is made up of three straps 5 cm wide; one bottom strap and two crutch straps (Fig. 14). The subject is almost always seated on the bottom strap (in the shape of a "U") which goes from one side of the body to the other and then forward to the shoulders. Each end of it is linked to the lift webs - two on the right and two on the left of the parachute, and on these the opening shock is uniformly transmitted to the shroud lines. The two crutch straps furthermore leave the bottom strap between the thighs and by an intricate course, complete the closure of the harness in front. This harness is basically the same as that specified by J. Reyne in 1925 with the object of spreading the shock load on opening over the greatest possible area of the body; applying the load to those parts of the body best able to tolerate it, that is those parts protected by the large muscle masses; keeping the shock points away from the more delicate organs, and lastly supporting the body in such a position that at the time of landing it is in as good a position as possible.

4.2.2.3 Leaving the aircraft and the jump

Shortly before the jump the speed of the aircraft is reduced to approximately 180 kms/hr and at an altitude of 400 metres (160 metres for operational jumps) the leader makes a final check of the equipment. The exit is made through a side door and on rare occasions through the aft end of the aircraft. At a signal from the klaxon the parachutist jumps out as far as possible from the aircraft and at right angles to the line of flight. At this precise moment he brings his legs together, feet forward, and with both hands folded on the ventral parachute (Fig. 15).

During free fall the static line uncoils, tightens and breaks the strings closing the pack, pulls out the canopy and finally breaks the air vent cord. The freed parachute fills with air and the automatic opening line remains fixed to the cable on the aircraft. About three seconds elapse between the start of extraction of the canopy and its complete deployment, during which time the body describes a parabola, travels about 50 metres, and slows down from 200 kms/hr to 30 kms/hr approximately. A good exit ensures a good position on opening of the canopy and therefore reduces the danger of injury.

4.2.2.4 The opening shock of the parachute

The position of the body at the time of canopy deployment resembles that of a foetus in the uterus. The back is rounded and the head is bent forward with the chin on the chest. The arms are folded across the body touching the thorax. The legs are held close together, slightly forward, so as to form an acute angle with the rest of the body and all the muscles are contracted to the utmost, especially those of the back of the neck and of the abdomen. The opening shock of the parachute has been considerably reduced with the current use of a technique of folding the shroud lines first so as to give a slower opening and deployment to the canopy. It has been reckoned that a body weighing 75 kilograms will in the harness straps weigh 375 kilograms in canopy first deployment and 225 kilograms in rigging lines first deployment.

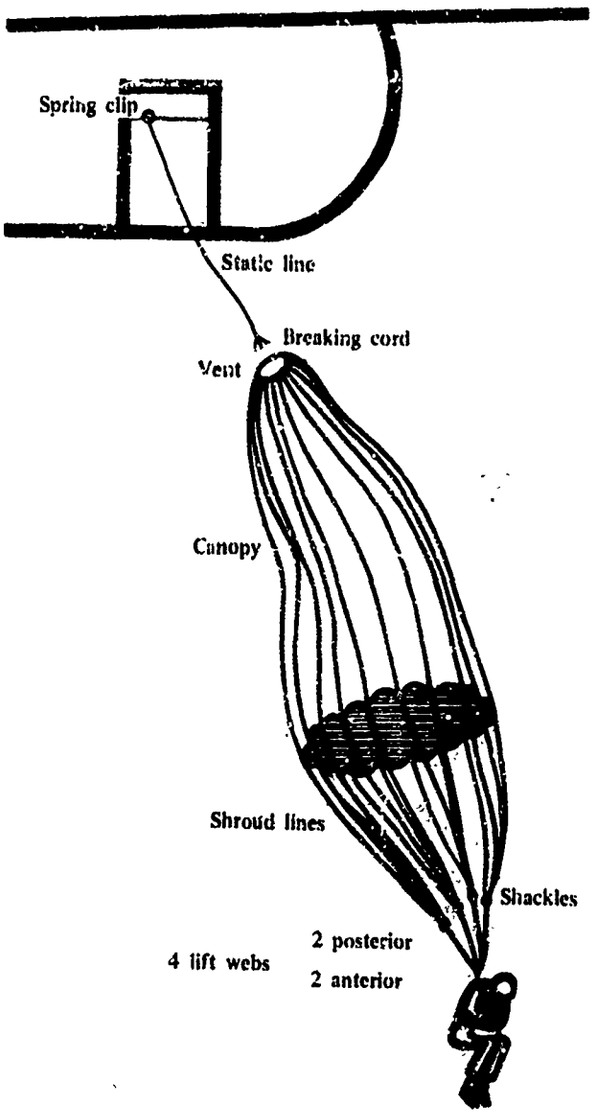


Fig. 13 Opening and freeing of parachute

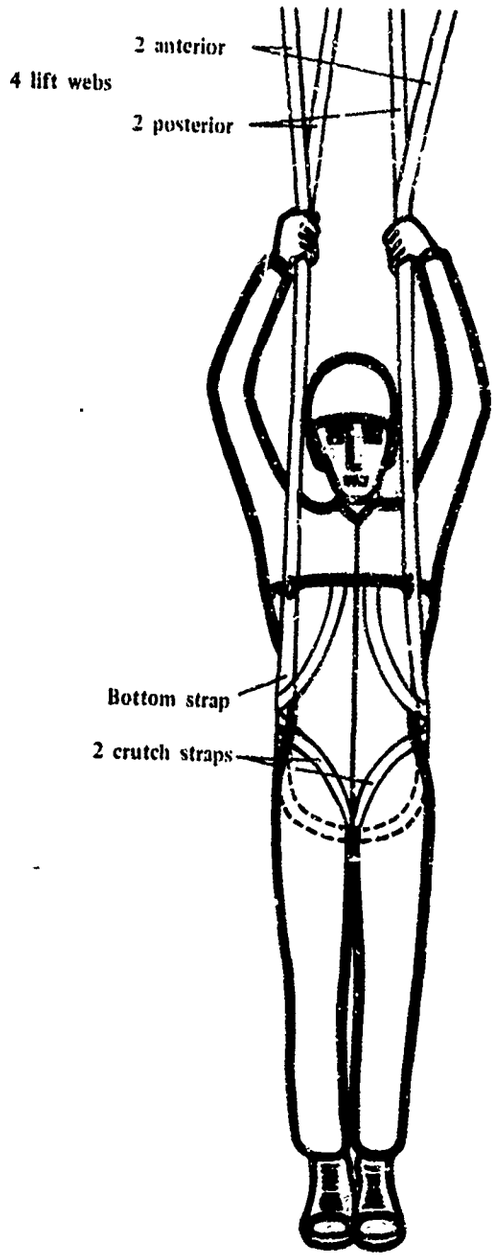


Fig. 14 Harness straps of a French parachute (diagrammatic)

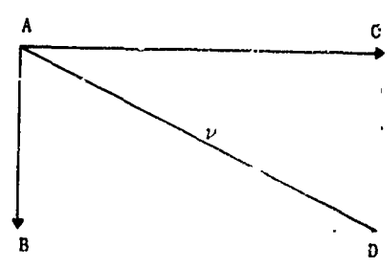
Fig. 15 Attitude of a parachutist on opening

The opening shock is always applied principally onto the bottom strap in a frontal plane passing roughly through the cervical thoracic hinge point.

4.2.2.5 The descent

The falling speed of a parachutist A is represented by a vector, AD which is, according to the parallelogram of forces, the resultant of two vectors acting at right angles to one another, namely, AC (the wind speed - variable) and AB (the velocity of the fall in nil wind - approximately constant for a given subject and for a given canopy).

It is in fact the terminal velocity of descent for a given mass supported by the parachute, and its value is of the order of 5 metres per second for a man of 75 kilograms using a French 60 square metre parachute.



$$AB = \frac{P}{KS}$$

P = subjects weight

S = surface of the canopy

K = lift coefficient.

The variation in $\vec{AB}$ are small, and depend on:

- canopy porosity (varies with texture and use),
- air humidity and temperature.

4.2.2.6 Landing

The landing impact can be calculated by the relationship:

$$F = \frac{1}{2}mV^2$$

hence

$$V^2 = \vec{AD}^2 = \vec{AB}^2 + \vec{AC}^2$$

$$m = \frac{P}{g}$$

$$\vec{AB} = \frac{P}{kS}$$

therefore

$$F = \frac{1}{2} \times \frac{P}{\mu g\, kS} (P + AC^2)$$

where g, k, S are constants.

For a given parachute, the landing impact F is proportional to the square of the windspeed AC and to the square of the weight P of the subject. Thus, a parachutist of 75 kilograms is subjected on landing to an impact of the order of 95 kilograms for low velocity surface wind, 190 kilograms for a surface wind of 5 metres per second, 290 kilograms for a surface wind of 7 metres per second, and 475 kilograms for a surface wind of 10 metres per second.

The physiological safety coefficient established by Blériot (1905) is 5 times the parachutist's body weight. A jump will therefore be forbidden when the surface wind velocity exceeds 9 metres per second. These values for the impact force and landing apply only for the case of the parachutist who descends without manoeuvring, for by correct traction on the two up-wind lift webs it is possible to lower the corresponding half canopy and reduce the swing amplitude as well as reduce the value of AC (representing the surface wind velocity) by 2 to 3 metres per second. On the other hand if one makes use of the wrong lift webs the value of vector AC can be increased by the same amount. This is where the usefulness of theoretical instruction in the judgement of wind direction during descent comes in.

It is somewhat difficult to adopt and to maintain the correct position of the body for landing as one approaches the ground. Forming a large part of the theoretical training, it calls for a symmetry of the body with respect to the sagittal plane in order to spread the shock wave uniformally onto the lower limbs. These latter must be kept tightly together and remain so with the soles of the feet placed at the same height and parallel to the ground (Fig. 16). In addition to this, the legs must be kept slightly bent with the muscles partly contracted so as to form a levered shock absorber around the axes represented by the joints of the ankles, the hips and the knees. The position of the rest of the body, is similar to that adopted by the parachutist on canopy opening, that is with the muscles contracted maximally. The landing of impact shock is thus located in a frontal plane which passes approximately through the ankles and the hips.

To maintain a good landing position requires considerable self-control for as the ground rises, there is a natural tendency to avoid it either by bringing up the feet under the bottom or by going out to meet the ground by completely extending the legs. In both instances the lower limbs cannot play the part of shock absorbers required of them and the spine is going to receive most of the shock on landing. The landing theoretically ends in a classical tumbling. In practice and according to body position with reference to the wind direction, one or other of the buttocks comes into contact with the ground as close as possible to the heels after which the parachutist rolls onto his back. He must then collapse the canopy - a task which is not easy in a strong wind - so as to avoid being dr[illegible] this is a cause of some of the injuries brought about by colliding with rough ground, trees or build[illegible].

4.2.3 Statistics of Spinal Injuries

In the course of 1,033,525 jumps carried out at the School for Airborne Troops at Pau from 1959 to 1966 inclusive, the following have been found: 1,962 fractures (i.e. 1.9 per 1,000 jumps) principally affecting the lower limbs; 947 injuries to the spine including 155 fractures.

Fig. 16 Attitude of parachutist for landing

These 156 fractures of the vertebral column represent:

1.35% of the total number of accidents;

7.8% of the total number of fractures;

16.7% of all spinal injuries noted.

A close examination of these statistics (Table VII) show that the number of spinal fractures related to the number of jumps made diminishes every year (2.7 per 1,000 jumps in 1959 and 0.5 per 1,000 jumps in 1962). This is due to the selection standards for airborne troops being progressively more rigidly applied, e.g. limitation of weight to 80 kilograms, elimination of all candidates showing spinal anomalies etc. Consistency of the other annual percentages leads one to conclude that the ground training and the French jumping technique are now well established.

A simple analysis of the different vertebrae fractured is most instructive (Fig. 18) even without taking account of the number of associated accidents. Thus in the course of 1,188,155 jumps it has been found that 159 spinal fractures have involved a total of 199 vertebrae. These multiple locations are detailed in Table VIII. In two cases two parachutists who had landed under particularly bad conditions showed an involvement of 7 vertebrae. In Table IX there can be seen the number of occasions on which the different vertebrae were involved; it is quite clear that the most involved spinal segment lies between the twelth thoracic and the third lumbar vertebrae which were injured 149 times - in other words, in 76% of cases. Injuries above and below this level are not unusual but cervical involvement is rare. Fractures involving the posterior wall described by Rieunau were observed less than once per 100,000 jumps.

TABLE VII

Occurrence of Spinal Fractures in 1,033,525 Jumps

Statistics from Pau		*A*		*B*						*Total*
Year		1959	1960	1961	1962	1963	1964	1965	1966	1959 to 1966
Number of jumps made		110 000	120 000	130 618	132 713	134 939	139 925	129 336	135 994	1 033 525
Total accidents recorded		1 435	1 836	1 413	1 508	1 291	1 444	1 359	1 247	11 533
Total fractures observed		232	245	249	253	231	237	254	261	1 962
Total spinal accidents recorded		103	171	127	124	102	130	102	98	957
Spinal fractures	Total number	30	20	33	28	19	7	11	7	155
	Number/10 000 jumps	2.7	1.6	2.3	2.1	1.4	0.5	0.84	0.51	1.5
	% related to number of accidents	2.05%	1.1%	2.3%	1.85%	1.5%	0.5%	0.2%	0.55%	1.35%
	% related to total fractures	13%	8.16%	13.2%	11.2%	8.26%	2.9%	4.3%	2.7%	7.9%
	% related to number of spinal accidents	29.2%	11.7%	26%	22.6%	18.7%	5.4%	10.8%	7.2%	16.7%

TABLE VIII

Multiple fractures - vertebrae involved	*Number of occasions*
T1 + T12	1
T6 + T7	1
T8 + T9	2
T11 + T12	1
T12 + L1	7
T11 + T12 + L1	3
T11 + T12 + L1 + L2 + L3	1
T11 + T12 + L1 + L2 + L3 + L4 + L5	2
T12 + L1 + L2	1
L1 + L2	1
L1 + L4	1
L1 + L2 + L3	3
L5 + S1	1
L3 + L4	4

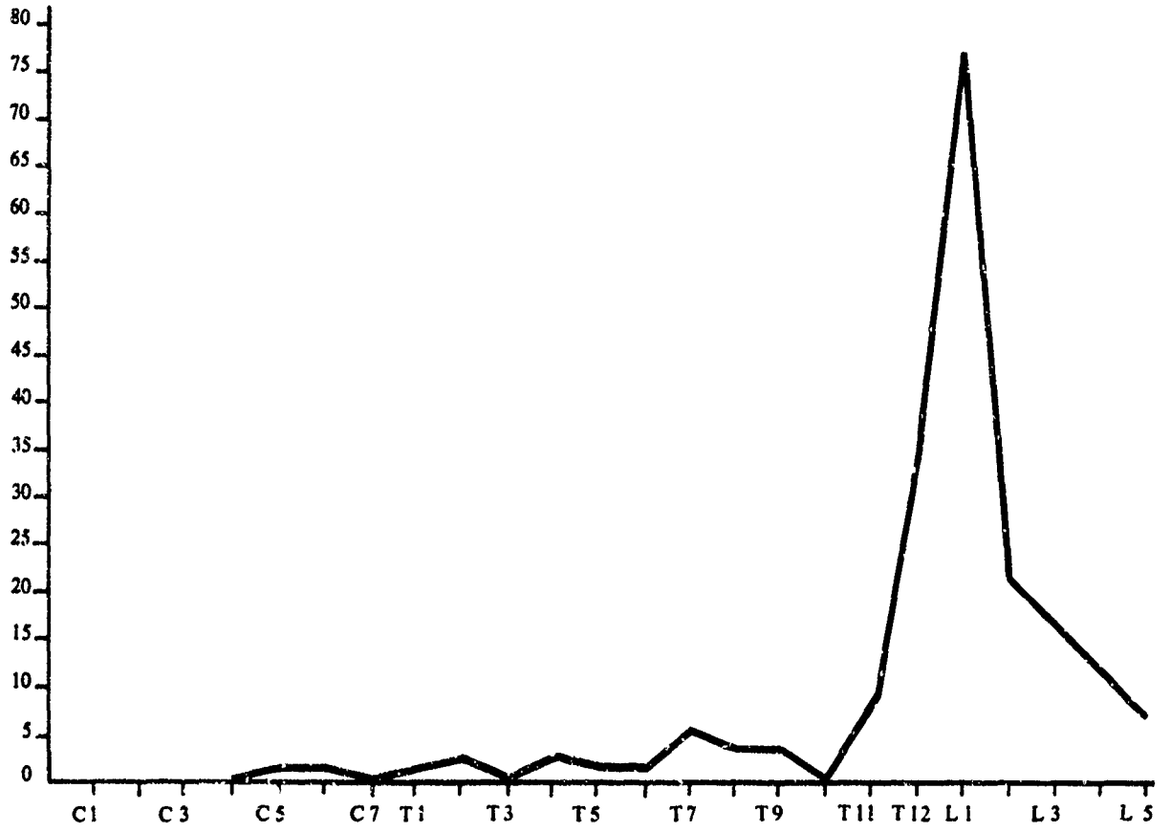


Fig. 18 Distribution of fractures in parachuting

TABLE IX

Distribution of 195 Fractures Observed in 1,188,155 Jumps by Airborne Troops

Vertebrae affected	*Number of fractures observed*
C5	1
C6	1
C7	-
T1	1
T2	2
T3	-
T4	2
T5	1
T6	1
T7	5
T8	3
T9	3
T10	-
T11	8
T12	35
L1	77
L2	21
L3	16
L4	11
L5	6
S1	1

4.2.4 *Pathogenesis of Spinal Lesions*

Since the work of Greifer (1939) all authors agree that 90% of the accidents due to parachuting occur on landing.

4.2.4.1 *Opening shock and landing impact*

In order to determine the nature of the spinal curvatures of a fully equipped parachutist at the time of opening the parachute and at the time of landing, G.M.Teyssandier and R.F.Delahaye have carried out a radiographic examination of subjects in various parachuting attitudes under the supervision of an Airborne Troops Instructor. It was not possible to obtain satisfactory AP views because of the density of the equipment and parachutes, but from the lateral views it was possible to obtain the tracings shown in Figure 19. For a French parachute (Type AP 600) the canopy opening shock (shroud lines first) can be represented by a vector acting from below upwards, whose origin is at the bottom web strap and whose value is of the order of 225 kilograms for a 75 kilogram subject. This vector is in a frontal plane which passes through the extremity of the coccyx then runs through the lumbo sacral hinge which crosses the spine round about the cervical thoracic hinge. This may explain the fact that certain cervical column injuries have been less frequently encountered since abandoning the system of folding the parachute for opening (canopy first).

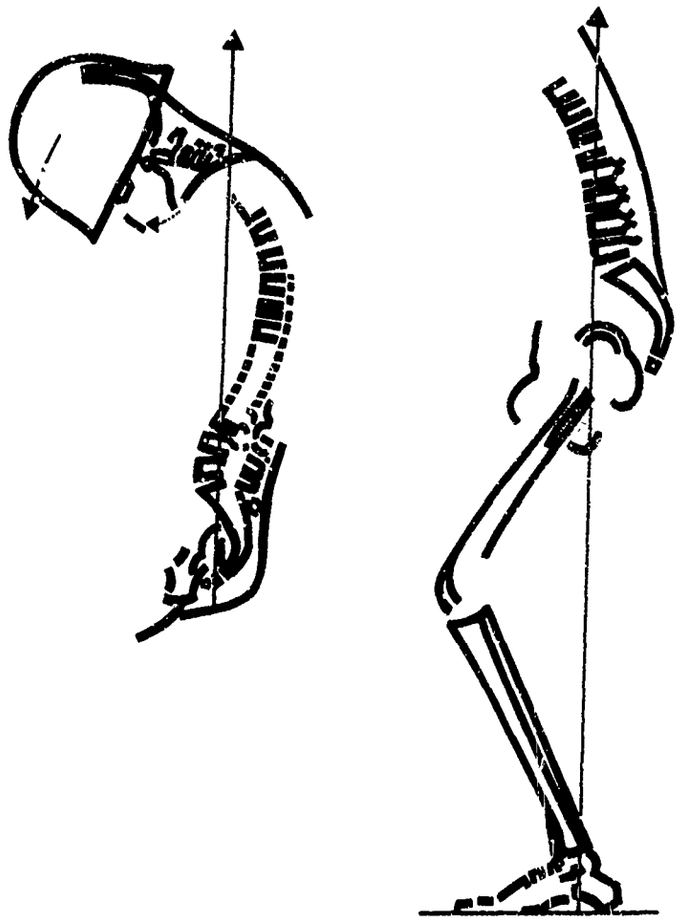


Fig. 19 Radiograph tracings of the parachutist's spine on deployment (left) and on landing (right)

The landing shock can be represented by a vector (Fig. 19) acting from below upwards, whose origin is at ground level and whose magnitude varies, for a given parachutist, with the square of the horizontal wind speed. This vector is in a frontal plane which passes through the ankles and the hips, runs through the vertebral bodies of T12 to L3 and crosses the posterior wall of the spine at the level of the lumbo thoracic hinge. These observations confirm the statistical data, namely, that the most vulnerable spinal segment lies indeed between T12 and L3.

4.2.4.2 *Mechanism*

The association of spinal hyperflexion with pressure on the vertebrae acting from below upwards, is the commonist mechanism responsible for the fractures of varying types, and for the disc and ligament injuries which usually occur at the level of T10 to L2.

The cervical column can be damaged by a similar mechanism in which the lever axis is situated about the cervical thoracic hinge. The injuries associated with flexion can occur either at opening of the canopy if the chin has not been pressed close to the sternum (this is unusual since the mental tension results in an intense muscular contraction) or again on opening of the canopy where over-confident qualified parachutists may insufficiently contract their neck muscles.

Spinal hyperextension

Spinal hyperextension can give rise to cervical injuries either on canopy opening or on landing if the neck muscles are not sufficiently contracted, but then the shock wave may sharply throw the head backwards. This results in fractures of the spinal processes, in disc or ligament injuries, or in rupture of the anterior anastomotic network of the medullary arteries. This usually gives rise to serious involvement of the central nervous system.

Direct impact to the spine

As he rolls after landing, if the parachutist strikes a stone or branch or any ground protuberance the impact can give rise to an unspecifiable variety of injuries; he could furthermore sustain a fracture of the first cervical vertebra from a "rabbit" punch caused by the posterior edge of his helmet. Injuries of this type however are most unusual. On the other hand at the instant of the opening of the canopy the metal buckles which unite the lift webs and the shroud lines, often strike the spine or the helmet with great force. The risk of such accidents has markedly diminished with the use of the parachute folding system "shroud lines first".

Finally one must refer to the observations of Haan according to whom as a result of a bad landing in England, the skull, acting like a hammer, caused the first cervical vertebra to burst. Death occurred 15 minutes later.

4.3 Ejection of Military Pilots from Jet Aircraft

4.3.1 Introduction and Definition

When the speed of an aircraft exceeds 300 kilometres/hr it becomes extremely difficult for the pilot to escape, and from 500 to 600 kilometres/hr this is practically impossible without serious risk such as collision with the rear parts of the aircraft. Ejections by means of an explosively propelled seat is then the only means of ensuring the pilot's escape from the cockpit.

4.3.2 The Principles of the Ejection Seat

In order to avoid collision of the seat and its occupant with the rear part of the aircraft, it is necessary to impart to these a speed which is in excess of that of the aircraft, by an amount determined by the height of the tail assembly and in particular the tail fin. At the moment of separation the speed of the seat must be at least 17 to 18 metres/sec. In order to obtain the acceleration necessary to give the seat its required velocity in the very short time available, the system makes use of the pressure of combustion gases from one or more cartridges. The combustion takes place in a gun, part of which is attached to the aircraft, the second part being ejected along with the seat. The accelerations reached are 20 - 21 g for 80 - 100 milliseconds with a simple gun, and 16 - 18 g for 180 - 200 milliseconds if a telescopic gun is used.

4.3.3 Types of Seats

Two types of seat can be considered according to the level of acceleration imparted and to the method of firing the gun.

4.3.3.1 The level of acceleration

Simple Gun - During the thrust imparted by the cartridge the seat travels a distance of 1 metre, the duration of the impulse being 80 - 100 milliseconds and the acceleration reaching 20 - 21 g. The speed at the moment of separation from the canon is 18 metres/sec approximately. The principal seats of this type are the Sud Aviation E86, E93 and E95.

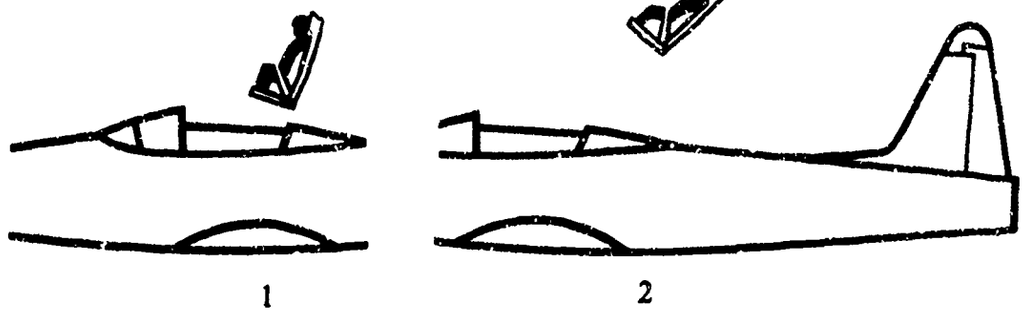
Telescopic Gun Seat - The duration of the impulse in this instance is 180 - 200 milliseconds and acceleration being from 16 - 18 g. The velocity of the seat at the end of its course and after a lesser acceleration is higher (25 metres per second for the MK4). The principal seats of this type are Sud Aviation E96, E97, Martin-Baker MK4 or AM4, RAC, North American, Martin-Baker AM6. Figure 21 gives the acceleration curve against time for a standard MK4 and for the AM6 rocket seat.

4.3.3.2 Methods of firing the seat

The two methods of firing the seat are either by means of a face-blind or by means of a low firing handle.

Seats with Face-Blind - The seat can be fired by pulling on a face-blind of either strong canvas or in some seats, of leather. The pilot must therefore put his head against the headrest obtaining thereby a position which is good for the vertebral column, in that it keeps it straight, while the face-blind protects the face and the pilot's oxygen mask from the relative wind velocity. Part of the weight of the chest is taken by the face-blind handle through the hand. The seats that fall into this category are Sud Aviation E92 - E95; Martin-Baker, all types; North American.

Different phases of ejection



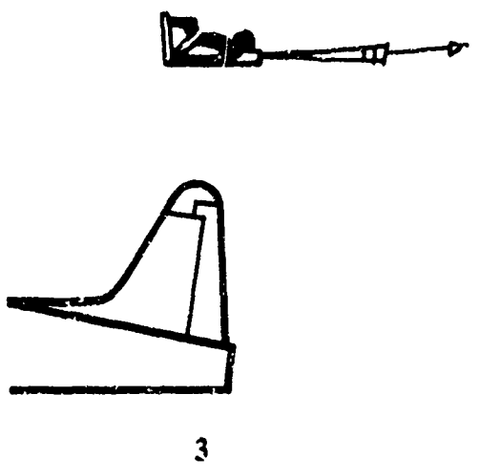
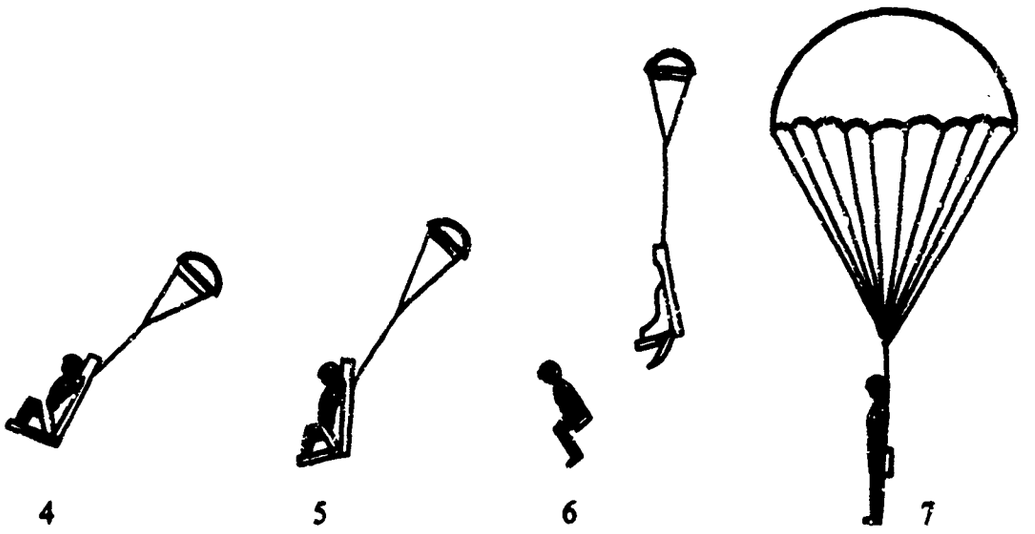


Fig. 20 Phases of escape by ejection seat

1. Seat leaves
2. Seat rises
3. Seat goes over tail assembly
4. Automatic opening of seat parachute
5. Automatic release of seat harness
6. Separation
7. Automatic opening of pilot's parachute



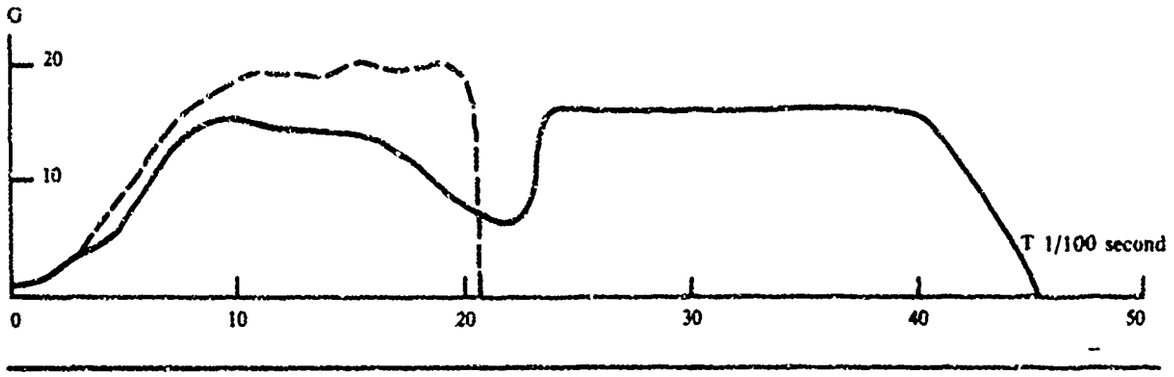


Fig. 21 Accelerations as a function of time. Ejection by two different seats: Standard MK 4 and Rocket AM 6 (accelerations measured at the seat, pelvis, head and vertebrae)

Ejected weight; seat + pilot = 172 kg

- - - - - - - - Standard MK 4

———————— Rocket seat AM 6

Maximum acceleration	=	20 g	Maximum acceleration	=	15 g
Seat velocity	=	80 ft/sec	Seat velocity	=	160 ft/sec
Acceleration slope	=	240 g/sec	Acceleration slope	=	200 g/sec

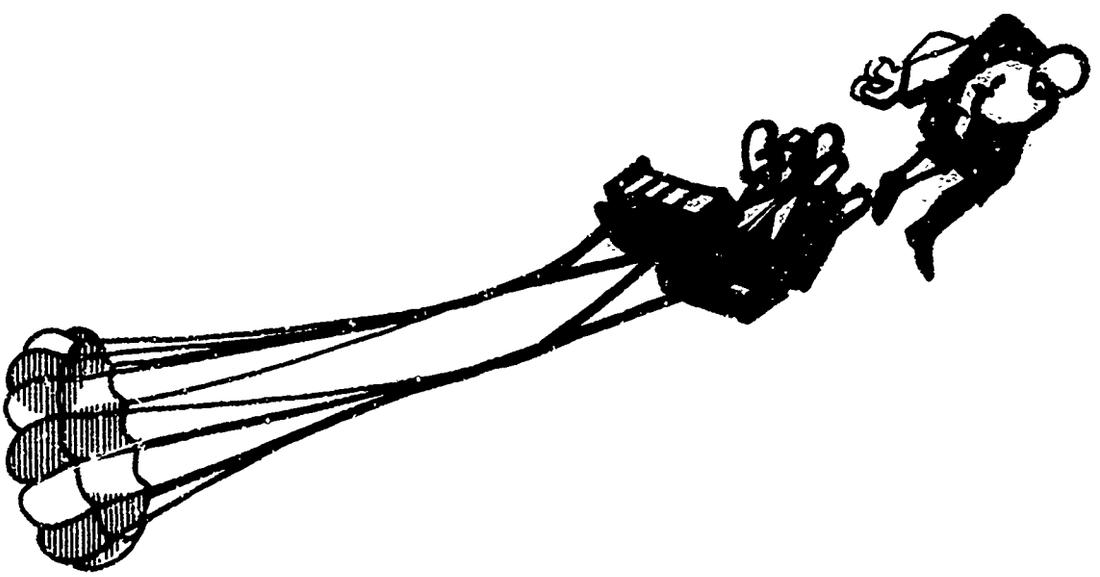


Fig. 22 Seat-pilot separation (after a USA publication)

Seats with Low Firing Mechanism – The seat is fired by first raising the arm rests thereby uncovering two triggers, pressure on which fires the seat. This system is employed in the following seats: RAC, E96, and E97.

Special case of the Martin-Baker MK4 – The Martin-Baker MK4 which is used in the most up-to-date aircraft, in addition to firing by a face-blind has a secondary or emergency firing handle situated between the thighs and the seat pan, being thus within reach of the pilot even at high g. By pulling this firing handle the pilot puts himself into a good attitude for ejection and furthermore his hands are only a short distance from the normal position on the control column hence saving time. The face however is in that case not protected by a face-blind.

4.3.4 Description of the Different Phases of Ejection

The phases to be considered (Fig. 20) are preparation, the ejection itself, leaving the seat, parachuting and landing.

4.3.4.1 Preparation

With the first seats the pilot had to prepare for ejection by following out a drill which was described in the course of training or of teaching and instruction sessions. The drill was as follows: get rid of the gun sight, jettison the canopy, place feet on the foot rests. In the case of a high firing drill, place hands on the firing handle, both hands above the head, and pull straight down to bring the handle on to the chest. This last movement fired the cartridge.

The current system of leg restraint simplifies this drill. The use of the face blind ensures correct position of the head on the head rest, and therefore avoids putting the spine in an unfavourable flexed position. With a low firing handle, if the pilot follows his instructions correctly, the spinal curvature will not be placed in an unfavourable position either. This system is a type of escape which is more suitable to certain types of aircraft.

4.3.4.2 The ejection itself

Under the action of the seat gun the seat is projected upwards. This causes an auxiliary gun to fire a small metallic bolt to which is fixed a drogue or seat stabilising parachute. Stabilised by this parachute the seat recedes from the aircraft, its speed rapidly dropping until it reaches its terminal velocity.

4.3.4.3 Separation from the seat (Fig. 22)

On the first seats the pilot had to separate himself from the seat by releasing his harness after 5 or 6 seconds and leaving it in free fall whilst the seat, braked by the stabiliser, was rapidly left behind him. He then had to open his parachute. Today, however, various improvements such as automatic separation from the seat and parachute opening ensure greater safety.

Two distinct cases, however, must be mentioned. First, at high altitude the pilot remains in his stabilized seat down to 10,000 ft and at this altitude a barometric capsule causes the separation of the seat and the pilot, whilst simultaneously setting off a sequence which results in the opening of the parachute. Secondly, at low altitude and at high speed, an accelerometer ensures that the separation sequence is initiated only when the seat has reached a velocity sufficiently low to be compatible with the strength of the parachute.

4.3.4.4 Parachuting and landing

Whether under manual or automatic control, parachuting and landing of these ejected pilots does not present particular difficulties unless the subject is unconscious (uncontrolled contact with ground).

4.3.5 Different Types of Ejection

4.3.5.1 Ejection in normal attitude

In this condition the aircraft is flying a straight line in an approximately horizontal flight path and with a weight load factor in the region of one. The pilot will be sitting in his seat at the moment of ejection. All other attitudes and configurations are abnormal.

4.3.5.2 Ejection in unusual attitudes

Here the aircraft attitude may be either inverted or banked, in both of which conditions the pilot is kept on his seat only by his seat harness. His back is not pressed against the seat back and above all his weight does not compress the seat cushion. Because of this the dynamics of the ejection are altered because the seat is already travelling fairly rapidly by the time it begins to transmit its impulse to the pilot's pelvis. In consequence the acceleration imparted to the body is therefore much higher and may in fact exceed the safety margin. In an ejection from a banked attitude the position of the spine is particularly bad and fractures of the spine have been observed under conditions such as these.

Variations in the flight path of the aircraft can give rise to additional accelerations, thus in a tight turn the resultant increased acceleration is added to that imparted by the seat.

In a low speed spin on a modern aircraft the Ax acceleration developed by the turning of the aircraft thrusts the pilot forward into his harness and, since the attachment points are low, his spine tends to be forced to a flexed position which favours the production of fractures on ejection.

In an ejection with jettisoning of the canopy there is a one second delay between the firing of the seat and its actual time of leaving the aircraft. This delay enables the canopy to be dragged away from the seat's trajectory by the force of the slip stream. In cases where the aircraft approaches the ground at high speed this delay can compromise the success of the ejection.

In VTOL aircraft operating near ground level and without any horizontal velocity here is no slip stream to help get rid of the canopy. Furthermore, if there is loss of control there may be a high degree of roll (360°/sec) which may affect the direction taken by the ejection seat as it leaves the aircraft.

In the case of a failure in a carrier catapult, the aircraft out of control can crash in a few seconds so the gain of one second can save the life of the pilot For these reasons ejection of the pilot through the canopy was examined in investigations carried out in France, Great Britain, USA and Switzerland. These investigations, subsequently confirmed by live ejections under emergency conditions, demonstrated the possibility of escaping by this means without sustaining serious injuries.

4.3.6 Statistics of Ejections in the French Air Force

From October 1951 to the end of 1966 259 ejections have been studied in the French Air Force. We shall now examine the results obtained from those ejections and then the injuries sustained.

4.3.6.1 Comprehensive results

According to the final outcome ejections can be divided into two groups according to whether they have failed or succeeded. We shall call failed ejections those which have resulted in the death of the pilot, and successful ejections those in which the pilot has survived even though he may have sustained severe or slight injury. We shall examine first of all the overall results then the annual statistics.

Overall results

TABLE X

Shows the Ejection Data as Unsuccessful or Successful

Total number of ejections	*Unsuccessful ejections (killed)*	*Successful ejections*
259 100%	64 24%	195 76%

TABLE XI

Successful Ejections

Total number of successful ejections	*Serious injury*	*Slight injury*	*Uninjured*
195 76%	34 13.1%	32 12.2%	129 49.7%

In over half of the injuries (Table XI) the pilot was uninjured.

Injuries without partial incapacity occur in 12.2% cases.

TABLE XII

Distribution of Injuries

Serious injuries	*Vertebral injuries*	*Fractures and dislocations of limbs*
34	22	12
a 13.1	8.49	4.6
b 17.4	11.2	5.2

a - percentage of all ejections
b - percentage of successful ejections.

One pilot presented a serious syndrome in which were associated involvement of the central nervous system (hemiplegia), fractured vertebrae and a fracture of the astragalus. The vertebral fractures appeared in 8.4% of all ejections and 11.2% of the successful ejections.

4.3.6.2 Annual statistics (Table XIII)

The annual distribution is fairly uniform and the annual percentage of successful ejections has slightly increased during the recent years. This improvement seems to be due in large measure to the installation of entirely automatic seats on the current aircraft.

TABLE XIII

Annual Distribution of Ejections and their Results

Year	*Killed*	*Serious injuries*		*Slight injuries*	*Uninjured*	*Total*
		Spine fractures	*Limb fractures*			
October 1951-1952	1	-	-	-	3	4
1953	4	-	1	2	3	10
1954	7	-	1	7	3	18
1955	4	1	-	2	6	13
1956	4	3	-	8	9	24
1957	5	1	-	2	11	19
1958	4	2	-	1	7	14
1959	6	2	-	1	9	18
1960	5	2	2	1	11	21
1961	6	1	-	1	15	23
1962	4	-	4	5	7	20
1963	5	1	-	-	14	20
1964	5	1	2	-	5	13
1965	1	5	-	2	12	20
1966	3	3	2	-	14	22
Total	64	22	12	32	129	259

4.3.6.3 Distribution of fractures on ejection

Spinal fractures are the most commonly encountered serious injury, appearing more frequently than injuries to the limbs such as fractures of the humerus, femur, tibia or open dislocation of the knee joint. Thirty spinal fractures were distributed amongst 22 pilots (Tables XIV and XV).

TABLE XIV

Distribution of Ejection Fractures According to Location (French Air Force)

Fractures	
Location	*Number*
T4	1
T5	-
T6	1
T7	4
T8	5
T9	1
T10	3
T11	-
T12	3
L1	9
L2	2
L3	-
L4	1
Total	30

TABLE XV

Multiple Spinal Fractures from Ejection (French Air Force)

Vertebrae involved	*Number*
T7 - T8	1
T7 - T8 - T9 - T10	1
T7 - L1	1
T8 - L1	1
T12 - L1 - L2	1

4.3.7 Mechanism of Production of Spinal Fractures During Ejection

The mechanism is one of fracture by compression of a more or less flexed spinal column. Broadly the injuries are of two types - firstly, occurring at the dorsolumbar (or lumbo thoracic-translator) hinge (T10 to L2) and on landing; secondly a high or medium thoracic location (T4 to T9) occurring at the moment of ejection from the aircraft.

Dorsolumbar hinge fractures (T10 to L2) are met with 17 times out of 30 after a landing under poor or difficult conditions (parachutists fractures occurring in hilly terrain or with high surface wind). The fractures of T4 to T9 are due to the seat harness altering the spinal curvature. A bad seated posture of the pilot on his ejection seat leads to flexion of the spinal column. These observations have been made as a result of examination of crash injuries and statistics. The classification is obviously somewhat broad because it is not always possible to state that a lower thoracic fracture in particular, may be due to poor position of the pilot as the seat leaves the aircraft, or as he lands, for these two mechanisms may combine to give multiple fractures.

4.3.8 Studies Carried out at the Flight Test Centre

In spite of its great interest, the assessment of strength of the spine in kilograms is not entirely useful when one is referring to ejection seats employed in aviation.

4.3.8.1 First studies

From the very first studies carried out in Germany it has been mandatory in any investigations on acceleration to consider the factor of time.

Richter in 1940 applied accelerations increasing from 2.2 to 15 g for a period of between 1/10 to 2/10 of a second. It was found that from 10 g the subjects felt pain at the level of the chest and neck. The vertebral thrust from bottom to top results in a bending forwards of the head, and subsequent trials showed, at accelerations above 15 g, compression fractures of the lumbar vertebrae (Weisehofer (1943)). Previous work had shown that accelerations above 18 g could be tolerated and that the peak could reach a value of 25 g for 1/10 second for an acceleration of 300 g seconds. Subsequently experiments in aviation medicine centers of USA showed that the human body could tolerate without risk of serious injury, accelerations greatly in excess of 40 g for very brief periods (less than 1/10 second).

4.3.8.2 The studies of Latham (UK)

The studies of Latham (UK) were the first to draw attention to the role of the seat-pilot assembly as represented by two masses suspended together by a spring. This idea explains in a general way the origin of the vertebral injuries noted in some cases of ejection (as where the pilot has replaced the seat cushion by another much softer one - Figure 26). Subsequent work especially that done with the Flight Study Center at Bretigny (H. Seris and R. Auffret) has shown that the seat-pilot combination is in fact much more complex. The pilot must himself be considered as a combination of suspended masses, each elementary mass being joined to the next mass by combination of spring and shock absorbers.

Latham placed accelerometers on the ejection seat and at the level of the pilot's hip, and the data he obtained (Figures 23 and 24) showed differences in the level of acceleration as well as a dephasing between the ejection seat and hip. When the pilot was seated on an elastic cushion it was found that increases of acceleration took place at the level of the hip.

4.3.8.3 Studies carried out at the Flight Studies Center at Bretigny

H. Seris and R. Auffret at the Flight Studies Center at Bretigny have studied ejections through the canopy, by making use of the series of accelerometers, amplifiers and tape recorders with very high band pass (Fig. 25). This enabled more accurate measurements to be made.

These authors recorded especially the resonant frequencies of the seat pan (260 hertz) and, even more important, the accelerations of the seat. The curves obtained indicated that these very high frequencies were completely filtered out by the cushion although the level of acceleration in them reached a value in the region of 50 g. The corresponding accelerations at the level of the pelvis and of the lumbar region was of 20 g.

The same phenomenon is observed in the pilot in whom each vertebra along with the environmental soft tissues, constitutes a distinct mass, each of which is bound to the next one by a spring (the intravertebral disc) and by a shock absorber (the paravertebral muscle masses) (H. Seris). The importance of this fact is highlighted when one measures the compression of a lumbar vertebra of the cadavar during ejection.

On Figure 25 a peak seat acceleration of 50 g gives rise to an acceleration of 21 g at the right iliac crest and 38 g at the level of the head. It will be seen on the vertebral compression curve that this peak only gives rise to a compression of 2.25 kn* (about 225 kg). On the other hand at time 0.17 on Figure 26 an acceleration of 8 g becomes 10 g at the iliac crest and 12 g at the head. The vertebral compression in spite of the longer duration is then of 4 kn (400 kg).

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* Kn = kilo-newtons (translator).

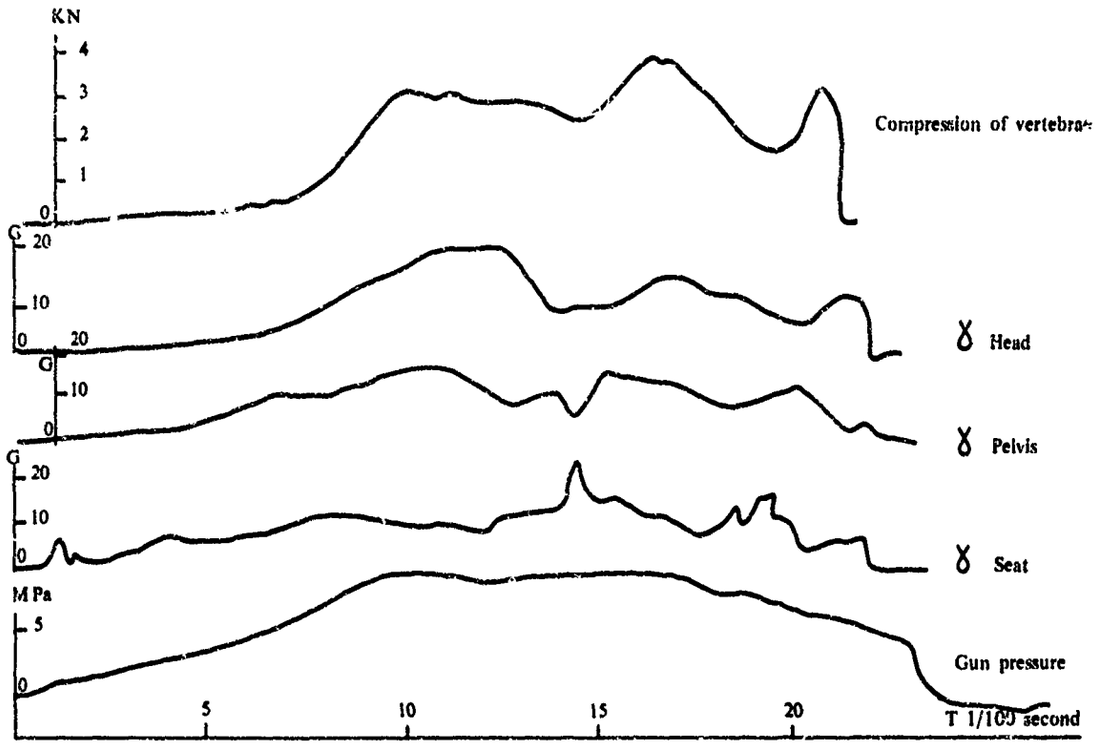


Fig. 23 Martin-Baker AM 6 ejection seat

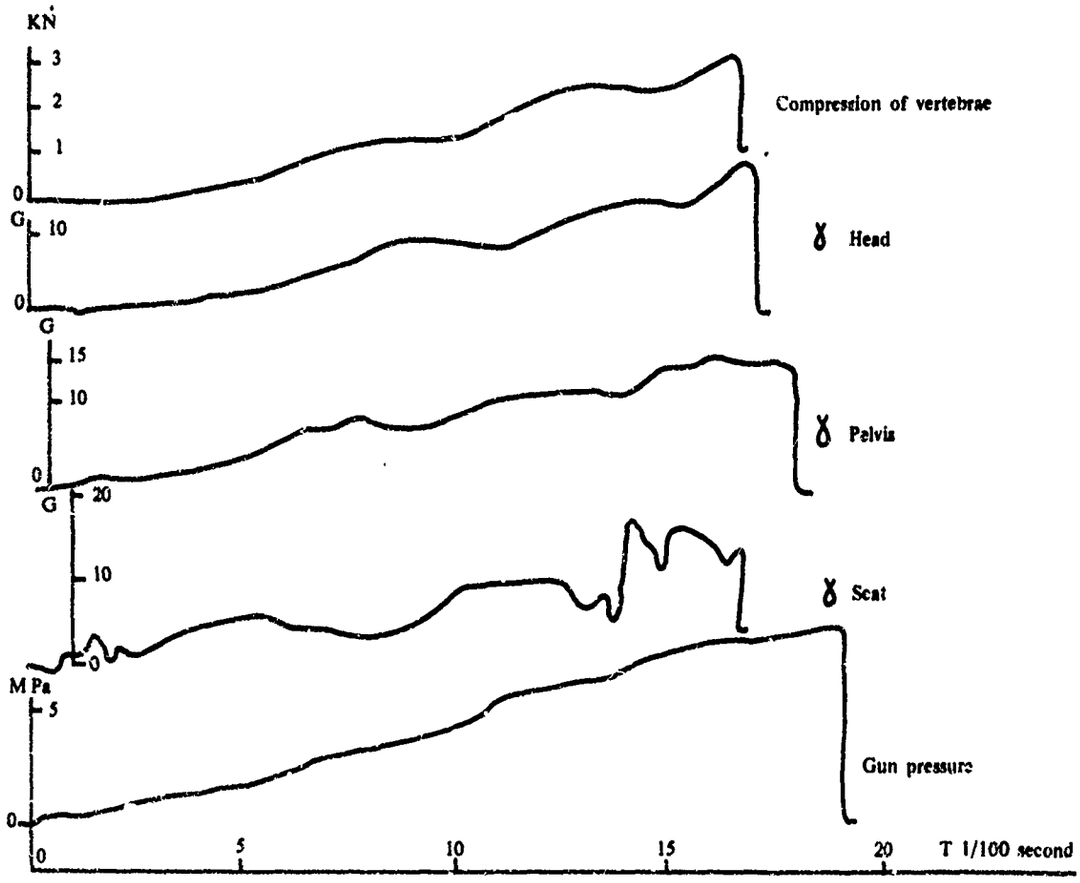


Fig. 24 Martin-Baker MK 4 ejection seat

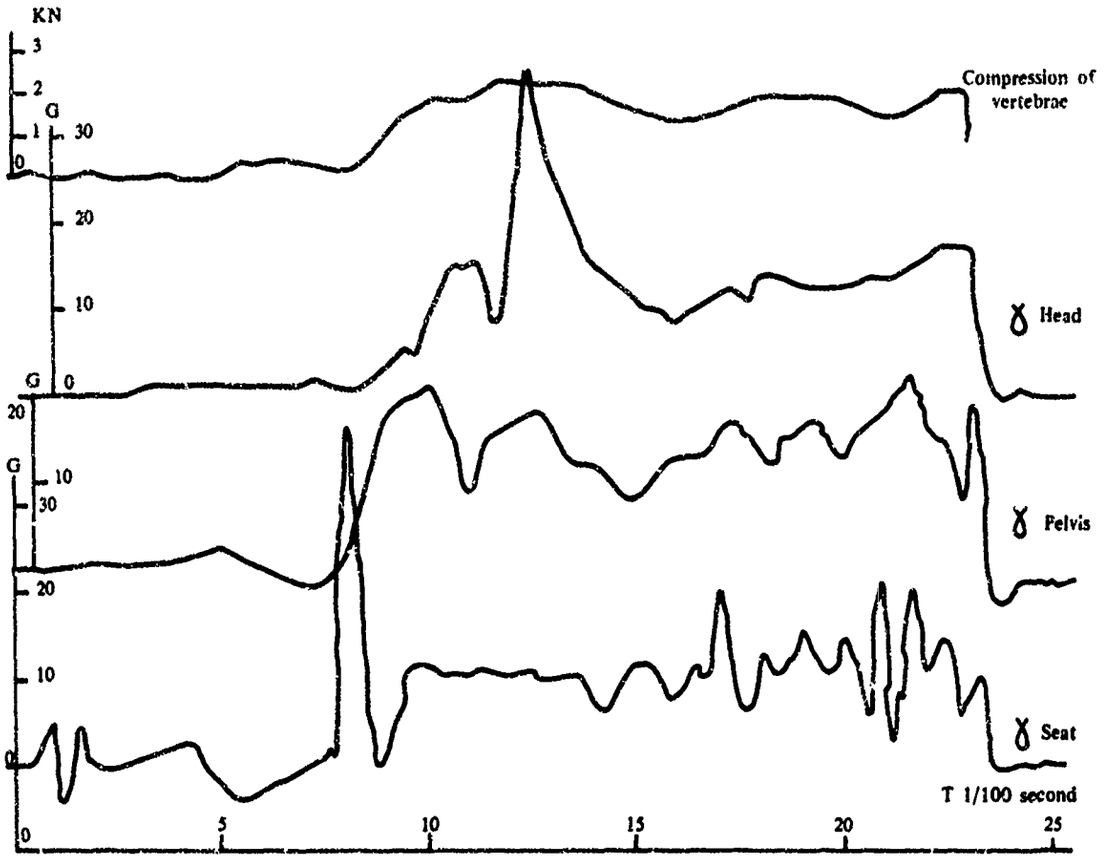


Fig.25 Through canopy ejection - MK 4 seat

Figure 26.
Courbes de Latham.

Réaction d'un pilote à différents coussins de siège.

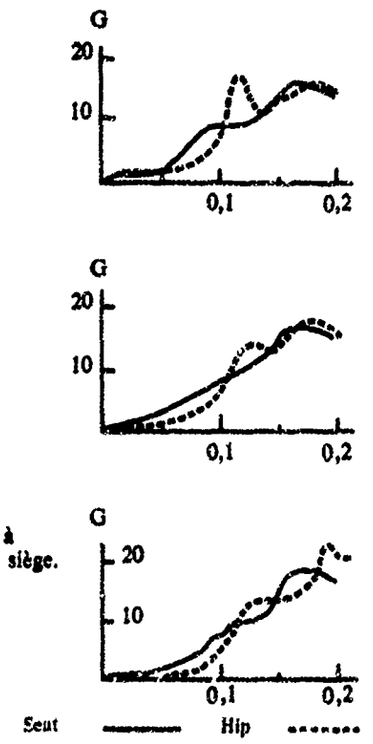


Fig.26 Pilot's response to different seat cushions. (Latham's curves)

These facts can be explained on the basis of the response time of the vertebral column. Thus, 0.03 seconds is required for the acceleration to be transmitted from the pelvis to the head. If the peak lasts less than 0.03 seconds, when the head is accelerated the vertebral column will be less compressed (Curve 25). If the acceleration lasts several hundredths of a second, all the shock absorber systems are at their limit and the vertebra is subjected to compression corresponding to $F = m\gamma$. Thus the ideal cushion will filter out high accelerations corresponding to vibration of the seat while the body also will act as a filter. One can thus follow the concept of very high acceleration acting for a very short time. After all are not American rugby players subjected to 70 g for 6 to 8 milliseconds during a violent tackle?

In conclusion one can agree with J.Martin and H.Seris that accelerations of less than 80 g and lasting less than 1/100 second do not give rise to body injury on a spine which is receiving these accelerations in the correct attitude.

4.3.9 Radiological Studies of the Vertebral Column of a Subject in an Ejection Seat

4.3.9.1 1961 experiments

R.Delahaye, R.Auffret, H.Seris and H.Magin in 1961 examined the radiological appearance of the spine of subjects on an ejection seat supplied by the Aerospace Medical Laboratory of the Flight Test Center of Bretigny. The studies were carried out in the Radiology Department of the Army Teaching Hospital Dominique-Larrey at Versailles.

The investigation was carried out on 10 subjects equipped with flying overalls, helmet and breathing apparatus. These men were placed on a Martin-Baker MK4 seat using first the face-blind and then the low firing handle on the seat pan. The X-rays (AP and lateral) were taken with a Langcais (CGR) machine with a cross beam.

We carried out two types of examination. In the first the adjustment of seat restraint harness was perfect and the instructions for ejection were followed scrupulously. These were: head on head rest; buttocks well wedged into the back of the seat; leg restraint straps tightened.

On the other hand in the second series of tests, the seat harness was loose and the head was allowed to be off the seat. In this position there is a slight dorsal flexion which is usually encountered at the time of faulty ejection. In both instances the lateral views were the most useful, since they enabled one to study the spinal curves. The AP plates were rather difficult to make use of in spite of the use of varying degrees of penetration because of the intrinsic opacity of the seat structure.

In the first series of plates our aim was to look for changes in spinal curvature according to whether the high or low firing position was used but the plates revealed no substantial differences in the appearance of the spine in the two systems. On the whole, the seated position reduces the physiological curves of lumbar lordosis and thoracic kyphosis.

The second series of experiments enabled us to show that the thrust axis passes through the centre of curvature as determined by the degree of dorsal flexion. Thus the lumbar spine reduces its lordosis, while the thrust axis passes through T6, T7 or T8 according to the degree of flexion. This variation in the thrust axis affords an explanation of the high thoracic location of fractures on ejection as well as of the anterior cuneiform compression which takes place.

This type of radiological examination on an ejection seat has subsequently been carried out by Levy in USA. Our aim has been to determine the appearance of the spine in two kyphotic subjects sitting on an ejection seat. In spite of following the drill carefully and, in particular, paying attention to having the head well pressed against the head rest, the thoracic curvature did not vary and the thrust axis passed through the centre of curvature. It therefore seems that the presence of kyphosis is a contra indication to ejection. This elimination is in fact dealt with adequately by the existing selection standards.

4.3.9.2 Experiments 1966 to 1967

From 1966 to 1967 Delahaye, Auffret, Seris and Mangin carried out an investigation on the fractures contributing to bad position of the pilot: height of the seat, position of the legs, the effect of a cushioned head rest and the effect of wearing different helmets on spinal posture.

The seat employed was a Martin-Baker AM4 mock-up with however textile and soft wear as for an airborne ejection seat. Two types of cushioned head rest and two different helmets were compared. In order to give the subjects an environment as close as possible to reality, a floor resembling that of the Mirage III was placed on the seat support and a movable foot rest in the shape of a rudder bar, and adjustable in distance and height, was fixed to the floor.

Several subjects were X-rayed in fourteen configurations. In the first four radiographs, a full plate was used to examine the entire spinal cord and in the fifth to fourteenth case the radiograph concentrated on the skull, and the cervical and thoracic column. Photographs were taken antero posteriorly and laterally in each of these conditions, and a tracing of the X-rays subsequently enabled a comparative study of the different curvatures to be made by super position (Figures 27 and 28).

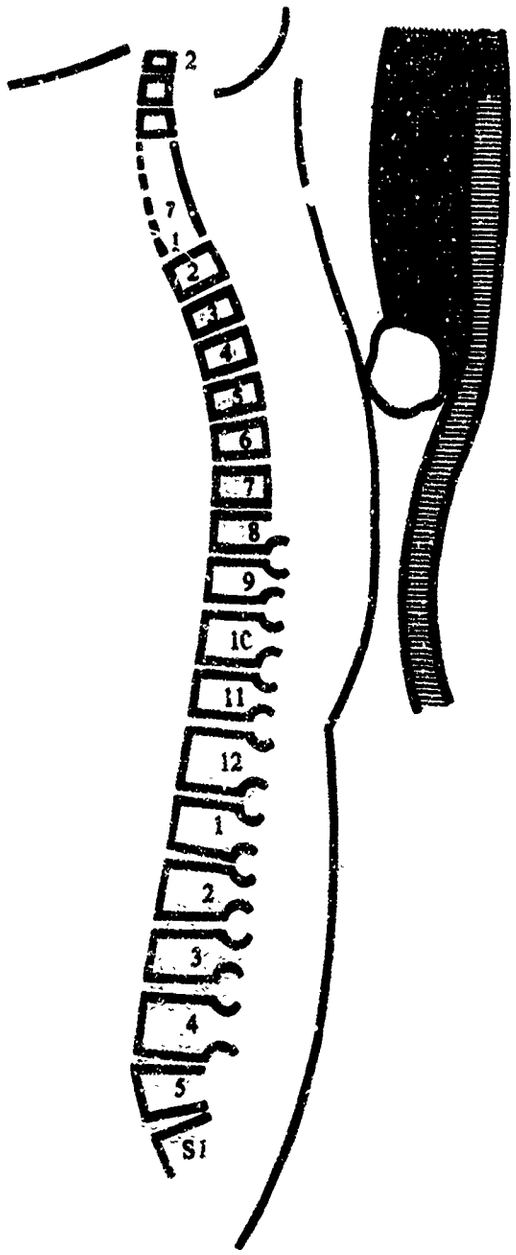


Fig. 27 2/12/1966 - Legs normal, seat pan position normal

1^{a}_{b} : helmet 312

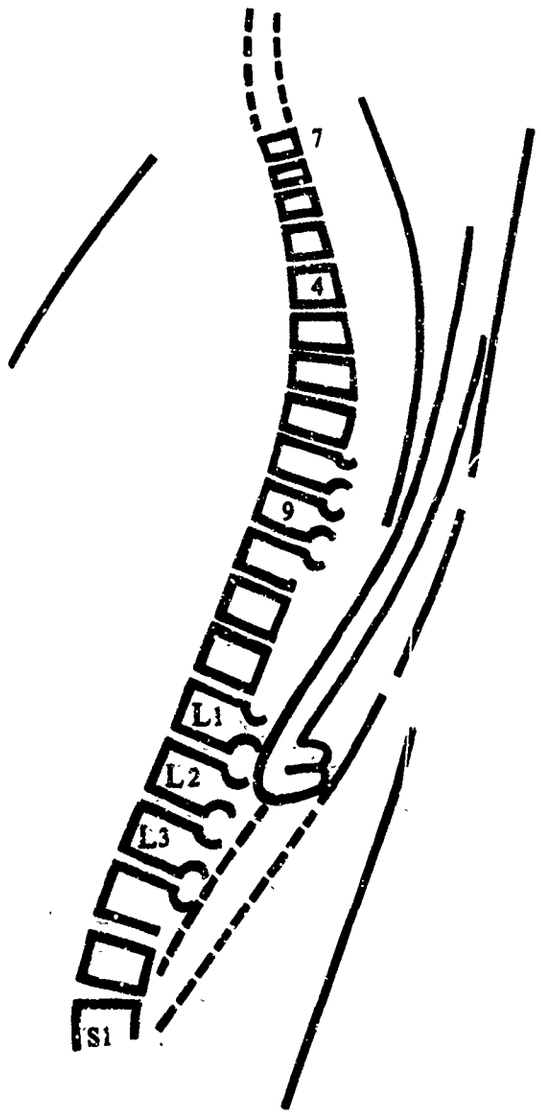


Fig. 28 2/12/1966 - Legs normal, seat pan low

2^{a}_{b} : helmet 312

Results

A low position of the seat pan tends to restore the lumbar lordosis and the thoracic kyphosis thus nullifying the changes on spinal posture brought about by sitting down. No variations in spinal posture have been noted even if the subject brings his legs under his seat when it is in the normal position.

On the other hand a low seat position and the l[illegible] under the seat, does straighten the lumbar lordosis but it still does not alter the kyphosis. On the X-ra[illegible] [illegible]lates an angulation is seen at the level of the critical zone between T4, T5 and T6 in the low seat position. The fact that a subject might be kyphotic clearly worsens this observation and favours the development of fracture.

Spinal Posture and the Wearing of a Helmet

On the lateral X-rays the distance between the structure of the helmet (visible on X-rays) and the vault of the skull has been measured. Greater than with helmet A, this difference provides an explanation of the changes in spinal posture, especially in the critical zone, which are more obvious with the A helmet. The region T4, T5 and T6 tends to become more flexed while a low seat position merely increases flexion of this critical zone. This effect would certainly be increased by wearing too large a helmet.

Influence of the Type of Cushion

The various types of head rest cushion can bring the head forward causing only a variation of cervical posture although occasionally a flexion of the thoracic cord in the critical zone. All factors responsible for bringing forward the head or the shoulders are undesirable. Some of these are beyond the pilots control, e.g. poor folding of a parachute, wearing too large or a badly fitting helmet, both of which can cause flexion of the spinal cord.

The most important factor however remains the pilot's position. It is important that the seat height be the same at the time of ejection as during flight. The importance of a tight harness is obvious, especially since the trunk tends to be compressed under the effect of acceleration. The leg position is less important, but it is preferable to leave the feet on the rudder bar. In this way the body has a more stable seating and the back is more easily pressed back into the seat cushions. This is obviously applied only to seats having leg restraint without which it is essential to place the feet upon the stirrups. Certain deformities of the spine, in particular kyphosis are a contra indication to ejection. Each of the factors discussed has only a small influence on vertebral posture but in combination they may give rise to a flexion of sufficient importance to bring about a fracture.

5. CLINICAL FEATURES OF SPINAL INJURIES

It is necessary to make a distinction between the spinal fracture with clinical symptomatology and asymptomatic fractures. It is this well established fact which today justifies the systematic practice of spine radiography after serious injury.

5.1 Fractures with Clinical Manifestations

The majority of fractures seen after a crash, ejection or parachuting accident, are accompanied by thoracic or lumbar pain but seldom by cervical pain. Pain, the essential symptom of simple fractures of the spine, can assume several forms – sometimes violent, appearing immediately after the injury and frequently giving rise to serious functional difficulty, whereas in other cases it may be discrete in the initial stages, becoming more severe several hours after the injury.

Clinical examination, in particular palpation and percussion, reveal localized pain, whilst on inspection it may be possible to see the protrusion of a spinal process or the localized contraction of a muscle mass. Usually examination of the nervous system reveals no abnormality but one may encounter paraplegia or a cauda equina syndrome appearing very rapidly after the injury. In other cases the pain may be very slight, may not be increased by percussion and simple contusion or bruising would be diagnosed if the existence of a fracture were not revealed by X-ray examination.

5.2 Asymptomatic Fractures

In 15% of fractures observed after aircraft accidents (crashes of light aircraft, helicopter crashes, glider accidents and ejections) the systematic radiological examination which is nowadays mandatory in the French Air Force has revealed the existence of spinal injuries. The pilots do not have necessarily any clinical signs.

5.3 Injury without Fractures

After a jump, a parachutist may develop lumbar pain accompanied occasionally by irradiation of a root type pain. Out of 136 cases of parachutists vertebral syndrome, 89 (65%) appear immediately after the jump (Richaud). Repeated injuries, even minor ones, can play a very important part (see later).

6. RADIOLOGY IN THE DIAGNOSIS OF SPINAL INJURIES IN AVIATION MEDICINE

The diagnosis of spinal fractures amongst flying personnel and parachutists is almost always by X-ray. This reveals the "latent forms" described, the seat of lesions, and the number and type of these and governs the treatment according to the observed condition.

6.1 Radiological Technique

The radiological examination of the spine in aerospace medicine does not differ from that for any other spinal injury. Let us therefore recall the principles which seem to be fundamental to this examination.

1. The entire spine must be X-rayed both by antero-posterior and by lateral views. According to the casualty's condition, plates will be taken either in the standing position or in decubitus. In the Air Force, this complete examination of the vertebral column is compulsory after any aircraft accident.

2. All spinal anomalies call for the use of localised X-rays (AP and lateral) in which attention must be paid to the roles of angles of incidence by approaching the examination of each segment via its concavity and by adapting the technique to the needs of each particular case. Lateral views will enable one to calculate precisely the correct incidence for the localised plates.

3. The examination of a posterior arch in the lumbar region can be made at angles of incidence from ¾ right or left and at an angle of 45° to the plane of the posterior articular processes in the median sagital plane. At the thoracic level, the fact that the posterior articular facets are on the horizontal plane, calls for the use of lateral view tomograms.

4. Tomograms, both antero-posterior and lateral, enable one to make a fine and minute examination of the lesions as well as of the posterior wall of Rieunau. Antero-posterior tomograms particularly in the lowest posterior planes, are particularly useful since they ensure an almost complete exploration without having to move the patient out of his supine position.

5. In certain cases with simple compression, a dynamic radiological examination enables one to assess the degree of mobility of the spine, any variation in the shape of the intravertebral spaces, and thereby confirm the presence or absence of injury either of the inter-spinal ligament (widening of the space between the spinal processes) or of the discs (pinching or selective widening). This radiodynamic exploration makes use of antero-posterior views with lateral right and left flexion and lateral views with flexion and extension.

In conclusion, the radiological examination is always made up of plates of the entire spine, and also of localised plates. If there is an injury, then antero-posterior and lateral tomography is essential for a precise examination of the posterior wall and of the vertebral lesions. We are of the opinion that radio-dynamic examination should be more widely employed in the examination of simple compression fractures.

6.2 Locus of the Fractures

Since the lumbo-thoracic hinge is the most frequent seat of vertebral fracture in aviation medicine (Table XVI) whatever the cause of the injury, (aircraft or helicopter crash, parachuting, ejection) the vertebrae most frequently involved are T11, T12 and L1 in more than 60% of cases. Nonetheless, high or medium thoracic, or low lumbar locations must be systematically looked for as they are frequently encountered. On the other hand cervical fractures are unusual and are almost only encountered in parachuting as a result of the opening shock.

TABLE XVI

Showing the Various Sites of Vertebral Fractures in Aviation Medicine

Type of injury	*Commonest sites*	*Less usual sites*	*Most unusual sites*
light aircraft crash	lumbo-thoracic hinge T10 – L2	upper or mid-thoracic	low lumbar
helicopter crash	lumbo-thoracic hinge T10 – L2	low lumbar	upper or mid-thoracic
parachuting	lumbo-thoracic hinge T10 – L2	upper or mid-thoracic low lumbar	C5 – C7
ejection	lumbo-thoracic hinge	upper or mid-thoracic	low lumbar

3.3 Signs

6.3.1 Generalities

According to Decoulx and Rieunau it is possible to distinguish two types of spinal fracture (Fig. 29); fractures without lesion of the posterior wall (the stable fractures of Nicoll) and fractures in which the posterior wall is affected (unstable fractures of Nicoll).

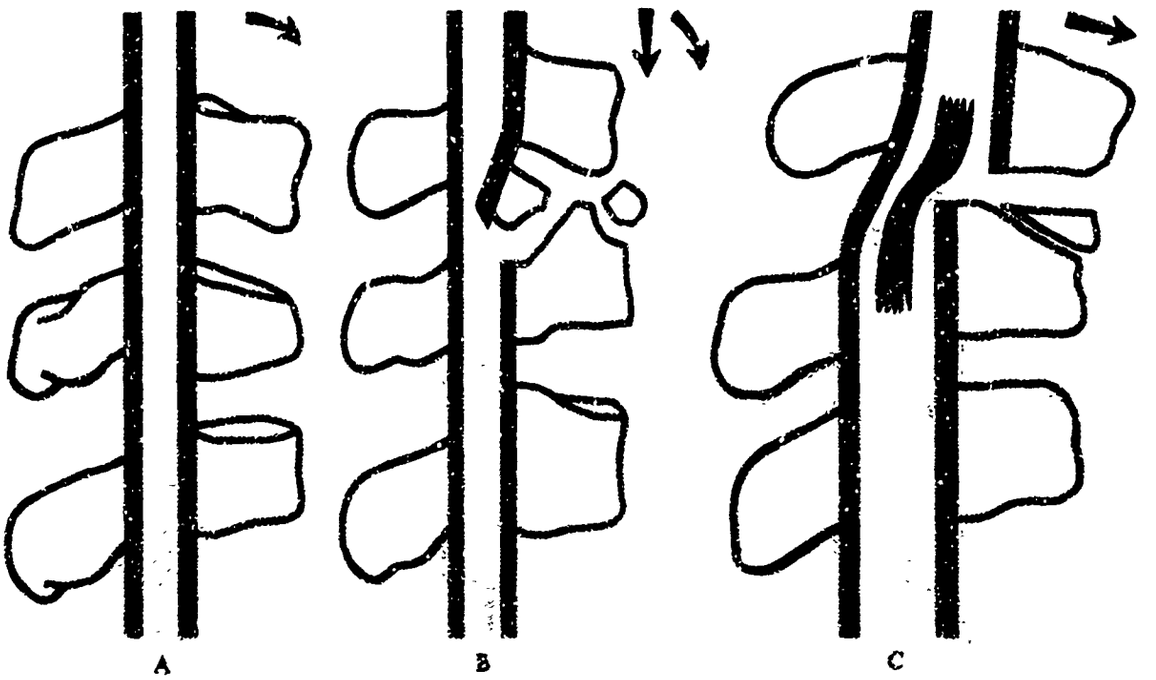


Fig. 29 Anatomo-pathological classification (after Rieunau). Left to right: lumbo-thoracic fracture without involvement of the posterior wall (A) and with involvement of the wall (B & C)

The first type of fracture is the most frequently encountered (Table XVII). In the various statistical data made use of in this work we have found that in 94% of fractures, the posterior wall was intact. This proportion is in the region of that quoted in several works on spinal injuries (85-95%).

TABLE XVII

Giving the Distribution of Fractures With or Without Involvement of Posterior Wall (Data from Air Force, Light Aviation, Army, Airborne Troops)

Type of injury	*Number of fractures*	*Without involvement of posterior wall*	*With involvement of posterior wall*
light aircraft crash	24	23	1
helicopter crash	26	23	3
parachuting	195	187	8
ejection	30	27	3
TOTAL	275	260	15

The infrequent involvement of the posterior wall (15 cases) has to be looked for systematically because it can give rise to lesions of the central nervous system by the displacement of a bony fragment. With such cases, surgical treatment or the application of a plaster under X-ray surveillance are essential.

6.3.2 Fractures not Involving the Posterior Wall

In the majority of observations the posterior wall of Rieunau is intact as can be confirmed by localised X-rays. As a check, and as part of the routine examination, frontal and saggital tomograms confirm the impression given by examination of the standard plates.

The lateral plate taken in flexion demonstrates in general a normal separation of the spinal processes, confirming thereby the integrity of the ligaments.

We can now describe the injuries observed, by considering in succession (Figures 30 to 31):

(a) the shape of the body,

(b) the appearance of the contours of the plateau and the angles,

(c) the density of the bony structure,

(d) affections of the posterior wall,

(e) displacements and postural difficulties,

(f) association lesions (discs, ligaments and soft tissues),

(g) remote lesions.

6.3.2.1 The shape of the body of the vertebra

The questions here is usually one of anterior cuneiform compression, in other words a reduction in the height of the vertebra localised to its anterior part. This usually only affects one vertebra, but multiple fractures are not unusual, e.g. 30 cases have been recorded in statistics from the School for Airborne Troops at Pau; 5 cases amongst the ejection statistics of the Air Force and 8 in aircraft crashes (light aircraft and helicopters).

The side view is the more useful to show up the degree of compression which in the majority of cases is slight. Occasionally the antero-posterior view may reveal a widening of the vertebral body or an asymmetric lateral compression.

6.3.2.2 Appearance of the contours of the plateau and the angles

The anterior contours are often irregular, and in compression fractures the anterior angle overlaps the vertebral contours. The line of the fracture is rarely visible which has enabled Watson-Jones to refer to fractures impacted by compression. In many cases there is a tearing of the antero superior corner when the line of fracture becomes visible as an irregular and serrated edge. The anterior edge of the vertebral body in such cases is in the shape of an obtuse angle. Compressions fractures are accompanied by a break of the anterior part of the plateau, in 75% of cases only the superior plateau being affected. In serious injuries it is not unusual to note an involvement of the two vertebral plateau. On the various tomographic sections there has been no evidence of the contour erosion which is characteristic of an inflammatory process.

6.3.2.3 Density and bony structure

In the fractures examined systematically shortly after injury there is no marked change in the density or in the structure of the bony area. There is only some increased density in the injured portion.

6.3.2.4 Injury of the posterior arch

In all these observations the posterior wall of Rieunau was intact. The posterior arch fractures which have been encountered usually involve the transverse processes. Although the sole involvement of these processes is rare in ejection injuries, it can arise in some crash landings or in a landing on the back.

6.3.2.5 Displacements and postural complaints

In simple compression fractures which do not involve the posterior wall, the immediate sequelae neither involve vertebral displacement nor postural difficulties.

6.3.2.6 Associated injuries

In anterior-cuneiform compression fractures, the disc and the ligamentary system are usually intact, but the disc next to a fractured vertebra may be affected when the nucleus causes a collapse of the vertebral plateau on which the disc is resting. This can cause the disc to break without separating, and on radiographic plates one sees a narrowing of the intervertebral space. These are usually fractures corresponding to the second mechanism of Watson-Jones (i.e. anterior-cuneiform compression fracture with comminution of the anterior part of the vertebra). This disc lesion can bring about a more or less rapid anthrosis and is encountered in cases of serious injury, e.g. as a result of helicopter or aircraft crash landings on hilly terrain or parachute landings under poor conditions.

Fig.30 Fracture of T8 (affecting superior vertebral plateau) - Ejection from supersonic aircraft

Fig.31 Fractures of L3 and L5 - Helicopter crash

6.3.2.7 Remote lesions

These are infrequently found but one may mention reflex aerocoly. and other traumatic lesions, such as limb fractures.

6.3.3 Fracture with Involvement of the Posterior Wall (Fig.32 to 38)

Less frequently encountered than the type considered above, they are however more serious since they are sometimes accompanied by neurological lesions (paraplegia and cauda equina syndrome). This time of fracture involving the posterior wall may arise in all types of injuries in aviation medicine (Table XVI). The localised lateral radiograph should lead one to suspect involvement of the bony posterior wall for it enables one to study the vertebral fragments and to measure the degree of gibbosity. Tomographic techniques enable one to identify the number of vertebral body fragments, the orientation of the fracture lines and enables one to determine the extent of posterior wall involvement.

6.3.3.1 The shape of the vertebral body

In antero-posterior view the vertebral body is more or less compressed and generally larger. The lateral view shows separation into two or more portions, the anterior fragment being distinctly displaced forward while the posterior trapezoid shaped fragment bulges posteriorally.

6.3.3.2 The appearance of the contours, the plateaus and the angles

In a tomographic section, the contours of the fragments are quite sharp, bearing no appearance of lacunar or erosion changes. The vertebral plateau show depressions.

6.3.3.3 Bony structure density

Usually reveals no abnormality.

6.3.3.4 Involvement of the posterior arches

The posterior arch, and especially the blades of the articular processes are usually normal.

6.3.3.5 Displacement and postural changes

Along with Decoulx and Rieunau the majority of authors stress the importance of measuring the degree of gibbosity in the examination of the patient. This is a measurement which can be effected in several ways - either by measuring the angle between the superior and inferior plateaux of the affected vertebra or by the ratio of the height of the posterior to the anterior edge of the affected vertebra.

If one delineates the spinal axis, the line passing through the anterior edges usually describes a regular curve with a large radius. In a case of vertebral fracture with compression, the angle made by this line accurately measures the extent of the compression fracture, that is to say, the degree of gibbosity. Although it does not take into account the frequently marked and variable compression of the discs, this second method is none the less preferable because the first method depends on a degree of parallelism which does not always exist between the superior and inferior facets of the vertebra.

6.3.3.6 Associated lesions

One or more discs may exhibit an overall compression or pinching and the ligamentary system may be damaged.

6.3.3.7 Remote lesions

In some cases of extensive trauma the patient may have other fractures e.g. limbs, skull or thoracic cage.

6.3.4 Isolated Fractures of the Transverse Processes

Isolated fractures of the transverse processes are sometimes encountered in parachutists who have landed on the back, or in aviators after a crash landing. In one case of supersonic ejection, L.Tabusse, R.Pannier and R.P.Delahaye found two fractures of the transverse processes of L1 - L2 associated with fractures of the body of T12 - L1, with an involvement of the posterior wall.

6.3.5 Isolated Fractures of the Spinal Processes

Isolated fractures of the spinal processes especially at the levels of C2, C6 and C7 can be produced by the opening shock of the parachute. They are, however, uncommon (2 cases), and since the new system of parachute folding has been employed this type of injury has no longer been encountered in airborne troops.

6.3.6 Isolated Fractures of the Isthmus

If it is indeed possible to sustain these, they have never been detected in the data employed in this current study.

Fig. 32 Parachuting accident. Paraplegia. Fracture of L1 with involvement of posterior wall

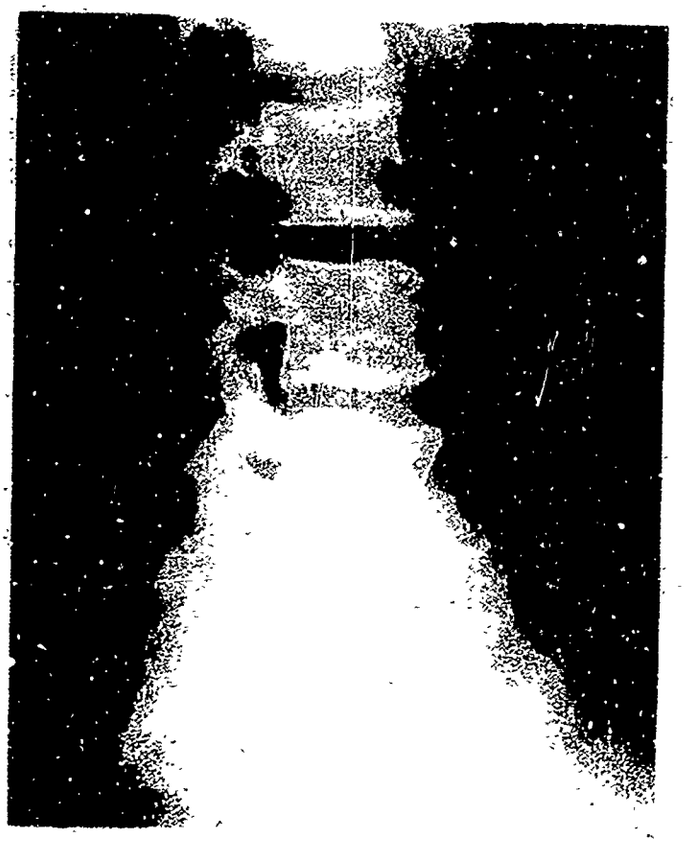


Fig 33 Glider crash - Fracture of L5

F'.34 Glider crash (same subject as in Figure 33). Tomograms defining involvement of posterior arches of L3 and L4

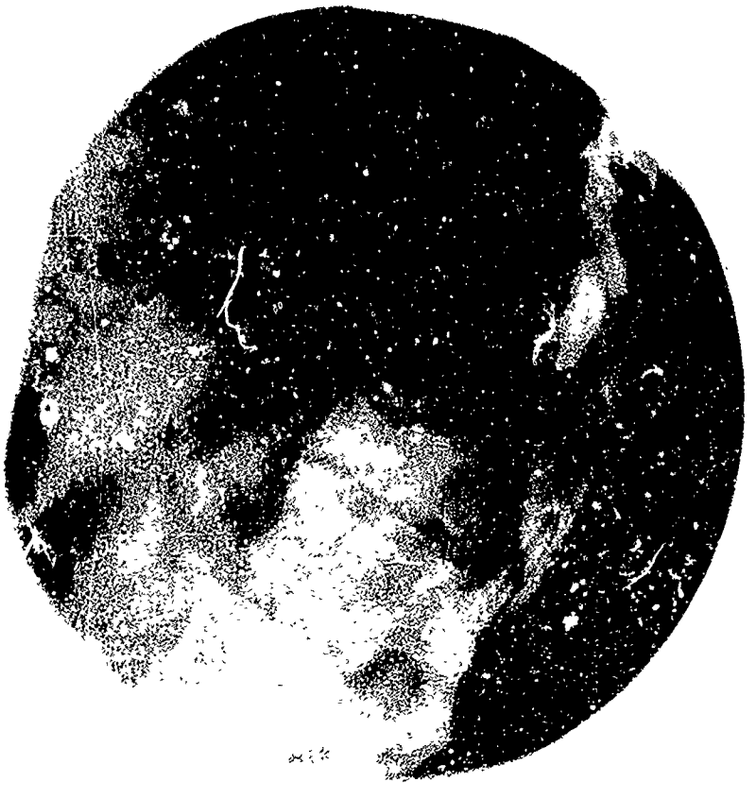


Fig.35 Supersonic ejection - Fractures of T12 and L1

Fig.36 Supersonic ejection (same subject as Figure 35). Rapid appearance of perivertebral calcification (1½ months after injury)

Fig.37 Parachuting accident - Fracture of [illegible] with involvement of posterior wall

Fig. 38 Ejection - Comminuted fracture of T8 with involvement of posterior wall

6.4 Differential Diagnosis

The differential diagnosis of spinal fractures in aerospace medicine presupposes a thorough knowledge of the morphological variations and developmental anomalies of vertebral bodies which must not be confused with traumatic sequelae. We shall therefore study in turn the morphological variants capable of being confused with vertebral fractures, and the alterations associated with a disorder of the embryological development of the vertebral body or of the vertebra and disc combination (anterior corners, retro-marginal hernias, Schmorl's notches).

6.4.1 Morphological Variants

The most frequently encountered morphological variant in vertebrae is a cuneiform tendency which is congenital but which may be confused with a traumatic condition.

6.4.1.1 Definition of the cuneiform vertebra

The concept of a cuneiform vertebra has not always been made clear, and furthermore its definition depends upon the author. One can none the less differentiate the truly cuneiform vertebra, the result of injury and the vertebra with a cuneiform tendency.

Dubouloz, Legro, Merjanian and Serratrice, in a statistical examination of vertebrae having a cuneiform tendency, only took account, on antero-posterior views, of differences in height greater than 2 mm on one side of the vertebra compared with the other. In lateral views, the differences between the anterior and the posterior edges has to be 3 mm or more for L1, and 2 mm for the other vertebrae. These last figures can be accepted as showing the criteria for a vertebra with a cuneiform tendency, and it is our opinion that the lateral views only are of value in such determinations. In addition to these numerical data, it seems advisable both to Seze and Djian and to ourselves to bear in mind the fact that a vertebra with a cuneiform tendency has regular corners, is not damaged, and shows no changes in structure or in density. Such a vertebra is usually the result of a congenital abnormality. In doubtful cases in spite of the apparent precision of these definitions, it is obvious that to be certain one is dealing with an acquired compression one must take account of a comparison of X-rays taken before and after the accident as well as taking note of the results of tomographic examination in AP and in lateral views of the suspected vertebra. The medico-legal aspects are obvious.

6.4.1.2 Vertebrae with a cuneiform tendency

This type of morphological variant certainly exists and is frequently encountered in daily practice. Indeed Brocher lays stress on the fact that the thoracic vertebrae exhibit a moderate degree of cuneiformity which is purely physiological. Vertebrae with a cuneiform tendency are especially found at the centres of the physiological curves such as T6 for the thoracic column, and T12 - L1 at the lumbo thoracic hinge.

For the diagnosis of cuneiform compression fractures in aviators or in parachutists it is essential to be familiar with these facts, since these zones are also the point at which the fracture preferentially occurs. In order to avoid the mistaken or a missed diagnosis of fracture, we would stress the importance of an intact structure and the slight reduction in height of those vertebrae having a cuneiform tendency. With aviators our task is always easier since we can refer to his radiological dossier, so that here, the differential diagnosis presents no great difficulties.

6.4.2 Changes due to a Disorder of the Vertebral Body and of the Disc-Vertebra Complex

These morphological changes of a pathological nature present the radiologist with diagnostic problems more difficult than those presented by cuneiform variants we have studied above and a knowledge of the embryology and appearances of the vertebral bodies enables one to avoid making a mistaken diagnosis of fracture. To Decoulx, such a differential diagnosis presents no difficulty, but he none the less stresses the mistakes frequently made, even by professional radiologists. We shall therefore examine the following 3 conditions:

- The absence of union of the corners of the vertebra in an adult.
- The anterior retro-marginal hernia (of Seze and Rotes-Querol).
- The results of the disease of the epiphyses.

6.4.2.1 Failure of union of the vertebral corners in the adult ("paradiscal defect" of anglo-saxon authors)

This common abnormality has been described in the literature as: persistent process of the spine; anterior paradiscal defect (Hellstadun); vertebral osteochondrosis dissecans of the adult (Galland); persistence of epiphyseal corners.

Schmorl and Junghaus consider the term vertebral ephiphyses to be incorrect, because one is dealing with a marginal ring. On lateral radiographs of a child one can often see a clear streak at the base of one or of several vertebral angles. The vertebral angles then appear as little triangular and rounded fragments detached from the vertebral body (Fig.39). In a child this appearance is normal since fusion takes place physiologically about the age of twenty-one to twenty-two years. The persistence in the adult indicates a developmental condition which has prevented normal fusion from taking place.

The separation of the fragment from the vertebral body, although usually complete, is sometimes incomplete. This effect is most frequently found in the anterior and superior corner of the vertebral body, whilst the anterior and inferior corner is infrequently involved. The free vertebral corner is separated from the body by a straight clear line which is regular in appearance and quite distinct from the irregular and serrated appearance of marginal fractures. Whereas the para-discal defect will remain unchanged without tendency to union, the union of a marginal fracture will be accompanied by a characteristic deformity: an irregularity in the curvature of the anterior surface of the vertebral body (a transverse fault).

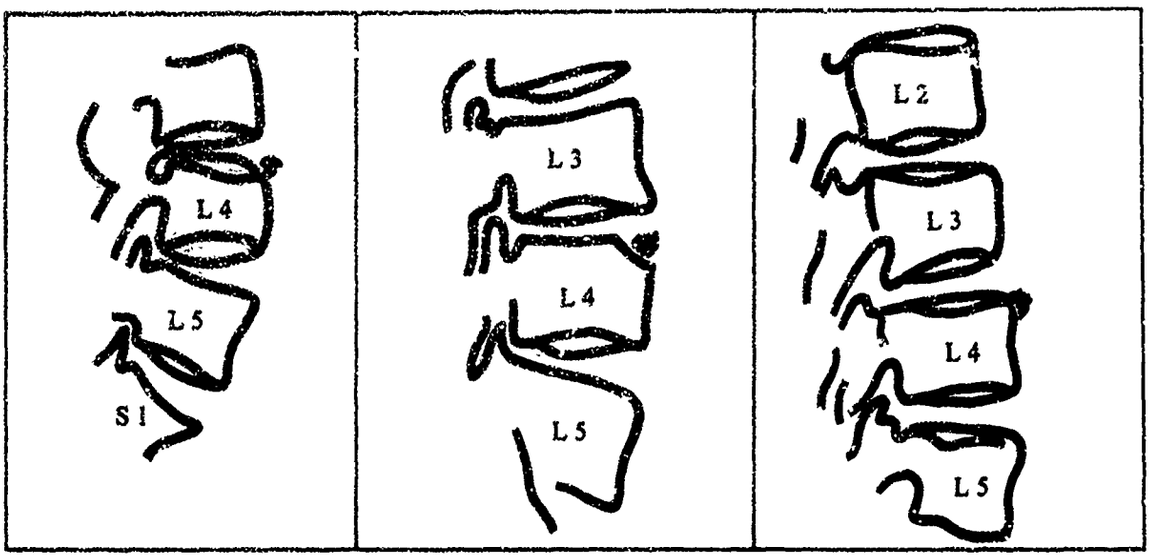
It is unusual for the detached corner to fit exactly into the contour of the vertebral body because either it is too small, being atrophique or even punctiform, or else too large by reason of excessive growth so that it overlaps the vertebral contours. We have usually seen this abnormality on only L1 - L2 but it may be associated with other lesions which may facilitate diagnosis.

Decoulx recommends an examination of the entire vertebral column for although the vertebral body may retain a normal shape it may also be cuneiform with the base posterially. On the plateaux, irregularities and depressions which are hernias into the spongy bone may be encountered. Occasionally the complete picture of the sequelae of epiphysitis may include the existence of free vertebral corners. Many authors think that even in isolation this abnormality renders the adjacent disc more fragile, inducing thereby an earlier degeneration. The existence of a lack of union of this type in an injured person has on occasion led to a mistaken diagnosis of fracture in spite of the fact that the characteristic features are easily recognisible. In the ejected pilots we have dealt with, the absence of union has not given rise to any special problems but on the other hand, after crash landings (landing with under-carriage up) we have observed this anomaly on a number of occasions. In one case in particular, the careful examination of the radiological case history of the pilot of a piston engine aircraft enabled us formally to eliminate the diagnosis of fracture which had been suggested.

We would emphasise in this connection the value of a faultless technique in taking the lateral X-rays since slight rotation may cause a super-position of the vertebral body and of the anterior corner, giving it thereby an appearance of overflowing like a fractured fragment. In such a case any discussion on the interpretation can be eliminated by a tomogram which brings proof of the nature of the abnormality by highlighting the regularity of the contours and the integrity and the structure of the detached fragment. An examination of reference plates or dossier can sometimes introduce a long delay but it can confirm the presence or absence of union of the vertebral corner.

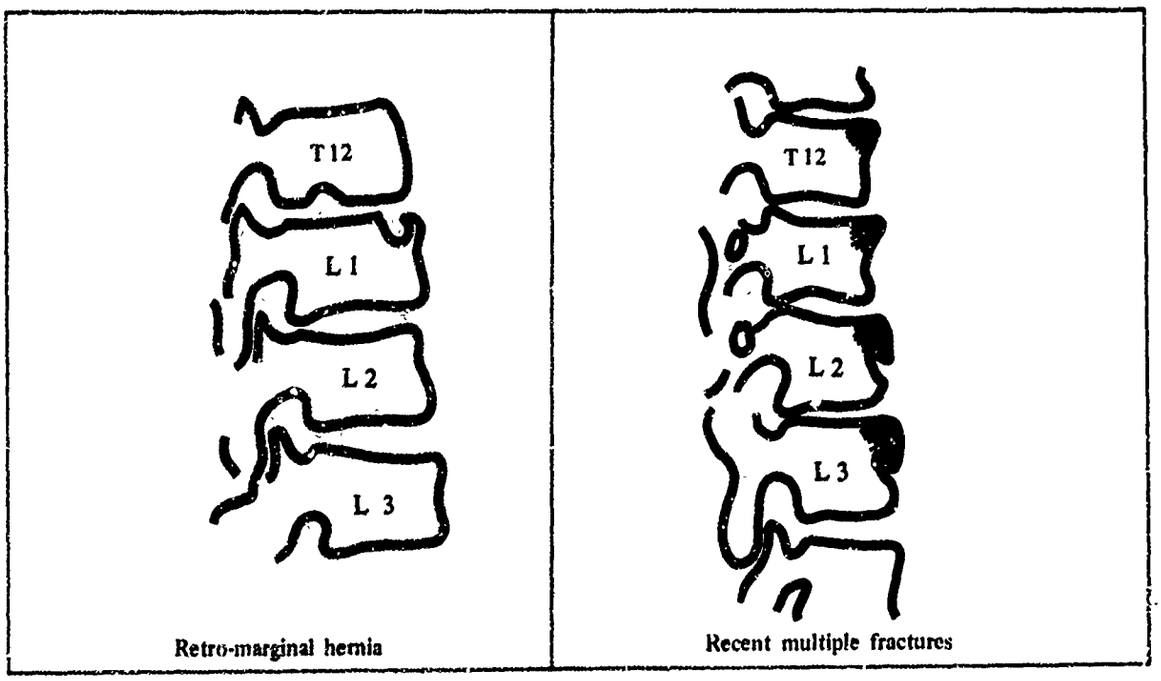
6.4.2.2 Anterior retro-marginal hernia (Fig.40)

De Seze and Rotes-Querol describe, under the name of anterior retro-marginal hernia, a peculiar notch on the superior vertebral plateau of a thoracic or lumbar vertebra. This abnormality can easily be diagnosed since on lateral view it shows a gentle slope posterially and on the anterior aspect, a sharp slope. It is surrounded by a zone of dense bone. On the antero posterior view it has the appearance of a large cupola or of a raised



Anterior corners (after Decouix)

Figure 39



Retro-marginal hernia

Recent multiple fractures

Figure 40

cuoule. This notch may be accompanied by an overall reduction of the height of the intervertebral disc, and occasionally one may observe an osteophytic excrescence on the anterio vertebral lip. De Soze considers that this change is not associated with injury but that it is simply a growth dystrophy which takes place at the level of least resistence, that is, anterially in the spongy vertebral structure which runs obliquely down and forw .

This anterior retro-marginal hernia which is a variety of intra-spongy tissue hernia, is most frequently observed in Scheuermann's disease and as sequelae of epiphysitis. Although it is generally associated with other characteristic signs of the condition, it is possible to find a retro-marginal hernia in isolation. After an injury, the use of the term "anterior retro-marginal hernia" should be avoided because the patient may interpret it as a traumatic condition with the possible psychological effects which are typically associated with spinal injuries.

Good quality radiographs usually enable this abnormality to be diagnosed but it is, in this connection, essential to stress the need for impeccable techniques. In our examination we have come across two cases in which insufficient radiographic evidence led to a wrong diagnosis of injury. A further examination employing standard techniques and carried out in the department was sufficient to eliminate the question of fracture. Tomograms enable one to confirm the presence of an anterior retro-marginal hernia since the section clearly delineates the contours of the hernia, the dense appearance of its margins and the characteristic orientation of its slopes.

6.4.2.3 Epiphysites - Scheuermann's disease type, and their sequelae

These conditions should under no cirumstances give rise to problems of differential diagnosis from fractures and they are mentioned here only because in a foreign survey of ejection fractures a certain number of the cases appeared to us to be uncertain or doubtful. Multiple fractures on ejection are indeed mentioned but the X-ray plates show lesions typical of epiphysitis.

The number of vertebrae affected, together with the cuneiform aspect of the body, the irregular laminated appearance of the plateaux, the unfused angles, the anterior retro-marginal hernias, appear to be sufficiently evocative. None the less a localised effect can in certain cases give rise to difficulties in diagnosis. Thus, we have found in one ejected pilot a discrete compression of 3 - 4 mm localised to T8 together with a Schmorl marking on the vertebral plateau above it. This compression whose origin could be disputed was associated with a slight asymmetry of T6 (reduction in lateral height on the left of the vertebral body), T6 being the inflexion point of a slight right scoliosis. The intervertebral discs adjacent to T6 were normal. Less marked deformations of T7 and T9 enabled one to suggest the diagnosis of the sequelae to epiphysitis.

The reference dossier confirmed the existence of these abnormalities and after ejection the pilot exhibited no clinical complaints. In accordance with Decoulx it must none the less be noted that localised lesions in the lumbar segment are much less well understood; none the less they do not give rise to any special diagnostic problems.

In closing this chapter we shall cite one classical cause of error, namely, the cuneiform pseudo vertebra of Schmitt caused by the projection of the glenoid cavity of the scapula onto the first thoracic vertebra.

7. TRAUMATIC SEQUELAE IN AVIATION MEDICINE

7.1 Generalities

Pilots of the Air Force and of Army Light Aviation who have been involved in an accident are all examined clinically and radiologically in the course of the medicophysiological supervision of flying personnel.

It should be noted that amongst these highly motivated persons, the presence of pain or discomfort is not necessarily always notified to the medical personnel examining the pilots and parachutists. Along with P.Lance, we can examine successively:

1. Pain in subjects having an unknown or unrecognised fracture.
2. Pain in subjects whose fracture has been identified and treated.
3. The so-called lumbar pain of effort (parachutists).

7.2 Pain in Subjects having an Unknown or Unrecognised Fracture

The fracture is unrecognised because there has been no radiological examination. In pilots from the Air Force and from the A.L.A.T., radiographs of the whole of the spine are compulsory, but in pilots of private light aircraft and gliders as well as in parachutists we have noted the appearance of secondary pain usually at the level of T12 - L1.

7.2.1 Clinical Findings

Chronic lumbar pain is the most frequent finding. It is generally aggravated by standing and sometimes by sitting for a long time, e.g. motor car journeys, helicopter flights and aerobatics. Quiet rest usually eases

this discomfort which is usually localised between T12 and L1, together with occasional root pain. The clinical examination occasionally reveals a gibbosity and more rarely a slight curve. There may be a backward movement of the spinal processes with reference to those immediately above and below, whilst on palpation a process may be tender.

The muscle masses about the spine are atrophied and there is reduced vertebral mobility.

7.2.2 Radiology

The radiograms show signs of fracture: anterior cuneiform compression fracture and comminution. Arthrosis is not unusual. According to P.Lance it is to these unrecognised fractures appearing only secondarily that we have for half a century been giving the names of traumatic spondylitis or the syndrome of Kummel-Verneuil. We shall return to this rather important point.

7.3 Pain in Subjects whose Fracture has been Recognised and Treated

The pilot or parachutist reports sick, with pain appearing after a variable time (Table XVIII).

TABLE XVIII

Consultation after injury	*Number of cases*
under 3 months	4
3-6 months	7
6 months - 1 year	12
1-2 years	13
2-7 years	14

Many of the subjects had been advised to carry out vertebral exercises under medical supervision but some had not understood the need for this treatment, whilst others who had started work had sustained injury (motor car accident, heavy landings in parachute on difficult terrain).

7.3.1 The Clinical Findings

The clinical findings are almost identical to those in the preceding section, and a fairly consistent finding is of hypotonia and atrophy of the paravertebral muscle masses. Lumbar pain is for the most part chronic.

7.3.2 Radiology

AP and lateral X-rays enable one to make an inventory of the injuries. Again we take the liberty of stressing the value of X-rays taken beforehand (at the entrance examination for flying personnel). In one case, a cuneiform appearance of T12 had been considered as of traumatic origin, whereas the plates taken before the accident revealed the same appearance which was thus a physiological variant. There are some post-traumatic sequelae and occasional signs of arthrosis on the radiographs.

7.3.2.1 The results of fracture

The radiological examinations consistently show a persistence of the cuneiform compression. There is often an increase of density in the compressed corner, but the contours remain regular. In the case of fracture of the anterior corner there is a remodelling which entails an increase in size antero posterially, of the vertebral plateau. In these observations of anterior cuneiform compressions, the intervertebral spaces maintain their normal height.

7.3.2.2 Vertebral arthrosis

Vertebral arthrosis is not constant amongst those who have vertebral fractures. It appears only if the disc has also been affected in the injury. The radiological picture of anterior marginal osteophytotis, pinching of the intervertebral spaces and condensation of the plateaux, is not specific. Indeed there can be an increase in density of the edges and vertebral angles opposite the damaged vertebra, whilst most often the inferior vertebra acts as a supporting bracket. In serious injuries the arthrosis can become a synostosis - a veritable bony bridge crossing the disc and fusing together two of the vertebrae. In one supersonic ejection, a bilateral synostosis of T12 - L1 appeared within a month and a half.

We have however been intrigued to see an atypical radiological picture in a fighter pilot who received another injury secondary to ejection. The appearance of the vertebral bodies of L1, L2 and L3 was normal on antero posterior and on lateral views; the intervertebral spaces were at the normal height but at the superior angle of L3 and at the intervertebral spaces of L3 - L4, curvilinear calcifications appeared. Antero posterior tomograms confirmed in planes 8, 9, 10 (equatorial plane 9), the calcifications which had been detected on the standard plates, furthermore at the level of the inferior right angle of L4, there was a similar type of calcification,

although less dense and going obliquely outwards and downwards. The implantation base was at the inferior left angle of L4. This latter calcification made one think of a syndesmophyte type of formation (Fig.40). A complementary examination of the dorso lumbar hinge and of the Sacro-iliac joint revealed no associated lesions, so it would appear that this is indeed a case of post-traumatic calcification.

7.4 Lumbago of Strain

7.4.1 Generalities

In their report to the French Orthopaedic Congress, A.Beau and A.Lemoine considered that muscular strain should be thought of as a muscular contraction taking place in unusual conditions and giving rise thereby to anatomical and functional disorders.

Into this framework falls the symptomatology presented by the parachutist M.J.Teyssandier who has made a particular study of this problem in French Airborne Troops, and who has described the vertebral pain as the "vertebral parachuting syndrome". The pain occurs frequently - 6.1-12.5 times for 10,000 jumps in the data relating to the 1,033,525 jumps made at Pau.

The number of cases which do not come to the attention of the doctor on a parachute unit must be emphasised since some individuals with pain do not consult the doctor but prefer to treat themselves by means of common remedies so as not to run the risk of being temporarily grounded. The motivation of parachutists must be borne in mind for in their specialty they are accustomed to a life which is not free from hazard and they tend not to dwell on their symptoms. All this enables one to understand how important it is for a doctor of an airborne unit to have the trust and confidence of the personnel he is dealing with.

7.4.2 Clinical Findings

The parachutist's vertebral syndrome can appear at any age and with a variable delay according to the number and frequency of jumps. In all cases the principal signs are pain which can appear either as chronic (this is most frequent) or as acute in which it is most marked.

7.4.2.1 Acute pain

The acute pain can either graft itself onto a basis of chronic discomfort or less frequently it may appear first. It is usually triggered off by a muscular strain such as carrying a suitcase or winding a starting handle or more frequently by an injury (parachute jump).

In 136 cases of parachutist's vertebral syndrome, 89 (i.e. 65%) appeared immediately after the jump (Richaud). Occasionally the pain was general over the entire spinal axis, but frequently it was localised and accompanied by irradiation of a root type pain in a belt or bar or in a well delineated dermatome. It is made worse by coughing, sneezing and defecation. It appears preferentially at the lumbar and lower thoracic level but it can also appear in the form of backache, orticolis, cervical pain and occipital headache. Such cases are much more frequent than one would believe from the topographical analyses of fractured vertebrae. The contracture of the paravertebral muscles brings about a marked functional impairment as well as characteristic postures.

7.4.2.2 Chronic pain

Where is the qualified parachutist who does not in the course of private conversation complain of lumbar pain or of other discomfort of vertebral origin? Our observations have been confirmed by many doctors of airborne troops. Sometimes diffuse, this pain is in general localised to a distinct spinal segment and is not usually accompanied by any root pain except in a subacute form.

This type of pain is of varying severity, eased by rest in bed, increased by a long period of sitting much more so than standing, it is increased of course as the day wears on and is awakened by the first movement after a prolonged stay in one position. It resembles the ligamentary type of pain which can be observed in "loading syndromes" (Hackett and Troisier).

If there has been a causal injury it will in general have been forgotten and will only be brought out on careful interrogation. In other cases the time between the injury and the appearance of first discomfort can vary from 3 months to 10 years, being on an average 1-3 years. Examination of the spinal cord reveals some reduction of movement and hypotonic or atrophed lateral spinal muscle masses. It is occasionally possible to elicit tenderness to either percussion of a spinal process and more frequently to pressure in the lateral spinal fossa.

7.4.3 Radiology

We learn from some incomplete statistics of Richaud involving 89 clinical cases of parachutists' vertebral syndrome, that the radiological examination was normal in 42 cases (47.2% of cases) and reveals signs of previous spinal complaint in 47 cases, i.e. 52.8% of cases. The detail of the identified lesions is as follows:

25 sequelae of Scheuermann's disease, 3 moderate arthroses of the cervical column; 6 moderate arthroses of the thoracic and lumbar column, 4 sacralisations of L5 or lumberisation of S1; 3 scolises.

The injury represented by the jump is thus revealing as all these subjects had undergone many selection examinations during which nothing in particular had been noted, whereas many of their friends had been eliminated because of clinically detectable diseases.

7.4.3.1 Radiologically detectable spinal lesions

Occasionally the syndrome may find its origin in a radiologically detectable spinal condition of which the patient may or may not be aware and which may have been present before he took up parachuting or which may have been acquired since.

Amongst the congenital lesions the following have been noted: slight spondylolisthesis of L5 on S1; transmission abnormalities of the lumbo sacral hinge (sacralisation and lumbarisation) and frequent morphological abnormalities (blocks or gaps in the posterior arcs of the last vertebrae). The sequelae of epithysitis (Scheuermann's Disease) are frequently encountered. In this the vertebrae are frequently deformed with flaky plateaux showing multiple notches. Affections of spinal posture (scolisis, kyphosis and lordosis) are sometimes encountered in the parachutist's vertebral syndrome. Normally discrete, these may not have been clinically detectable.

It is sometimes very difficult to link acquired lesions with a neglected or unsuspected causal injury. One should not lose sight of the fact that a minor physical condition can be associated with marked symptoms.

The acquired lesions of this type occur either infrequently, as a result of fractures of the processes or of the isthmus, or incidentally as a result of disc lesions with pinching of the intravertebral space, or more frequently with cuneiform or communuted fractures of the vertebral body. Very frequently these lesions may occur in association with signs of vertebral arthrosis. These latter are usually situated in the lumbar segment or in the lower part of the thoracic spine whilst a location in the cervical or upper thoracic segments is far from being exceptional. They can be detected from 25 to 35 years of age and at the 30th as well as at the 300th jump. The arthrosis may be generalised or may be associated with an old and quiescent osteoligamentary lesion.

It is often an osteophytosis localised near a vertebral interspace which draws attention to a disc involvement which would otherwise have passed unnoticed.

7.4.3.2 Comparison with other investigations on parachuting and sports

The Italians Fraitta and Cazzato have also remarked that "old parachutists" frequently exhibited a clinical syndrome of vertebral origin which is an analogous to that which we have described. In the course of systematic radiographic examination of the lumbar spine of a 100 of these subjects, they discovered that 50% of cases had radiological signs of spondylarthritis; 21% of cases had radiological signs of Baastrep's syndrome and 29% of cases had radiological signs of Baastrep's syndrome in its initial phase.

In the course of our observations we have not been able to demonstrate a single case of Baastrep's syndrome, and furthermore it seems to us that the figure of 50% for the occurrence of spondylarthritis is very high. It is possible that their sampling dealt with older and more experienced parachutists who had done more than 300 - 400 jumps.

In other respects Villiaumey has found arthrosis type lesions in 60% of subjects who were acidulously practising judo and only 18% in a control group. After having selected a group of judo experts who had pain corresponding to that of parachutists, he was able to detect in 63% of his subjects, signs of disc involvement which was sometimes minimal and without any arthrosis reaction. On a control group the figure reached was barely 7% of cases.

In view of the lack of systematic radiographs of the parachutists' spines we have no precise reference point. However, for some months, the selection tests for instructor now comprise such an examination so that in a few years we shall be able to examine this problem more extensively.

7.4.3.3 Spinal lesions with radiological signs

Very often it is the accumulation of microtraumae to which the vertebrae and discs are subjected at each jump, that in the end gives rise to a deterioration of these. Radiographic examination reveals no abnormality even in spite of the use of tomographic techniques and angles of incidence specially selected for the examination of L6, C7 and T2.

7.5 Other Problems

This radiological examination of post-traumatic effects cannot end without considering two problems which have already been the subject of much work, namely, the spondylolistheses and their traumatic etiology, and the syndrome of Kummel-Verneuil.

7.5.1 Spondylolistheses and its Traumatic Etiology

Certain authors such as Sicard have reported cases where the traumatic etiology of spondylolistheses of L5 on S1 is indisputable. In the radiological routine examinations made after ejection or after an aircraft accident (crash landing in particular) we have never come across a case of spondylolistheses. The type of

fractures observed did not predispose the development of this condition. However we must stress that it is possible to encounter spondylolistheses as a result of trauma. Obviously as a result of the tests made on entry (Chapter 3) everyone showing a dissolution of continuity of the isthmus with or without spondylolistheses will be eliminated.

7.5.2 The Kummel-Verneuil Syndrome

Since the work of Decoulx and Rieunau (1959) the syndrome of Kummel-Verneuil as originally described has ceased to exist.

This syndrome described by Kummel (1891) then by Verneuil (1892) is characterised by a three stage development as follows: First, initial trauma with moderate and transitory clinical signs; secondly, an interval without symptomatology and thirdly the appearance of gibbosity with a re-appearance of pain.

The anatomical basis of the syndrome is the appearance of a secondary collapse of the vertebral body as a result of injury. The frequency of occurrence of this entity was high. Let us note however that no precise radiological examination was carried out at the time of the initial injury. This failure to examine sufficiently the patient with a spinal injury had led to a false pathogenic concept which for a long time has been widely accepted. In fact this traumatic spondylitis of Kummel-Verneuil was according to Kummel, secondary to a post-traumatic osteoporosis. The vertebral compression appeared subsequently.

As a result of the increased numbers of routine radiological examinations it has been possible to demonstrate numerous types of fractures. Decoulx and Rieunau with their large number of cases have never seen a post-traumatic osteoporosis and they believe that the Kummel-Verneuil syndrome no longer exists as a clinical entity.

H.Magin and R.P.Delahaye have examined 102 case histories of spinal injury in the course of aircraft accidents from 1951-1963 inclusive. Amongst the recent injuries (1963) were 8 compression fractures of the spine and 12 cases with no lesion demonstrable by radiological means. Old injuries (82 cases) included 8 compression fractures and 74 injuries without detectable initial lesion. Delayed vertebral compression has never been met in the various examinations made.

Most orthopaedic specialists are in agreement with the ideas of Decoulx and Rieuman, that one should no longer refer to the syndrome of Kummel-Verneuil. The compression is not secondary; it is present on the first X-rays where it had been missed as a result of absence of radiographic examination.

8. AIRCREW SELECTION AND SPINAL INJURIES

8.1 Acceptance

8.1.1 Generalities

Having accepted that certain factors in flight are harmful, it is necessary during selection to detect any acquired or congenital spinal abnormalities which could be a zone of least resistance.

The case histories and the static and dynamic clinical testing eventually guide the radiological examination which is made systematically on all candidates for pilot, flight engineer, navigator or parachute instructor.

We shall now consider in turn the statistical studies bearing on homogenious populations (non-aircrew); statistical studies on aircrew; our policy on clinical investigation by radiological examination (reference dossiers), and the action taken in regard to minor congenital alterations of the spine.

8.1.2 Statistical Studies Relating to Homogenious Populations (non-aircrew)

Runge (1954) found 1174 clinically silent vertebral alterations (25.44%) in the course of 4654 entrance examinations. These malformations were distributed as follows; lumbarisation of S1 (0.68%); sacralisation of L5 (0.16%); supplementary vertebral segment (0.29%); scoliosis (2.23%); spinabifida occulta (3.09%); antero posterior displacements (spondylolisthesis) (2.03%).

P.Lance quotes the survey of Lindem Brown, Larsen and J.R.Mitchell who out of 6748 spines examined found 1929 subjects suffering from congenital abnormalities. R.P.Delahaye, H.Mangin and P.Boursiquot discovered 801 congenital abnormalities out of 6687 examinations of the spine (partial or total) (survey of 1959-1964 included subjects examined at Hiad Larrey).

It can therefore be estimated that 1 individual out of 10 (Lance thinks 1 out of 5) has a spinal malformation or deformation which may make his spine at least partially unsuited to some types of physical stress or to serious physical insult.

8.1.3 Statistical Studies on Aircrew

Following the finding of vertebral lesions after ejection, the need to verify the radiological integrity of the spine has been readily accepted by doctors in the French Air Force. In 1953 F.Montagard drew attention to

the theoretical aspects which have guided research and techniques. The entire spine was explored. F.Montagard and R.Picanoles (1956) reported the results of a survey of 1552 radiological files from 1953-1956. The vertebral investigation was rapidly narrowed down to the lumbar segment since at that time the authors believed that the lumbar spine received directly the impact of ejection and was therefore the most exposed to injury.

The radiological examinations concerned different groups of aircrew: experienced fighter pilots whose ages seldom exceeded 30 years and candidates for admission to aircrew aged from 18-20 years.

8.1.3.1 Results of pain

Of the conditions encountered Montagard and Picanoles list the following:

Vertebral postural conditions, slippages and alterations in the disco-ligamentary system.

Vertebral postural conditions

The authors seldom found serious vertebral imbalance and they report only two serious scolises; one without modification of the vertebral bodies, the other secondary to a thoracic wedge shaped hemivertebra. On the other hand some less obvious imbalance is frequently described as secondary to a marked asymmetrical sacralisation. The authors were of the opinion that this resulted in a marked lack of fitness for flying. Frequently occurring slight asymmetries of L5 causing a marked imbalance were also noted.

Vertebral slippage

Only one case of retrolisthesis was observed but on the other hand out of the 1552 files studied, the authors noted 36 cases of spondylolisthesis (2.23%). In most cases the spondylolisthesis affected L5. It was always of first degree, the fifth vertebra being only a quarter off the sacral base with respect to the posterior plane, and encroaching not more than 1-1.5 cms. Lysis of the vertebral isthmus was usually seen, especially on the three quarter and lateral plates and less frequently on the AP views.

The lysis was sometimes unilateral while the gap could either be slight or marked. In one case there was no gap but it was the presence of a lengthening of the isthmus which caused slipping. In one subject two spondylolisthesis at the level of L4 on L5 and of L5 on S1 were demonstrated.

Alterations in the disco-ligamentary system

Seldom met with, neglected at first, and later considered as a contra-indication to flying they were distributed as follows: 8 cases of intraspongy hernia (0.51%); 7 cases of antero retro-marginal hernia (0.45%); 5 cases of free anterior corners (0.32%). Of the subjects examined 4% presented anomalies which Montagard and Picanoles consider to be a contra-indication to acceptance.

8.1.3.2 Comment

This interesting study underlines the frequency with which anatomical variations occur in a homogenious population with no clinical signs of spinal disease. However, this survey, directed as it was especially to the lumber spine, gives no appreciation of the general position especially in regard to the thoracic spine which may be injured by ejection or crash.

Not knowing the remote consequences of ejection, the decisions taken have been too categorical. The importance of the lumbo sacral hinge pathology at that time may have justified these decisions as did simple dehiscences of the posterior arch which resulted in decisions of unfitness for ejection, however on the basis of wider experience legislation subsequently became more flexible and better adapted to reality.

Ejections, crashes and slight malformations

Chance has made it possible to observe the results of ejection or crash of pilots with slight congenital malformations. The pilots belonged to the first group, that is, of experienced flying personnel who were already converted to a jet aircraft and whose fitness had to be maintained. The fact that two of these pilots, showing a dehiscence of the posterior arch of L5 and S1, ejected without injury resulted in cancelling the regulation of unfitness on the basis of "spina bifida".

In this connection we think that this expression should not be used to describe a simple dehiscence of the posterior arch of L5 or of S1. We ourselves would rather refer to the frequently occurring condition as "dehiscence of the posterior arch". We think that this gap of the posterior arch is not a weakening factor. In a true spina bifida there is a congenital cleft of the vertebral column with meningal protrusion. The fact that a qualified pilot suffering from a spondylolithesis had no vertebral lesion after ejection allows us to think that we must not be too categorical with regards to fitness of a pilot with congenital abnormality of the lumbar spine. Physiopathogenical studies have furthermore taught us that ejection lesions are localised to the mid thoracic spine or to the lumbar thoracic hinge so these regions must be checked by radiological examination.

8.1.4 Our Position

8.1.4.1 Role of the routine radiological examination

In the light of previous work and of the experience emerging from the various surveys in crashes, ejections and parachute accidents, it appears that radiological examination has two roles. First, the elimination of serious lesions incompatible with flying, and secondly, the compilation of a reference dossier of diagnostic and medico legal interest.

Elimination of serious lesions incompatible with flying

In subjects exposed to a strict clinical examination this eventuality is rare. An unusual finding, however amongst candidates for flying school, other aircrew or parachuting students has been that of 4 cases of osteoarthritis (3 of which were tubercular) and 3 of rheumatismal pelvispondylites. Among parachutist instructors, as sequelae to epiphysitis, spondylolithesis of L5 on S1 with spondyloptosis have been encountered.

Establishing a reference dossier

The radiological examinations carried out before admission make up the reference dossier and provide a radiological inventory of the spine in aircrew before flying. The medical interpretation (not read by the candidate) is detailed and will note very carefully all the morphological variants as well as the discrete congenital abnormalities.

The comparison of this reference dossier with that made at the time of an examination when an air accident occurs or on the occasion of clinical changes seems to us essential. It may remove the doubt in the face of some small alteration and will enable the all too frequent wrong interpretation to be corrected.

Personally in our experience of injuries (crashes, parachuting, ejections) we have on a number of occasions been able to eliminate the diagnosis of fracture. We note principally 3 causes of mistaken diagnosis of fracture:

1. The anterior corner.
2. The retro-marginal hernia
3. The vertebra with a cuneiform tendency.

The reference folder is a medico legal document which not only facilitates the study of an occupational disease but also is essential to the defence of interests, either of the State or of the flying personnel.

In commercial aviation this radiological examination seems to us indispensible for investigation and for admission to the profession. Thus all progressive diseases and those likely to complication will be eliminated. Some air stewardesses and stewards have complained of lumbo thoracic pain due, according to some of them, to flying. In fact, however, this is sometimes a case of patients with sequelae to Scheuermann's epiphysitis who have had to be grounded.

These radiographs for admission will make it possible to list the findings and to assert which are due to flying.

8.1.4.2 Technique of the systematic examination

The whole of the spine is explored by antero posterior and by lateral views. Two techniques are used, firstly, segment by segment X-rays and secondly X-rays of the whole of the spine.

Segment by segment X-rays

If an incidence of L5 is used, the taking of 6 or 7 negatives per day in a radiology department should present no problems.

X-rays of the whole spine

This method which is not yet currently used seems none the less interesting. On two negatives 30 cm x 90 cm the entire vertebral column is explored and its balance is determined. Gros, Bloch and Walter (of Strasborg) have recently described a technique enabling an examination of the whole spine including the lower part of the skull and whole of the pelvis to be made in a physiological position. The subject stands, the distance from source to film being 3 metres.

In order to obtain a negative of perfect quality, these authors advised the use of a 6 kenotron generator (kenotron = high tension rectifier - translator); a tube with a focus of 2 x 2 mm with possibility of obtaining 110 kV at 500 - 600 mAs; 3 second exposure; a stand with a mobile grid and a suitable correcting filtration.

Sollmann has perfected a device comprising a rotating compensating shutter mounted on a perspex disc. This device compensates for the different densities of the body segments, the radiation being filtered for a varying time. We have no experience of this technique.

The second method uses ordinary equipment which can take a negative of 30 x 90 cm. It is necessary with this, to use a 30 x 90 cm cassette.

A series of screens compensate for the differences in opacity of the cervical-dorso-lumbar segments; a grid of 110 lines to the inch, ratio 10, for a film focus distance of 180 cm; a holder for the cassettes so that they may be placed on a vertical stand.

As with the preceding technique, development is made easier by the use of a folding developing frame which does not give rise to any special difficulty when used with a developing machine. This method seems simpler as it involves less cost, and the negatives thus obtained are furthermore identical to those of the Strasbourg authors' methods.

Localised negatives eventually define more precisely the morphological abnormalities which can be detected on these 30 x 90 cm negatives. Personally we are of the opinion that this method is sufficient to compile the reference folders.

8.1.4.3 The problem of gonade dose

It has been said that the practice of routine radiography dangerously increases the gonade dose given to the flying personnel. The importance of this problem, common to all routine examinations, must neither be exaggerated nor under-estimated. In fact measures effected on a model varied from 25-125 mrads for each antero posterior or lateral negative (Lindell and Lowry-Dawson). These small doses do not appear to constitute any serious hazard as the advantages of the use of routine X-rays are greater than the risk eventually taken.

8.1.5 Conduct in Relation to Minor Congenital Impairment

It is of course the case that acquired diseases (inflammatory or tumours) or serious congenital ones (adventitious hemi-vertebra, kyphoses, essential or acquired scoliosis) are to be considered as a reason for rejection. The intention is not to fail the well motivated subjects yet at the same time to maintain a normal margin of safety. The attitude adopted towards congenital anomalies differs according to the vertebral elements affected: disco-somatic anomalies, anomalies of the posterior arch and morphological variants.

8.1.5.1 Disco-somatic anomalies

Disco-somatic anomalies mostly give rise to spine deformities and to posture inbalance and are thus incompatible with flying. Only 2 common anomalies will be considered; first, the congenital fusion and vertebral plateaux notches.

The isolated congenital block or fusion, in principle entails neither a modification of the height of the spine nor an abnormal deviation except when the fusion concerns a large number of vertebrae. The commonest are the fusion of C2 - C3 and the sacralisation of L5 on S1. Since cervical lesions are exceedingly rare in aviation medicine, the fusion of C2 on C3 must not be considered a cause of rejection if it occurs in isolation. The same applies to the sacralisation of L5, or the lumbarisation of S1 if they are clinically quiescent.

We are of the opinion that this anomaly as regards the profession of physical training instructor, must be a cause for rejection especially if a military or test parachutist's career is envisaged.

Notches of the vertebral plateaux (Schmorl's notches) result from abnormal discal expansions. In general, these notches when multiple or associated with marked alterations of the plateaux, are a reason for rejection. On the other hand an isolated and medium grade Schmorl notch must not be considered a cause for rejection.

An anterior retro-marginal hernia, even isolated, however, seems to us a cause for rejection from the task of flying a high performance aircraft or from parachuting since this alteration makes the vertebral body more fragile. Moreover, it must be remembered that this anterior retro-marginal hernia is frequently associated with other alterations of the spine and in particular with the sequelae to epiphysitis.

8.1.5.2 Posterior arch anomalies

Posterior arch anomalies result from disorders of the neural canal development. There may also be various menigo-medullary malformation, but alterations of a minor type and without any clinical manifestations are very frequent (10% average).

Fusion failure of the secondary ossification centres with the various articularly processes has no bearing on fitness. It is enough to be aware of them in order to establish a differential diagnosis (possible confusion with a fracture). It is to be remembered that injury to these vertebral elements in isolation is unusual.

The posterior arch dehiscence is without doubt the commonest congenital malformation. Most often found in isolation, it is especially found at the lumbo sacral hinge and is usually asymptomatic. It does not alter the strength of the spine and is not a cause for rejection. The pathogenic study of spinal fractures in aviation medicine as well as a precise knowledge of the effects of ejection, crashes and parachuting on the spines of many subjects with this anomaly confirm this opinion.

Dehiscence of the isthmus or on the other hand spondylolysis is a cause for rejection. This fairly common anomaly (5-3%) is mostly bilateral. In general it affects on the last lumbar vertebrae (L5 in most cases). Although the gap filled with differentiated tissues offers a certain resistance and also since this spondylolysis is not situated in a region liable to flying injuries, it must call for rejection for its progression towards spondylolisthesis is too frequent to be neglected.

8.1.5.3 The morphological variants

The morphological variants are the least important congenital malformation. Their existence does not carry any limitation to fitness but on the other hand they pose problems of differential diagnosis (see above). They consist of cuneiform vertebrae and vertebral corners.

8.2 Surveillance

1. In cases of fractures with intact posterial wall, most pilots and parachutists have regained normal activity 3-6 months after the injury. They have followed a treatment based on progressive vertebral gymnastics under medical supervision. Surgical treatment (graft) is not practiced for this category of fractures. The clinical examination must be concentrated on the state of the lateral spinal musculature.

Flying personnel and parachutists very quickly learn the value of vertebral gymnastics but unfortunately in some situations, operational needs or a lack of co-operation by the patient explain the possible appearance of a secondary post-traumatic syndrome dominated by a persistent pain.

2. In the case of fractures involving the posterior wall, definite rejection has been the rule for the parachutist and parachutist instructor alike. After a year clear of symptoms certain jet pilots have been recategorised and authorised to fly. Indeed, one fighter pilot had become an excellent navigator on transport aircraft. Another - a Mirage III pilot is now a transport pilot, but these are exceptions which have needed numerous medical examinations and they must not let one forget the seriousness of these fractures with injuries to the posterior wall. An injury of this type involves a definite unfitness to piloting a high performance aircraft and to piloting a helicopter. The downgrading to light planes may be authorised but each particular case has to be considered on its own merit.

The pilot, however, must be warned of the fragility of his spine which has shown a fracture with injury to the posterior wall and of the seriousness of a subsequent fracture. Up till now only the downgrading to transport aircraft pilot has been decided upon. It is a fact that the occurrence of fracture at the time of a crash in a heavy aircraft is exceptional. It should be noted, however, that some pilots have been downgraded as a result of posterior wall fractures sustained in road accidents.

PART II: THE AFFECTIONS OF POSTURE IN AVIATION MEDICINE

1. INTRODUCTION

This chapter will deal only with backache of helicopter pilots and the cervical injury of pilots of military jet aircraft. If the pathogenisis of the former appears to be clarified, the same cannot be said of the latter where many doubts still persist.

These two conditions constitute true occupational ailments of aviators in that they are caused by flying. Are there other occupational diseases? The vertebral syndrome of parachutists considered earlier comes into this category, being due to a profession in which microtraumae are frequent. Does the same apply to lumbar discomfort offerred by transport aircraft pilots and by cabin staff which some have considered as a separate condition? This is a case of common aches and pains caused by the presence of an arthrosis which would have been manifest even if the subject had not been aircrew so we shall not consider this type of discomfort in the framework of this study devoted to the pathology of posture.

2. VERTEBRAL PAIN IN HELICOPTER PILOTS

2.1 Introduction

Vertebral pain of helicopter pilots has been known for many years. "In 1938, the pilot Maurice Clausse reported unpleasant vibration causing the whole aircraft to shake which, after an hour's flight caused this pilot to hasten back to the hangar in order to look after his aches and pains." This sentence quoted by Vice Admiral Joubelin is still true. Since helicopters came into general use in the Air Force in 1950, doctors have demonstrated the relationship between vertebral pain and helicopter piloting.

We must quote the clinical work of Missenard and Ternaeu (1957), of Fabre and Graber (1959), of Montagard, Sais and Guiot (1961), of Sliosberg (1962), Haatk (1955) and Wiesner (1960) in regard to pathogenisis and also the measurements of vibration on heavy helicopters by Feris and Auffret (1966).

2.2 Clinical Studies

2.2.1 *Frequency*

The frequency of occurrence varies according to the authors; 60% (Montagard et al.); 80% (Missenard and Graber). Sliosberg noted 87.5% but this high value can be explained because the investigations concerned only pilots working in an operational area.

2.2.2 *Predisposing Conditions*

Pain occurs only after about 300 flying hours on an average. The frequency of the flight plays a great part, thus Sliosberg found that lumbar pain occurs after flying for 5 hours a day and from 40-50 hours a month.

Most authors stress the predisposition which results from pre-existing spinal lesions (arthrosis, sequelae to Scheuermann's epiphysitis for instance). These pilots experience symptoms earlier (50-100 flying hours) but on the other hand a strong lateral vertebral musculature can increase the resistance to vibration and delay the appearance of the discomfort.

Thus in a supine position, being on holiday, a change of aircraft, and in particular, being a passenger on an aircraft bring about a reduction in or disappearance of the pain.

2.2.3 *The Clinical Symptomatology*

The clinical symptomatology is essentially low back pain but it is possible to note some cases of cervical or of thoracic pain.

2.2.3.1 *Lumbar or low back pain*

Lumbar or low back pain is most frequent and may give rise to little discomfort or to muscle spasm situation in the low lumbar or sacral regions. This discomfort disappears after the flight. In the more severe condition this discomfort gives way to pain which becomes more intense towards the end of the day, persisting in fact throughout the evening but disappearing after a night's rest. The pain which is made worse by coughing, or by defaecation impairs flexion and can be localised either throughout the entire length of the spine or else only at the level of the lumbar thoracic or lumbo sacral hinges. It is furthermore not uncommon to find irradiation into the sciatic nerve.

The clinical examination of the erect subject shows from in front, a posture which is sometimes normal, sometimes towards or away from the side of the pain. Seen from a side view, the patient may less frequently exhibit an inversion of or a reduction of the lumbar lordosis. Antero posterior movements are limited and Lasague's sign is sometimes positive. Bonnett's sign (pain on adduction of the thigh) may give rise to some discomfort

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which may also exist with pressure on Valleix's points (tender points on the course of certain nerves in neuralgia - translator). The neurological examination is nearly always normal in regard to motor control, tonicity and reflex responses.

2.2.3.2 Cervical pain

The cervical pain arises both low and medially. Linked to a hyper-extension of the head, it can in some cases irradiate the upper limb and give rise to a classical symptomatology of cervico brachial neuralgia. Occasionally found in isolation the cervical pain is more usually found in association with low back pain.

2.2.3.3 Thoracic pain

Thoracic pain arises in the mid regions and its character is that of dull ache rather than true pain. Extension movements of the trunk combined with backward movement of the arms causes this pain to disappear.

2.3 Radiological Studies

Radiographs in 30% of helicopter pilots examined at the Dominique-Larrey hospital and taken before treatment confirm the integrity of the spine. On the other hand in 60% of cases there exists a scoliosis attitude without rotation of the vertebral bodies. This antalgic attitude generally centred on L1 or L2 is not accompanied by changes of vertebral morphology. Radiodynamic tests (plates taken in lateral flexion) do not reveal any gap or selective pinching of the intervertebral spaces. Observations such as these lead us to think that we are not dealing with a frank disc lesion.

It is possible in 10% of cases to note the presence of signs of low lumbar arthrosis (anterior marginal osteophythosis of L4 - L5 and pinching of the intervertebral spaces) and also the presence of traumatic sequelae (anterior cuneiform compression). In a helicopter pilot complaining of lumbar pain with sciatic irradiation after prolonged flights, we have by means of standard plates and tomograms, been able to observe a most unusual radiological condition: osteophytosis - marginal posterior and inferior - of L5. Radiculography using methiodal shows up an opaque bulging of the posterior column at the inter-space of L5 - S1 (probable discal hernia). Although it was not possible to be certain of the specificity of this unusual arthrosis it should be noted that it was in fact aggravated by helicopter flights and by travelling in a motor car.

For 6 months we have been studying the appearance of the spine in subjects seated in the same position as for piloting. We have had constructed, a mock-up of an Alouette II which was taken to the X-ray room at the Dominique-Larrey hospital. Antero posterior and lateral radiography will enable one to look for variations in spinal posture produced by piloting. This will be effected by 30 x 90 cm plates. Different types of seat and different positions will be employed and in parallel a questionnaire involving 100 pilots will be initiated.

2.4 Physio Pathogenesis

The vertebral pain of helicopter pilots is not specific since it is found in motor car drivers as well as in the drivers of agricultural tractors but they are none the less most severe in flying personnel. The pilots bad seated position and vibrations explain the appearance of this discomfort.

2.4.1 Bad Posture due to Piloting Conditions

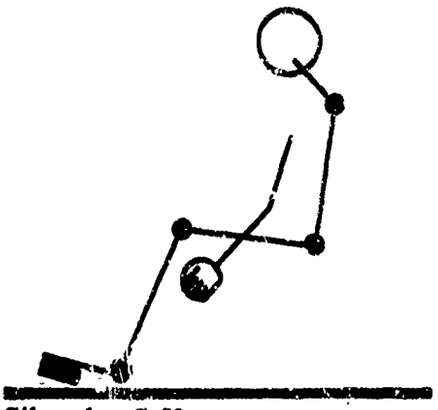
The limbs are constantly in use. Both feet operate the rudder bar, the right arm the cyclic pitch whereas the left arm operates the collective pitch and at the same time regulates the throttle control. This use of the collective pitch control causes the body to lean to the left and furthermore in order to see the pilot may have to lean forward. Thus his body is continually in a state of asymmetry and Sliosberg puts forward 3 causes of the discomfort (Fig. 41). There is first the asymmetric attitude prevention relaxation of the spinal musculature; secondly, the persistence of this attitude during the task of piloting and thirdly constant tension of the spinal accessory muscles due to the forward leaning position adopted by the pilot. Sliosberg furthermore attributes this pain to muscles being in constant tension (which may be itself accompanied by pain) and a mechanical vertebral cause.

Keegan has shown that a seated position brings on an increase in pressure at the anterior part of the intervertebral disc. The force exerted by the vibrations will therefore increase the existing higher pressure and press back the nucleus pulposus towards the ligamentary sheath and the nerve roots. Leaning forward will worsen this discomfort. In the phases of flight corresponding to take-off and landing this position is combined with a lateral flexion to reach the low stop on the cyclic pitch control. In those phases of flight marked low frequency vibrations are often encountered.

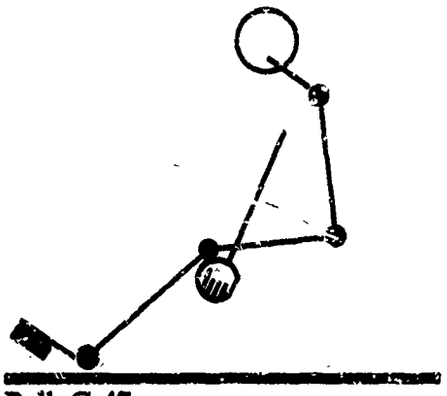
Wissner describes 6 comfort angles, according to which each segment makes a specific angle with the segment of the adjacent limb. This angle corresponds with the relaxation position of the antagonist muscle groups. According to these comfort angles as defined by Wissner, the pilot's position is very poor on the Sikorsky 358 and on the Bell, somewhat better on the Alouette, and excellent on the super Frelon (Fig. 41).

2.4.2 Vibrations

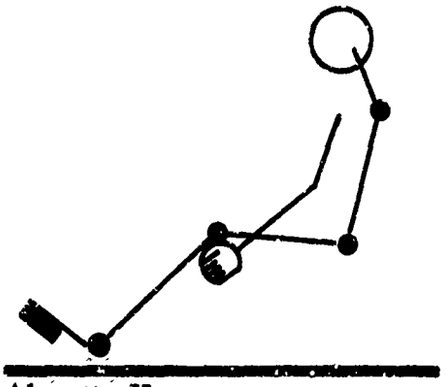
In helicopter flight the vibrations encountered have two distinct origins.



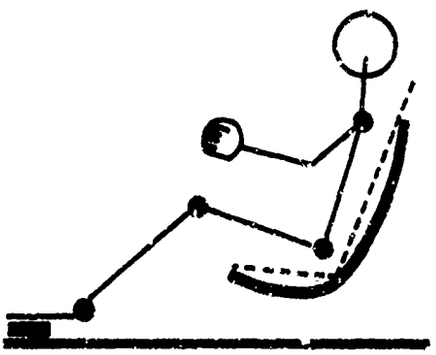
Sikorsky S 58



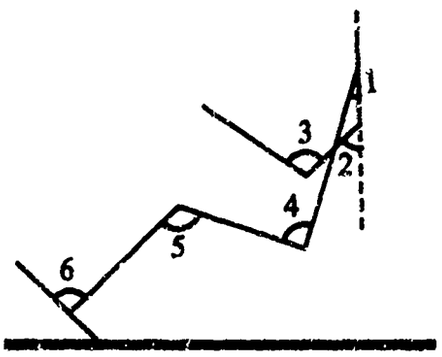
Bell G 47



Alouette II



Position of Swearingen



Comfort angles quoted by Wisner

$10^\circ < 1 < 20^\circ$
$15^\circ < 2 < 35^\circ$
$80^\circ < 3 < 90^\circ$
$85^\circ < 4 < 100^\circ$
$100^\circ < 5 < 120^\circ$
$85^\circ < 6 < 95^\circ$

Fig. 41 These diagrams show the poor posture on the S 58 and the Bell seats and the better position on the Alouette compared to the data of Swearingen and the "comfort angles"

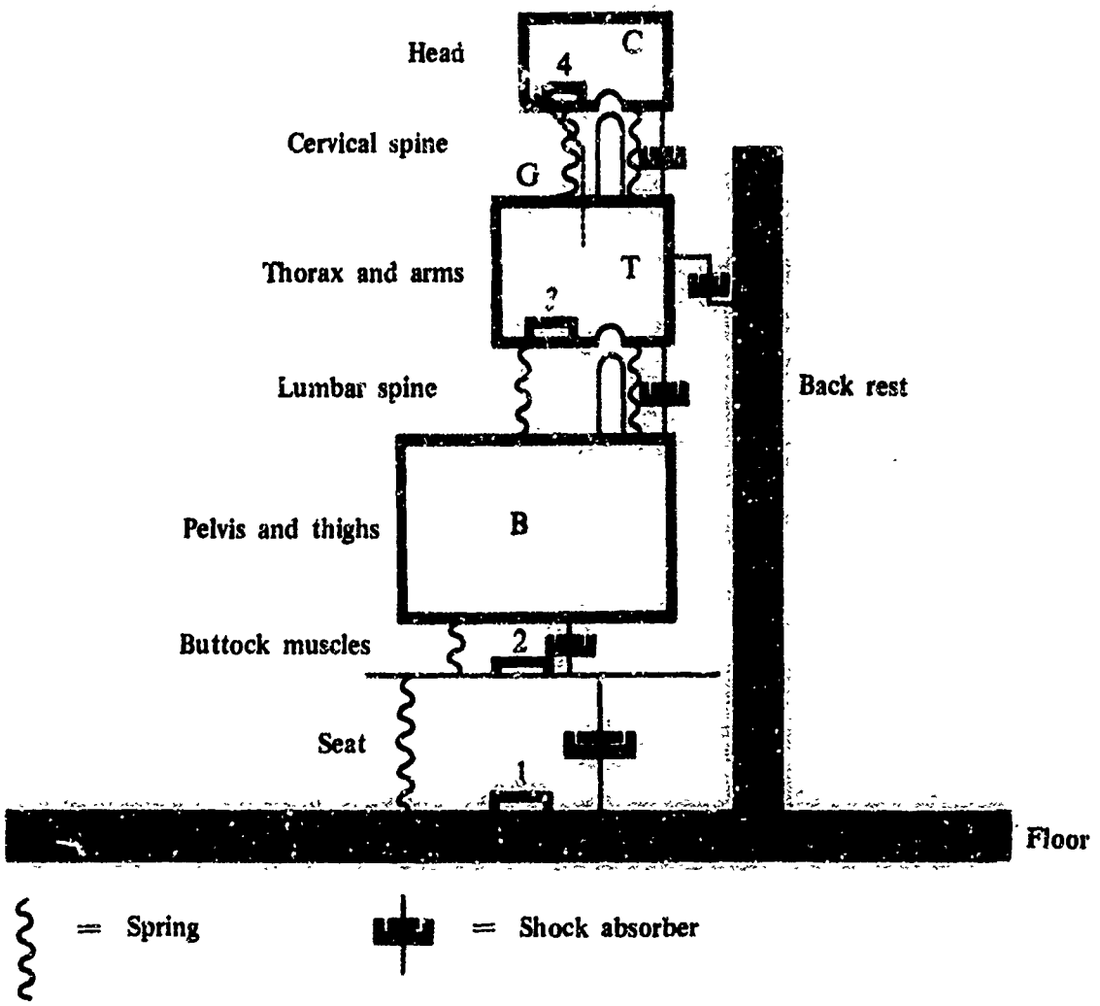


Fig. 42 Diagram of human body considered as a system of suspended masses (after Haack)

2.4.2.1 *Very low frequency vibrations*

Very low frequency vibrations due to atmospheric turbulence, appear in low level flight, and when flying through cloud. They are made up of the response to aerodynamic effects and to actions by the pilot mediated through his servo controls (Seris and Auffret). These vibrations are in the resonant frequency range of the human body and of the seat.

2.4.2.2 *Vibrations of mechanical origin*

Vibrations of mechanical origin are of higher frequency and come from the main rotor and the tail rotor; from the engine, and from the transmission. In the descriptions of Haack and Dackmann the human body can be represented as a system of suspended masses in which the muscle masses and the intervertebral interstitial tissues play the part of springs and of shock absorbers (Fig.42). The shock absorber paravertebral muscles limit the skeletal movements, and the hard work which this entails thus brings on contracture and then pain. With fatigue the efficiency of these shock absorbers is reduced and may even disappear in which case the vibrations may act directly on the entire vertebra and disc.

The system of suspended masses which the human body represents, resonates at particular frequencies (4-6 Hz). It is a fact that given equal level of stimulus, the further the frequency is from the body's own frequency, the less unpleasant it appears to the pilot so that the resultant discomfort is less.

2.4.3 *Measurement of Vibrations (CEV Bretigny)*

Seris and Auffret who studied the problem of the shock absorbing or amplification of vibrations by the super Frelon seats have found that most seats employed in aviation, have a frequency response within the resonant frequency of the human body. The vibrations of the aircraft are therefore transmitted to the pilot with an amplification of the most harmful frequencies.

On the Y axis of the helicopter the following have been recorded in low level flight at a frequency of 4 Hz: 0.05 g at floor level, 0.8 g at the level of the seat cushion and 0.16 g at head level. In this case the seat/pilot combination corresponds to an amplification of x3. Between the seat and the pelvis there have been recorded an amplification between the frequencies of 2 - 11.5 Hz; a damping (ratio 2) for the 20 Hz band; a damping (ratio 4) for the 40 Hz band and a damping (ratio 13) for the 150 Hz band.

The same phenomena are repeated along the body. Thus, according to Dackmann, the extent of damping between the pelvis and the shoulder is 1.25 to 15 Hz; 2.5 at 20 Hz and 6.5 at 40 Hz.

The harmful nature of the low frequency vibration (in particular between 4 - 7 Hz) must be stressed, particularly since these are poorly damped by the seat. To damp them out is difficult, and indeed it is impossible to lower the natural frequency of the seat to any marked extent without considerably increasing its mass. One possible solution might be to mount the seat on a hydropneumatic suspension.

Each seat has its own particular frequency spectrum, thus Alouette II has two peaks at 6 and at 18 Hz; Sikorsky 58 has two peaks at 3.7 and at 15 Hz whilst the super Frelon is mostly above 20 Hz. These vibration measurements explain (Fig.43) why the super Frelon enjoys a better reputation than other helicopters amongst flying personnel. Furthermore because of the backward tilt of the seat, the pilots position is more comfortable than in other aircraft, whilst thanks to a well positioned collective pitch control, the pilot does not have to lean forwards and to the left.

3. THE CERVICAL COLUMN OF MILITARY PILOTS OF JET AIRCRAFT

3.1 Generalities

The position of the pilot seated on an ejection seat is obviously far removed from the position of comfort as defined by certain authors, in particular Wissner. Certain requirements such as ejection, visibility of the radar tube and downward visibility - ahead and to the side, compel the pilot to adopt set attitudes.

These positions are in themselves certainly not sufficient to cause osteo-articulatory conditions but they act as an aggravating factor in regard to the effects of acceleration and vibration.

The most frequently encountered accelerations are in the seat to head direction when the weight supported by the cervical column is equal to the mass of the head multiplied by the load factor. One must of course bear in mind the weight of equipment which the subject may be wearing: a pressure helmet for example, weighs 4 kg.

Vibrations are particularly marked in certain phases of flight (taxi-ing, take-off, low level flight, turbulence and landing) in which the pilot is in a poor position, leaning forward and in a set posture.

3.2 Studies

3.2.1 *J.Sais (1958)*

J.Sais (1958) who is a doctor in the French Air Force, drew attention to the effect of the considerable statodynamic work to which the cervical spine is subjected.

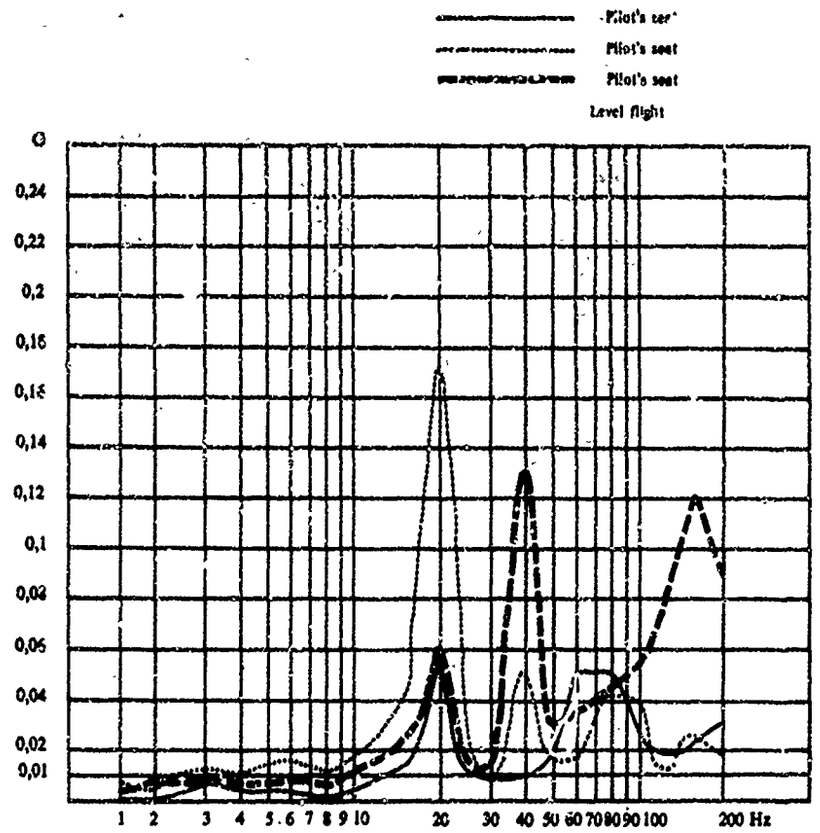


Fig. 43 Measurement of vibrations

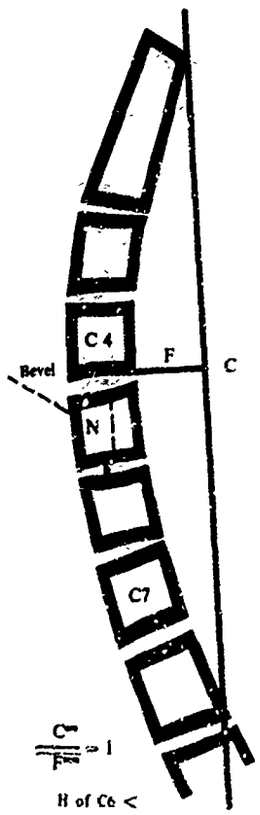


Fig. 44 Attitude and form of a normal cervical column (after Arlet and Lacomme)

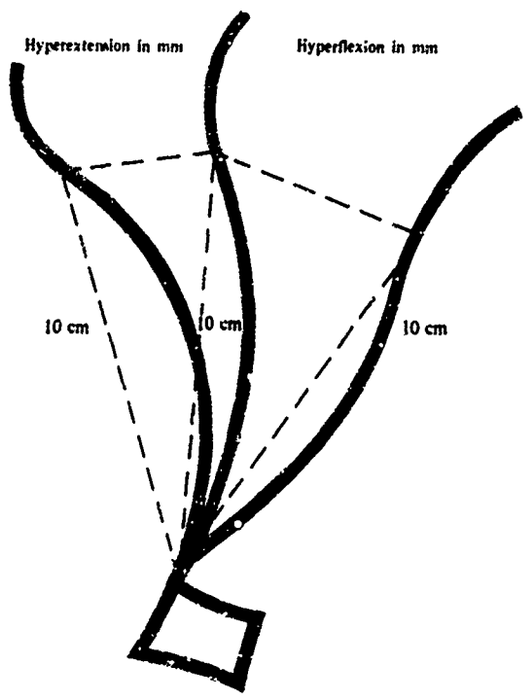


Fig. 45 Diagram of the mobility of cervical spine (after R. J. Hamburger and G. J. Puister)

Before beginning training on the ejection seat rig, the spines of 60 pilots of a Fighter Squadron, were systematically X-rayed. Sais found 40% of abnormalities at the level of the cervical spine and so he consulted 168 files at the Centre Principal d'Expertise Medicale du personnel navigant in Paris.

Frontal and lateral views of the spine, taken in a standing position, were in a number of subjects added to by a dynamic examination in which lateral views were taken in hyperflexion and in hyperextension.

In 228 young pilots (average age 25.4 years) Sais found 111 normal (48%); 121 showing pathology (52%); 116 cases of altered lordosis and 5 cases of arthrosis affecting C2 - C3 (1 case); C5 - C6 (3 cases); and C6 - C7 (1 case).

Irregularities in curvature were detected by a measurement technique described by Arlet et al. (Fig.44) were distributed as follows: 12 cases of attenuated C/F lordosis; 59 cases of straightening of the spine - either complete or affecting at least 4 vertebrae; 17 cases of reversal of the normal curvature.

These irregularities were sometimes associated with vertebral displacement or with limitation of extension.

Such a percentage of abnormalities in young jet aircraft pilots with no history or injury, urged Sais to establish a correlation between the observed irregularities and the work of the cervical spine.

3.2.2 R.P.Delahaye and P.Edouard

R.P.Delahaye and P.Edouard, in an unpublished study, analysed 120 radiographs of fighter pilots (1959-1962). They found over 60% irregularities of curvature amongst subjects aged from 20-30 years whereas a control group of 120 subjects of the same age, who had not been exposed to the hazards of flying, showed anomalies of curvature in only 5%.

3.2.3 R.J.Hamburger and J.G.Puister (1960)

R.J.Hamburger and J.G.Puister (1960), further to the report of J.Sais, carried out an extensive statodynamic examination of cervical spinal lesions in fighter pilots (National Centre for Aviation Medicine - Soesterberg, Netherlands). They examined 100 jet aircraft pilots of average age 27.5 years (Group A); 100 pilots of conventional aircraft (average age 26.1 years - Group B), and 100 student pilots of average age 20.7 years (Group C).

All these subjects were healthy and with no history of vertebral injury. Radiographs were taken in a normal attitude (AP and lateral) and in maximal hyperextension (lateral) and maximal hyperflexion (lateral). Hamburger and Puister looked for signs of arthrosis and abnormalities in curvature. They measured the mobility of the cervical column by a technique outlined in Figure 45.

3.2.3.1 Results

Research on Arthrosis

Group A (jet)	*Group B (conventional)*	*Group C (pupils)*
One established arthrosis at C6 - C7 16% slight signs of arthrosis	12% slight signs of arthrosis	One established arthrosis at C5 - C7 14% slight signs of arthrosis

These percentages are not statistically significant.

Anomalies of Curvature Classed as
R (Rectitude) L (Lordosis) K (Kyphosis)

	Group A	*Group B*	*Group C*	*Total*
R	42	35	26	103
L	51	55	65	171
K	7	10	9	26
Total examinations	100	100	100	300

The differences are not significant.

3.2.3.2 Mobility of the cervical column

The Dutch authors carried out a study of the total mobility of the cervical spine by a statistical method in which they compared hyperextension, hyperflexion and the total mobility in each of the groups A, B and C. They concluded that group C (student pilots) had a greater mobility especially in hyperextension, than groups A and B. They found that group B (conventional aircraft) showed less hyperextension but on the other hand greater flexion without impairment of total mobility. Hamburger and Puister therefore invalidate the results of Sals but it should be noted that in the Dutch study the age of the control population was relatively lower than that of the pilots. Furthermore, aircraft are flying at higher speeds and with higher accelerations. Finally, it should be noted that in the majority of cases which we have seen, it seems to us difficult to make a distinction between slight and marked signs of arthrosis.

3.2.4 Lamasson (1961)

Lamasson (1961), in a well documented study, stressed the frequent localisation of osteopathic lesions in the cervical and lumbar segments of the spine.

3.2.5 Volek Josef (1962)

Volek Josef (1962), found over 10% more arthrosis in a group of pilots than in a normal population of the same age. He suggested that microtraumae by accelerations and by prolonged vibrations might be responsible.

3.3 Observed Facts

In the practice of aviation medicine we have observed a certain number of facts which, it seems to us, should be borne in mind as arguments in favour of an occupational disease. Cervical pain is fairly common, especially in prolonged flight with low altitude, where the level of vibration is very high. It is probably linked to the fixed posture of the pilot and to the need to control the aircraft and to read the instruments.

After ejection where the radiological examination has established that the spine was undamaged several pilots none the less report sick with occasionally most persistent cervical pain which is sometimes accompanied by contracture of the vertebral muscles and of the trapzius. There is no neural irradiation of the type usually met with in a cervico-brachialis neuralgia. Is it possible that accelerations, and especially repeated accelerations in the + Gz axis, may give rise to a change in the discs particularly in the cervical region? That this may be so is suggested by the fact that cervical pain is sometimes experienced as a result of marked accelerations and in the absence of any arthrosis.

Jean Deb. This subject experienced his first cervical and lumbar pain at the age of 32 during an aerobatic sortie on a Fouga.

These acute pains diminished in a few days only to re-appear chronically. The spinal posture and movement revealed no abnormality and radiography of the cervical column revealed an anterior-marginal osteophytosis with signs of arthrosis to the right - C3 - C4, and left C5 - C6. The lumbar spine was normal on X-ray. The observations of a doctor-pilot have shown that accelerations may give rise to a cervico-brachial neuralgia as a result of arthrosis of very rapid onset (unpublished work). Lateral, antero-posterior, and oblique radiography in pilots of less than 30 years of age revealed an arthrosis whose high location (C2 - C3, C3 - C4, C4 - C5) has been often held in France to indicate the traumatic origin of the arthrosis (L.Roche). In all those specialist examinations in which our advice has been sought we have borne in mind this topographical argument to link arthrosis with air experience.

3.4 Current Studies

There being some contradictions in the investigations reported above, it is difficult at this time to give a definite opinion and it seems in fact necessary to continue the investigation over a period of years. As what is normality becomes more clear, a radiodynamic investigation of the normal movement of the spine should be initiated. Many rheumatologists and radiologists stress the frequency of occurrence of arthrosis in the young adult aged 20 years. X-rays of the cervical segment taken on entry for aircrew could be compared with those taken 5 years and 10 years later.

G.Gueffier, in a report on work carried out in the Radiology department of the Dominique-Larrey hospital with the help of the Flight Test Centre at Bretigny has drawn up a proforma on which will be the following information:

Subjects age; aircrew position, i.e. pilot, navigator etc; number of flying hours (conventional aircraft, jet aircraft, helicopters); type of curve in lateral view (straight, lordosis, kyphosis); index of lordosis (Arlet) (Fig.44); the extent of hyperextension and hyperflexion in millimetres (on the dynamic plates - Figure 45); the presence or absence of arthrosis; the type of arthrosis (osteophytosis, uncarthrosis); vertebral displacements (anterior or posterior); pinching of discs (anterior, posterior or general); the level of this pinching; the idea of a "break" in the cervical curve, its level and how it appears (flexion, extension or neutral lateral position).

The proformae concern aircrew chosen at random as well as a control population not subjected to the hazard of injury and a group of patients who have been injured (skull or cervical column). Some subjects have been examined by radiocinematography so as to verify the movement of the cervical column. The use of an image intensifying screen observed by television has enabled shots to be taken at twenty-four frames per second.

The results of this investigation on 400 subjects of whom 100 are aircrew, are being analysed. They will be followed up and particular attention will be paid to the changes in cervical dynamics arising from the wearing of a helmet. We have chosen to make use of the method shown in Figure 46 rather than other methods (Figures 47 and 48) which do not lend themselves so readily to a rapid statistical evaluation of angular displacements.

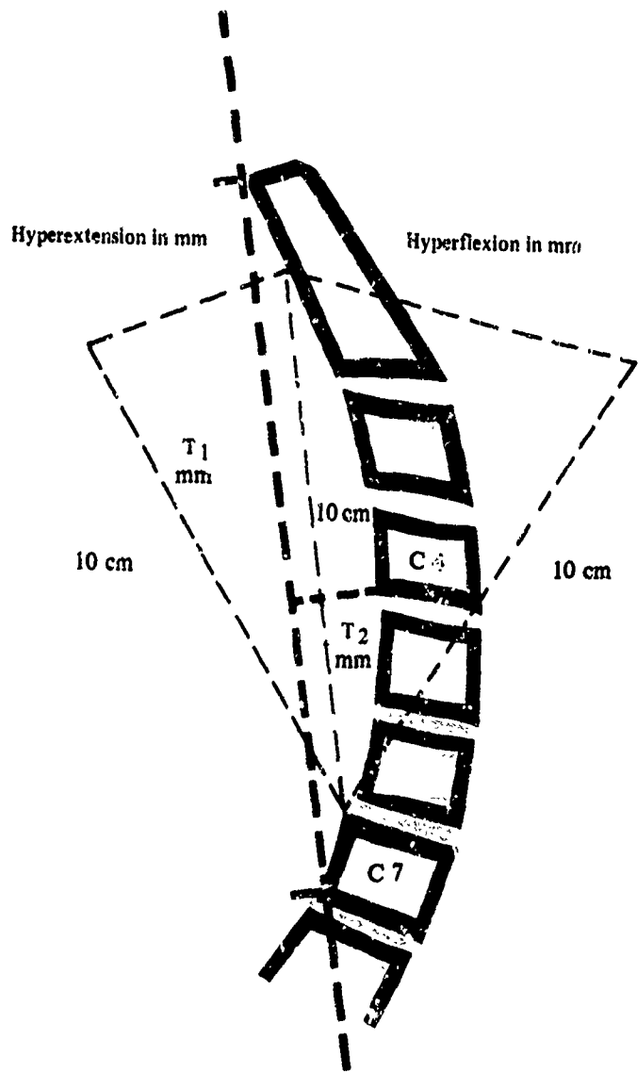


Fig. 46 Measurements made on our dynamic radiograms

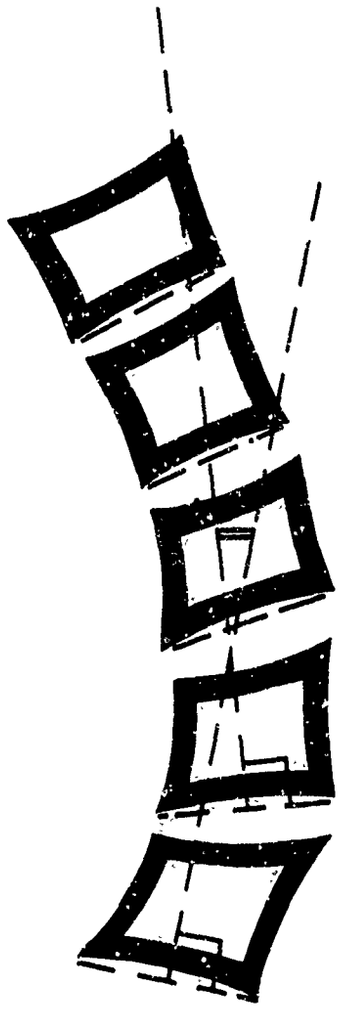


Fig. 47 Measurement of angular displacement of each vertebra with respect to the lower adjacent one

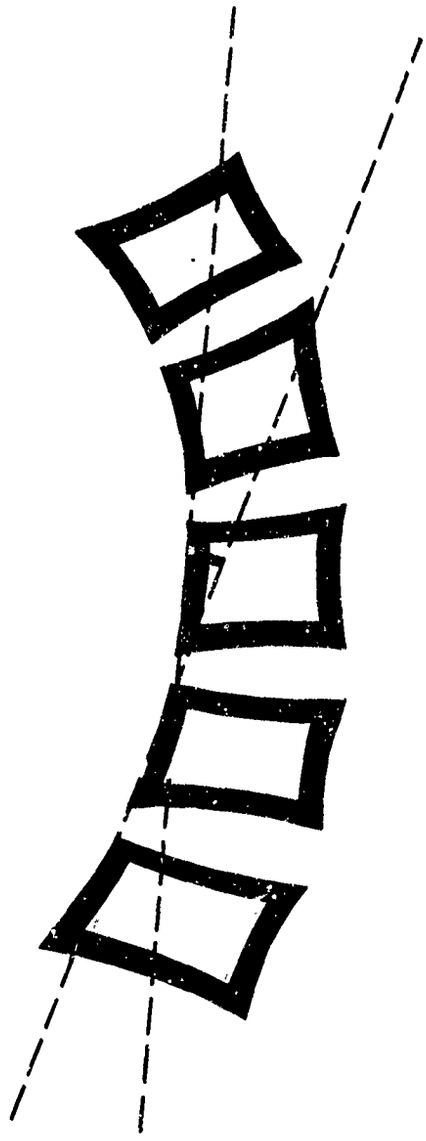


Fig. 48 Measurement of angular displacement of each vertebra with respect to the lower adjacent one

PART III: ACQUIRED VERTEBRAL CONDITIONS AND FLYING PERSONNEL

Two acquired conditions of the vertebral column are fairly frequently encountered in flying personnel. These are: arthrosis - a degenerative condition, and rheumatoidal pelvi-spondylitis - an inflammatory condition. These diseases are of equal interest by reason of the problems which they give rise to in aviation.

1. INTERVERTEBRAL ARTHROSIS

The arthroses are the chronic joint conditions whose lesions consist of destructive changes in cartilages and in joint ligaments associated with proliferative lesions.

1.1 Pathological Anatomy makes the Distinction Between:

1.1.1 A Menisco-Somatic Arthrosis or Disc Arthrosis

A degenerative arthrosis of the nucleus pulposus of the disc leads to the forces supported by the spine being badly distributed. This results in a spreading out of the nucleus which pushes back the fibrous ring, the anterior projection of which irritates the intra-ligamentary cellular tissue and thereby predisposing to osteogenesis in the form of osteophytes.

1.1.2 Inter-Apophyseal Arthrosis

This brings together cartilaginous lesions (the initial phenomenon) underlying bony lesions, and hyperphasic synovial reactions.

1.2 Pathogenesis

Arthrosis results from an articular ageing which is more or less precocious according to the individual. It is accepted generally that micro-traumae predispose to this condition (porters and labourers). One aspect in particular, however, which seems to be of interest in linking this condition with aviation is the role played by acceleration.

Claude Duf: This fighter pilot aged 26 has exhibited in the past 5 years, but more especially in the past 6 months, appreciably permanent lumbo thoracic pain which is aggravated by carrying a weight, by forward flexion, and by accelerations of more than 2g in the + Gz axis. The vertebral discomfort results in a reduction of the lumbar lordosis, a contraction of the paravertebral muscle masses and in a marked limitation of the flexion and extension of the trunk.

The radiological appearance of the cervical spine is normal but in the thoracic segment there is a scoliosis with arthrosis of T8, T9 and T10, characterised by anterior osteophytic localised changes. The part played by even low intensity accelerations is so obvious in giving rise to pain, that this pilot with 4,400 hours of flying, is apprehensive about resuming his flying duties since he feels that these can only make his condition worse. Is it not possible that repeated accelerations may give rise to disc lesions?

1.3 Arthrosis in Subjects Over Forty Years of Age

At the Dominique-Larrey Hospital in Versailles and at the CPEMPN in Paris, cases of lumbalgia have been noted in subjects usually over 40 years of age and suffering from arthrosis (transport pilots and other aircrew). This is a question of clinical and radiological manifestations of arthrosis with no particular characteristics to distinguish them from the arthrosis of non-aircrew. We can therefore not refer to this category into which commercial pilots may fall, as being an occupational disease. The subjects usually show a tendency to overweight and these aircrew, in spite of travelling great distances lead a sedentary life with little physical exertion. Furthermore, poor dietary habits such as meals which are too plentiful, rich and often not well balanced seem to us to be fairly common.

2. RHEUMATOIDAL PELVI-SPONDYLITIS

This is the commonest of the chronic inflammatory rheumatisms which affects flying personnel.

2.1 Clinical Findings

The clinical symptomatology may be neglected for a long time - particularly in helicopter pilots who too readily associate vertebral discomfort with posture in the course of piloting and with vibration. The location of low back and buttock discomfort, its appearance early in the day, and the importance of stiffening should however bring to mind rheumatoidal pelvi-spondylitis

2.2 Radiology

The lesions are at the level of the sacro iliac and dorso lumbar hinge. The sacro iliac intervertebral spaces are wider, and the articular surfaces are blurred and eroded. contrasting with the increased density in

the neighbouring regions of ilium and sacrum. Localised radiography reveals the existence of syndesmophytes most frequently at the level of T12 - L1.

The ESR (erythrocyte sedimentation rate) is a simple examination which is sufficiently precise to indicate the progress of the disease.

2.3 Search for Other Locations

It is in addition, necessary to seek the special loci of rheumatoidal pelvi-spondylitis which play a part in the prognosis and discussions on fitness.

2.3.1 Respiratory System Localisation

Localisation in the respiratory system with a restrictive type ventilatory insufficiency which is linked to an injury of the vertebral costal articulation, is well demonstrated by pulmonary function tests.

2.3.2 Cardiac Localisation

This may be a valvular cardiopathy, usually aortic insufficiency, or more frequently it may be a question of ECG anomalies in the shape of AV conduction difficulties. bundle branch block, disorders of rhythm or of repolarization.

2.3.3 Ocular Localisation

Ocular localisation consist mostly of iritis (10% of cases) which usually run an acute course and which may leave some synechiae.

2.4 Line of Conduct

With correct treatment this chronic disease is normally for some time compatible with more or less normal aeronautic activity. The treatment consists of regular vertebral and respiratory exercise therapy which is essential to maintain pelvi-vertebral suppleness and adequate ventilatory function. Acetyl salicylic acid and its derivatives taken daily can relieve the pain and increase mobility thereby enabling exercise therapy to be employed. Crenotherapy and physiotherapy are useful adjuncts.

It is only in the course of exacerbations that one employs phenyl butazone or indomethacine which are not without hazard. Some of the synthetic anti-malarial drugs which are less in use today than they were, call for special ophthalmological supervision.

The decision regarding fitness must take account of the fact that this is a chronic disease which has for some time been arrested by non-dangerous treatment and therefore was often compatible with more or less normal aeronautical activity. Nevertheless, the discovery of a rheumatoidal pelvi-spondylitis during selection examination must result in a definite rejection of the candidate.

On the other hand, should the condition arise in the course of an individual's career, the disposal has to take account of a number of other factors such as the course of the condition which varies from subject to subject and whose exacerbations are more objectively quantified by the increase in erythrocite sedimentation rate (ESR); the extent of functional impairment produced by stiffening of the spine; the existence of cardiac valvular lesions and ECG anomalies or the existence of ventilatory insufficiency; the necessity to make use of major inflammatory medication (phenyl butazone or indomethacine) which may give rise to digestive complications in particular, and lastly the individual's specialty has to be borne in mind.

A cardiac locus, ophthalmological sequelae reducing visual acuity, an irreversible reduction of vital capacity by more than 15%, frequent exacerbations, a marked rigity of the vertebral column all lead to rejection for certain jobs. The discovery of this condition in the pilot of a high performance aircraft leads to his rejection from that specialty and eventually to his re-categorisation. In other cases fitness is normally maintained as long as the individual is not affected by the possible complications.

CONCLUSION

The pilot and the parachutists spines are subjected to two types of aggression.

1. Aggressions of relatively small intensity whose effects are additive and which belong to the type of phenomena observed in the fatigue of metals.
2. Unusual aggressions (crash or ejection) of high intensity which bring into play the mechanical resistance of the spine and possibly give rise to fractures.

Because of their frequency, their variety, their symptomatology and their evolution, traumatic conditions of the spine met in aviation medicine deserve a detailed study. In crash landings and ejections, as in parachuting accidents, the fractures are frequently at the level of T10 - L2. These clinical and radiological findings are definite. The study of sequelae is necessary because of the pain suffered by the injured subjects. Atrophy of the lateral vertebral muscle masses represents a fundamental clinical finding and justifies exercise therapy.

Radiography of the entire spine is necessary at the selection examination and in the case of injury. The problems set by the supervision of subjects with a spinal fracture are more difficult.

The affections of posture are true occupational diseases of aviators. The pain of helicopter pilots and the cervical pain of the pilots of military jet aircraft have been particularly studied by an examination of the clinical findings, radiology and the physiopathological mechanism. The problem of vertebral pain in helicopter pilots has now been solved by a search for the correct pilot position and by a reduction in the harmful vibrations, especially those between 4-7 Hz.

The cervical pain of pilots in military jet aircraft often appears in certain flight configurations, and in particular, a repetition of accelerations in the Gz positive axis may give rise to alteration in the vertebral discs.

The studies now being carried out will help to determine the frequency of this pain. The acquired diseases (arthrosis and rheumatoidal pelvi-spondylitis) are frequently encountered, and the disposal policy throughout the evolution of the condition is influenced by a number of factors which are listed.

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