SPINAL PATHOLOGIES AND INJURIES IN HELICOPTER PILOTS

Hugues TIERNY
Osteopathy DO thesis
National University of Medical Sciences (Madrid, Spain)
National Academy of Osteopathy (Toronto, Canada)
June 2023

Acknowledgements

We would like to express our sincere and deep thanks to a few people who helped us during the redaction of this thesis.

To my colleague, Dr O. Cattin, Chief Medical Officer of Samitivej International clinic of Yangon in Myanmar who motivated me and encouraged me for this exciting piece of work with his pertinent ideas and knowledge.

To the pilots and mechanics of HeliUnion based in Myanmar whose discussions and information helped us considerably, in particular, the base manager Captain S. Carlin and Captain C. Martinand, who suggested the topic and advised me all along its progress. We would like to offer a big special acknowledgment to Colonel J.P. Rougé who patiently explained to us and supervised all the technical parts relating to the helicopter mechanics, as well as the posture and movements of the pilots. His clear explanations helped us significantly in the writing of the relevant sections.

To Dr G. Milazzo, Emeretus Mulligan Concept teacher, who accepted to read and correct this thesis and suggested the necessary changes to make it better.

Finally, we would like to thank all the people, relatives, friends, colleagues, and patients who encouraged, advised or offered their valuable opinions to us.

Table of Contents

1. Introduction

Over the three past years of practice working in an international clinic located in Yangon in Myanmar, we have provided treatment to many helicopter pilots and aircrew working for a private company operating in the oil and gas industry. In the clinical encounter and discussions with these aircrews the symptoms described, the injuries sustained, and the pathologies identified allowed an understanding that their occupation was not without negative impacts on their physical condition and health. This thesis will discuss the different spinal conditions that could affect these pilots.

In this dissertation we will first review the anatomy of the spine and explain its general pathologies. Next, the reader will be provided with basic principles of helicopter mechanics as well as the specificities of rotatory wing (RW) aircraft pilot's posture. That will allow us to explain the numerous spinal complications they can suffer from. We will later explain the different therapeutical options offered to them before mentioning our experience and practice with these patients with our small survey. In particular we will provide details of some of the osteopathic treatments and techniques we applied on our pilots.

2. The Spine

2.1 Anatomy of the spine

The spine is an major componant of the human body and skeleton. It is one of the first structure to be created during the embryogenesis with the neural tube formation that starts 4 weeks after the conception.

The vertebral column is made by 32 to 34 vertebraes: 7 cervical, 12 thoracic, 5 lumbar, 5 sacral and 3 to 5 coccyxgeals. The cervical, thoracic and lumbar verbebra are mobile, the sacral and coccyxgeal vertebra are fused.

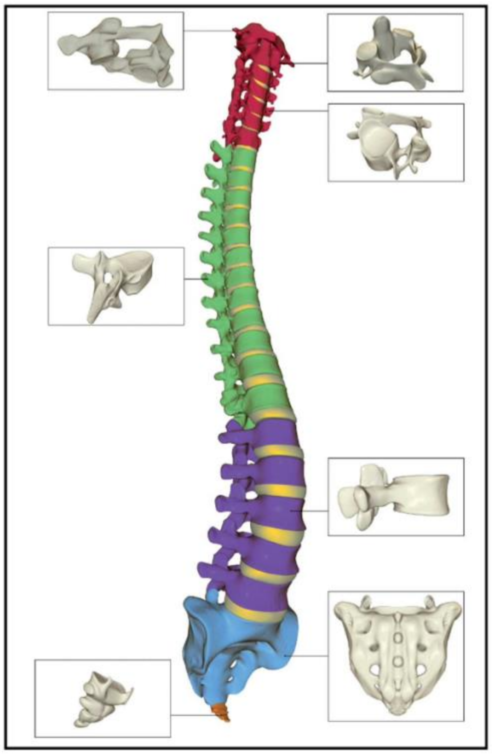

Figure 1: The 5 segments of the rachis
Cervical (red), Thoracic (green), Lumbar ((purple), Sacral (blue), Coccyxgeal (orange)

The Cervical spine

Comprises seven vertebrae (C1 to C7) and six intervertebral discs. It extends from the base of the skull to the top of the thorax and the first thoracic vertebra (T1). The Atlas or first cervical vertebra (C1) articulates superiorly with the base of the Occiput (C0), forming the occipito-atlanto joint (C0-C1 or OAJ). Inferiorly it is connected with the Axis or second cervical vertebra (C2) via the atlanto-axial joint (C1-C2 or AAJ).

The cervical spine can be divided between the upper and lower cervical spine. The upper portion is the C1-C2 segments and the lower part is formed by the vertebrae from C3 to C7.

The two first vertebrae of the upper segment differ anatomically from the lower section. The Atlas or C1 is the only vertebra that does not have a vertebral body, but a more ring-like structure for cradling the skull at the base of the occipital bone. The Axis (C2) encloses the odontoid process, a large bony protusion that extends superiorly from its body to articulate with a facet of the Atlas.

The whole cervical spine supports and cushions the loads to the head and neck, protect the beginning of the spinal cord extending from the brain, and allows movements of the head and the neck. These movements will be described later in the biomechanical paragraph.

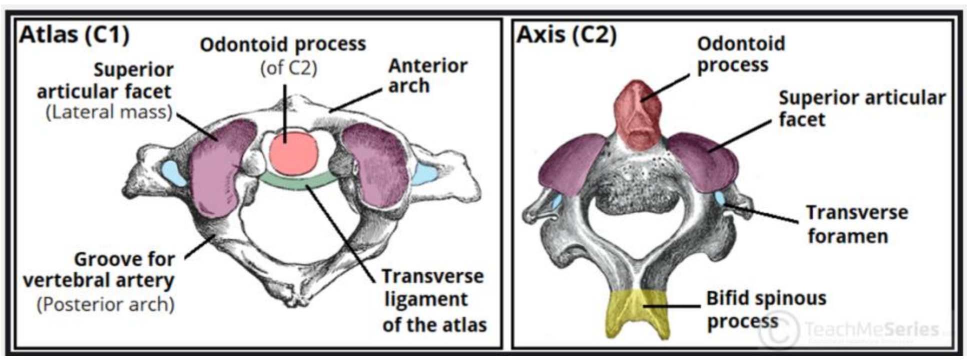

Figure 2: Atlas and Axis vertebrae

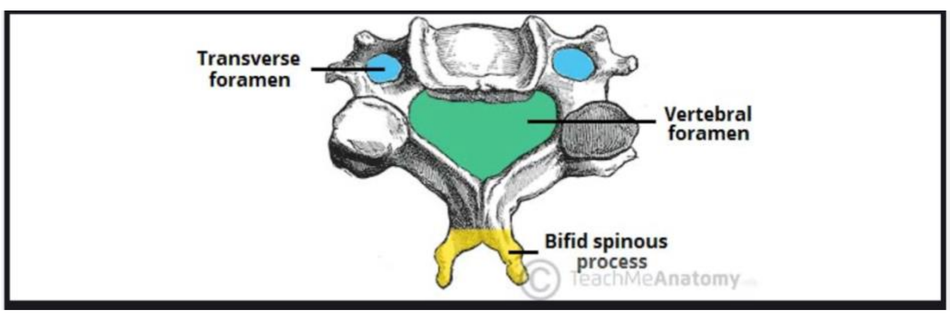

Figure 3: Characteristics of a cervical vertebra

The Thoracic spine

The thoracic spine consists of twelve vertebrae (T1 to T12) and twelve intervertebral discs; it is located between the cervical and lumbar spines. It participates to the bearing of heavy loads, stabilizes the trunk, supports the posture and is connected to the rib cage that contains and protects vital thoracic organs. Its vertebrae have specific costovertebral and costotransverse facets articulated to the ribs. However these connections reduce the mobility but offer a greater stability and support of the trunk, and therefore less discal degenerations.

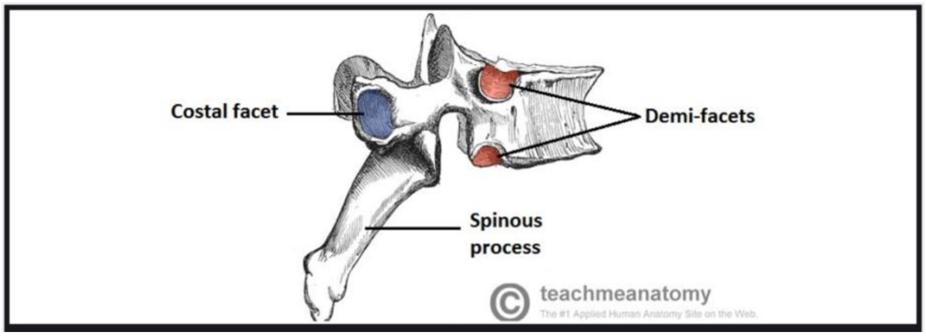

Figure 4: Lateral view of a thoracic vertebra
with the costal and demi facets for the articulations with the ribs

The Lumbar spine

The lumbar spine is formed by five vertebrae (L1-L5) and five intervertebral discs, and extends from the inferior part of T12 to the superior part of the sacrum (S1). Its strong vertebrae allow heavy weight bearing, maximum stability of the trunk and pelvis and hip during the movements of the trunk and lower legs. Lumbar vertebrae and intervertebral discs are the greatest in thickness, width and depth; their size and sturdiness increase from L1 to L5. The L5 vertebra being the most inferior mobile vertebra is the biggest and strongest of all the vertebrae in the spinal column.

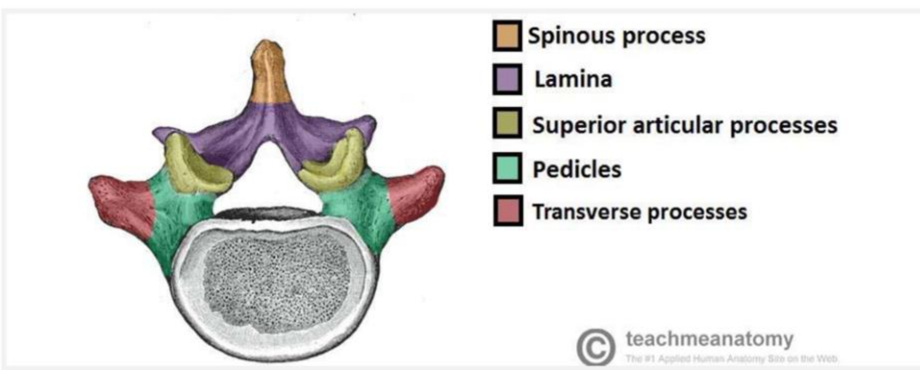

Figure 5: Superior view of a Lumbar vertebra

The Sacrum and Coccyx

The sacrum is composed of five fused vertebrae (S1 to S5) connected superiorly to L5, the last mobile vertebrae of the whole vertebral spine, and laterally to the two iliacs bones via the Sacro-Iliac joints (SIJ). The sacrum is the only bonny connection between the trunk and the lower body, creating a bridge between the hips and the rest of the spine.
Because of its fused vertebrae, the sacrum doesn’t have intervertebral discs. The sacrum protects important afferent and efferent nerves from and to the spinal cord and lower limbs via the sacral foramina.

Like the Sacrum, the Coccyx is made of fused vertebrae (3 to 5, depending on the individual). It is attached to tip of the sacrum and serve as anchorage point for ligaments, muscles, and tendons that form the perineum or pelvic floor that stabilize and support abdominal visceral organs.

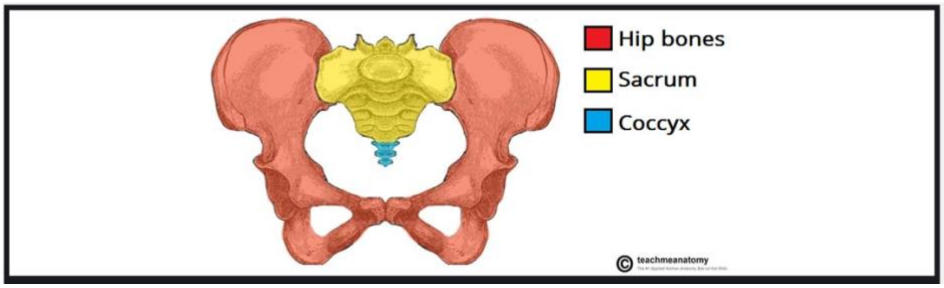

Figure 6: Diagram of the Sacrum (articulated to the hip bones) and the Coccyx

2.2 Biomechanics and functions

The main functions of the spine are:

- Axis or Static function: Support and erection of the skeletton,
- Protection: Of the spinal cord; part of the Central Nervous System,
- Cushioning: Of the stresses and loads on the body, and its transmission to the lower limbs,
- Movements: The dynamic function in the three plans of the motion,
- Support: To carry the weight of the upper body.

Static function

The spine is the central vertical of the body. It is straight in the frontal plan but has three curvatures in the sagittal plan: a cervical lordosis, a thoracic kyphosis, and a lumbar lordosis. These curves provide a mechanism to resist mechanical pressures and compression forces. The sacrum is also convexe posteriorly and the coccyx pointing anteriorly and inferiorly. Functionnally the spine is made of three columns: an anterior consisting of the vertebral bodies and disks, a middle column consisting of the vertebral arch forming the vertebral foramen housing the spinal cord, and a posterior column composed of the spinous process, the transverse processes, the lamina, pedicles and articular pilars. This system allows a certain mobility and spread the pressures received by the body.

Protective function

The vertebrae forming the spine enclose and protect the spinal cord within the vertebral foramen. They are assisted by the intervertebral disks, ligaments and muscles. The spinal cord contains the sensory and motor tracks connecting the brain to the peripheral nerves and are surrounded by the meninges that participate in this protective function. These meninges are consist of 3 layers that are (from lateral to medial) the Dura Mater, the Arachnoid and the Pia Mater.

The epidural and arachnoid spaces provide more shock absorption for the spine, while the cerebrospinal fluid (CSF) in the subarachnoid space (between the arachnoid and pia mater) provides extra cushioning to the spinal cord.
It is in the epidural space (between the dura mater and arachnoid mater) that anesthetics can be injected. A spinal tap into the subarachnoid space tests the CSF for infection (meningitis).

Cushioning function

Each vertebra of the spine (excepted between C1 and C2) is separated by intervertebral discs. These discs make up around 20 to 30 % of the total length of the spine. Their size increases progressively descending down the spine due to the progressive pressure and weigth the spine is supporting. Their function is to cushion the loads, to reduce the stress caused by impact (shock absorber), to disperse the weight, to allow vertebral movements and the passage of nutrients and fluids to the spinal cord [(1)]. Each disc is made of very strong tissue, with a soft gel-like center - called the nucleus pulposus- and surrounded by a tough outer layer of fibrocartilaginous tissue organized in concentric rings and called the annulus fibrosus.
Under the effect of axial pressure, the pressure within the nucleus increases, pushing the vertebral plates and the annulus towards the outer rim. The vertebral bodies are made of spongy bony tissue holding vertical, horizontal and oblique spans allowing the transmission of stresses to the neighbouring structures.
Under the constant pressures, the discs can become dessicated and lose their cushioning and absorption abilities. Their degeneratrion leads to tears in the annulus and the progressive expulsion of the nucleus pulposus from the disc causing disc bulgings and disc herniations.

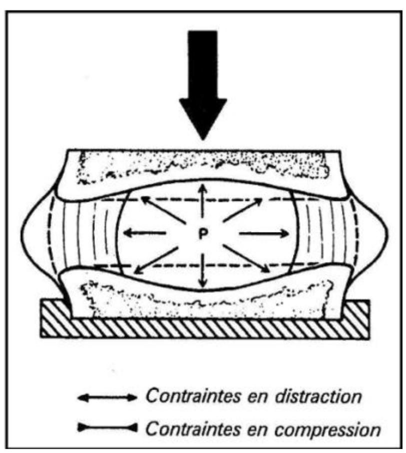

Figure 3: Response of the disc to axial compression

Dynamic function

The spine is a mobile segment allowing movements in the three planes of the space: flexion and extension in the sagittal (antero-posterior) plane, lateral side bendings in the frontal or coronal plane, and rotations in the horizontal (or transverse, or axial) plane. Each segment of the spine has its own proper ranges of motions (ROM) and participate to its local or general mobility.

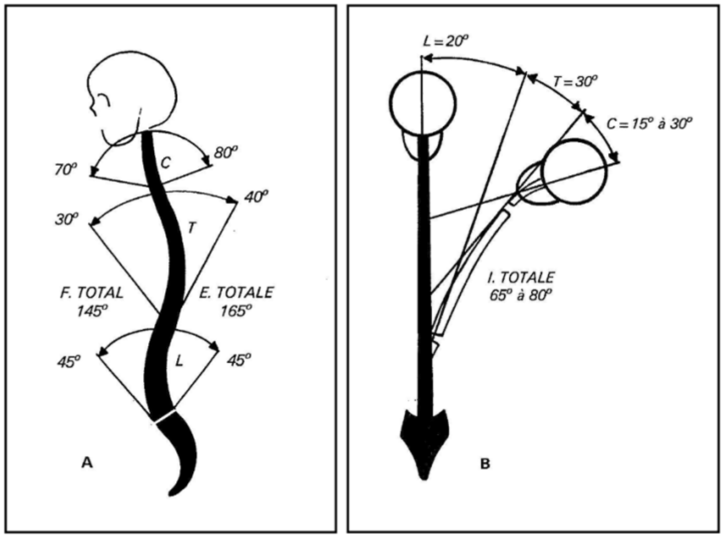

Figure 4: ROM of Flexion-Extension (A) and Lateral Flexion (B) of the Cervical, Thoracic and Lumbar Spine

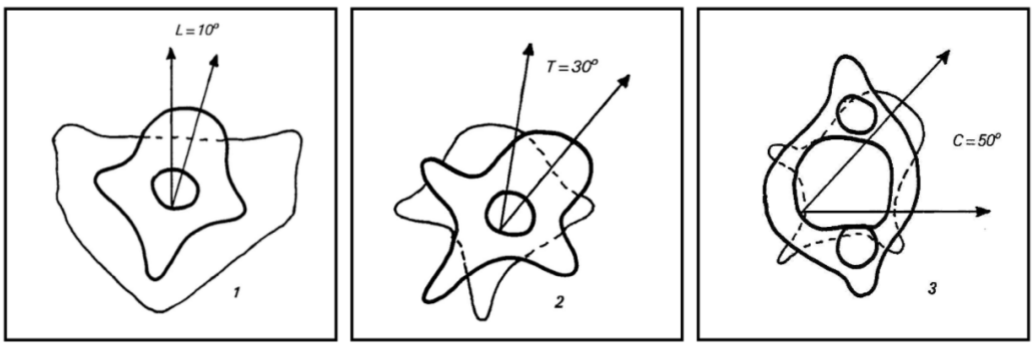

Figure 5: Rotation amplitudes of the Lumbar (1), Thoracic (2) and Cervical (3) spine

Research has shown that the global flexion of the spine is 145-150 degrees (d°), the full extension 165 d°, the lateral flexion 65 to 80 d°, and 90 d° for the full rotation.
In the upper cervical spine the occipito-atlantal joint (C0-C1) is responsible of 50% of the head's flexion and extension ROM, and the atlanto-axial joint (C1-C2) of 50% of neck's rotation, as well as the function of transferring the weight of the head through the rest of the cervical spine.
The thoracic spine offers less amplitudes due to the thoracic cage that restrains the intervertebral mobility.
The lumbar spine has very limited rotation (5 d° per vertebra) due to the alignment and angulation of its articular facets (that are vertical or 90 d° of orientation) but greater lateral flexion (30 to 40 d° each side) and flexion-extension range (up to 90 d°).

This mobile skeletton is maintained by numerous ligaments between the vertebrae and various postural muscles that help keep the spine erect and stabilize the whole column. Phasic muscles generate forces that result in differents movements of the spine.

From the intervertebral foramina leave the 31 pairs of spinal nerves to conduct sensory and motor informations from and to the brain via the spinal cord. There are 12 pairs of cranial nerves.

3. Spinal pathologies

As the vertebral column is a mobile unit, we can understand that it receives numerous stimulus and pressures that force it to constantly re-equilibrate itself. Positions, movements, aging, traumas or ailments affect the general condition of the spine and provoke several problems such as degeneration of the vertebrae or the discs, alignment defects and deformities, stenosis of the vertebral or intervertebral foramina, neurological sensitization, infections, tumors,etc. The common symptom is the pain that pushes people to seek consultations from a health provider.
It is estimated that every year 15 to 20% of the adult population experiences back pain, and between 50 to 80% have at least one episode during their lifetime.

3.1 Lumbar spine

Lumbar pain is one of the most frequent problems reported, affecting all ranges of age, from the teenagers to the elderly. Lumbar pain is the most frequent cause of medical leave in the world, and a major cause of disability in the adult working class. Lumbalgia is defined as a pain in the lumbar region that can irradiate lower into the buttocks or legs. The lumbago or acute lower back pain is characterized by a sharp sudden pain associated to a muscular spasm that limits the mobility. It is often caused by a banal daily movement or an effort activity such as lifting or carrying a heavy object. Patients present with varying degrees of pain, sometimes severe, exacerbated by movements or position changes; and muscle spasm that blocks the mobility of the spine.
Physiologically, the very commonly affected structures are the articular facets (posterior facets syndrome) and the intervertebral discs.
Complications such as degenerative disc disease can lead to neurosensitization of the sciatic or femoral nerves.

3.2 Thoracic spine

Thoracic spinal pain runs from the cervico-thoracic junction (C7-T1) to the thoraco-lumbar intersection (T1-L5). Thoracic pain is less studied than the lumbar or cervical regions but specialists agree that thay can be caused by more serious underlying pathologies than for the neck or lower back. It often has a musculoskeletal origin.
Causes of thoracic vertebral pain can be multiple and run from poor posture to sedentary life style, wrong ergonomy, lack of postural muscular tone, improper movements and lifting techniques, overuse, fall and accident,…
Affected structures are mostly the facet joints, the rib articulations and the muscles surrounding the area. Associated scapular pain or limitation of mobility is also common, affecting the shoulder girdle complex.

3.3 Cervical spine

Cervicalgia or neck pain is a very frequent musculoskeletal ailment affecting the posterior part of the cervical spine.
The causes are numerous: poor posture and ergonomy (especially professional), long term stress, alignment defect or kyphosis leading to forward head syndrome, bone and cartilage degeneration such as arthritis or osteoporosis, long term stress, accidents and injuries such as whiplash, muscular spasm or strain, some sportive activities flexiong the neck and trunk forward,….
The main symptom is pain in the cervical area, which can be either a sharp, stabbing pain or a dull, persistent pain. People can present with a siff neck that impairs its movements, muscular spasm, tenderness in the shoulders, cervicogenic headache or dizziness, nausea, tinnitus, retro-orbital pain or pressure, blur vision,… Sometimes patients present with an acute torticollis due to the muscular contreacture happening to protect the spine and spinal cord.

3.4 General risk factors

Risk factors are divided into individual and professional risks. Professional risk predominate over individuals.

Individual risk factors

Within these individual risk factors, we have identified:

- Non modifiable factors such as gender, age, heredity, pathology (for some rheumatoid or inflammatory diseases), previous history of spinal issues.
- Modifiable factors such as the weight, physical condition, fitness level, tobacco and alcohol consumption, hydration level, practice of sport activities.
- Psychological factors: psychological distress, mental illness, hypochondriasis, depression.

Professional risk factors

- Professional working station and occupational environment.
- Physical factors: heavy loads to carry, wrong postures, movements repetitions
- Exposition to professional hasards such as extreme temperatures or vibrations
- Occupational stress or pressure

4. Basic understanding of rotatory wings (RW) principles

In this chapter, we will see the basic points of a helicopter mechanics and its functioning. The goal is not to develop the whole aspects of rotatory wings areonautics but to try to understand some of the physical forces that can impact negatively on the human body.

Helicopters use the rotatory wings principle to fly. Their specificity -compared to a fixed wing aircraft- is their hovering ability, meaning the possibility to hold an immobile sustained position. To achieve this impressive degree of precision, their operating technology is complex and necessitates permanent or regular adjustments from the pilots (depending of the model) to control the different parameters of the flight, especially during takeoff and landing.

4.1 Key parts of a helicopter

A typical helicopter contains thousands of intricate thousands of components. The fuselage or main framework is built with strong but lightweight composite materials. According to the model one or two turbines, a transmission and a gearbox give the power to the main rotor(s) and the tail rotor.

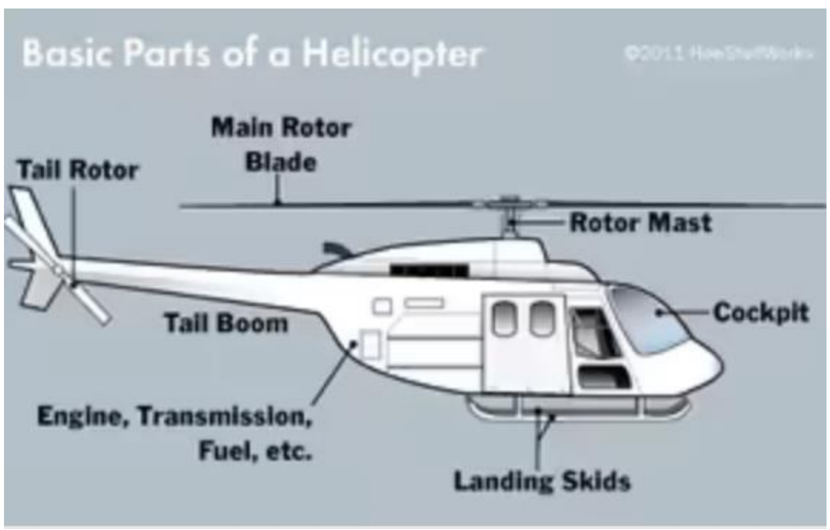

Figure 6: Basic parts of a helicopter

Rotor, gearbox and transmission

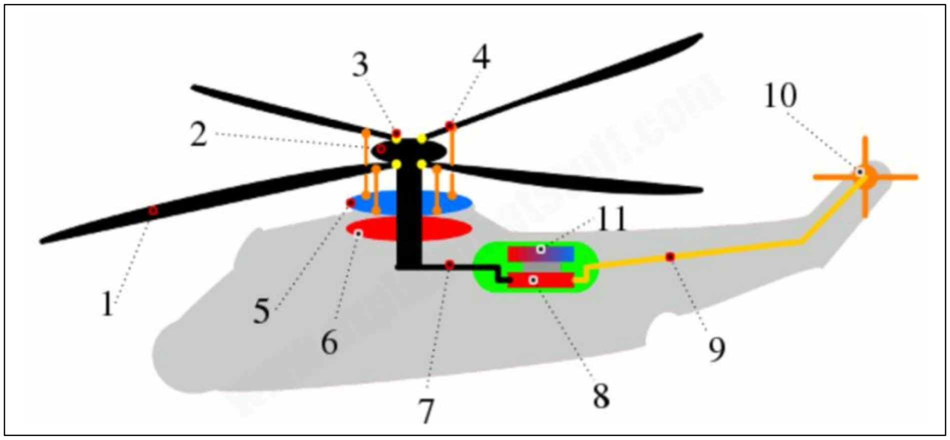

Figure 7: Major componants of an helicopter

Depending of the machine, two to seven blades (1) are connected to the hub (2) and rotating mast by a feathering hinge (3) allowing the rotation. The blades are linked to a short rod (4, in orange) which can change the angle of orientation (steeper or shallower) according to the position of the mobile rotating upper swash plate (5, in blue). This plate swivels on bearings around the static lower swah plate (6, in red). That's allows the helicopter to hover and steer.
The rotor(s) is (are) powered by a driveshaft (7) linked to a gearbox (8, in red).
This same transmission supplies the power to a second longer driveshaft (9, in yellow) connected to another gearbox that spins the tail rotor (10, in orange).
The pilot controls the vertical movements (up and down) and side angulations of the two swash plates with his pilot cyclic stick and collective commands.

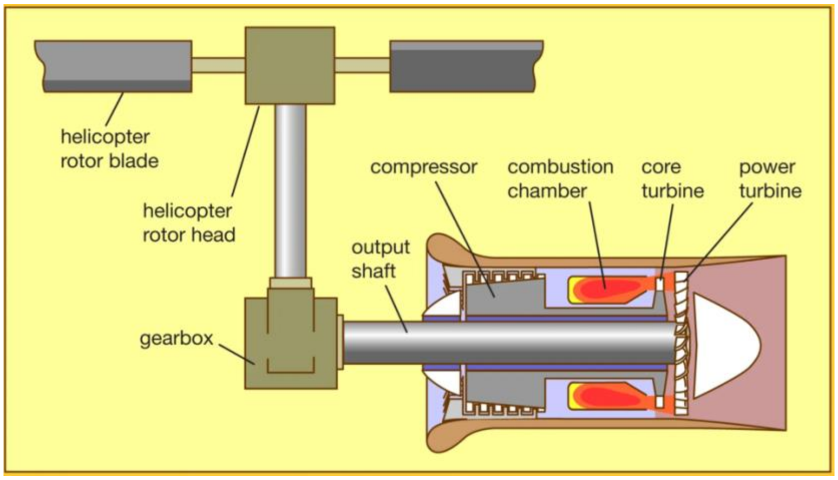

Figure 8: Diagram of the turbine, gearbox and rotor head

Finally there are two kind of rotors: rigid and soft. The rigid rotors have straigth blades and produce more vibrations, while they are inclined in soft rotors and provide less vibrations. We will review the vibrations, their types, production and effect later in a specific paragraph.

The cyclic stick, the collective and the rudder pedals

Basically there are three main controls in a helicopter:

- **The Cyclic stick**, located between the legs of the pilot. Its function is to change cyclically the angulation of the blades depending of the amount of lift at different points of the cycle and to eliminate drift in the horizontal plane (forward, backward, and side to side motion).
- **The Collective lever or thrust lever** -located at the left of the pilot- allows to change the force generated by the rotor and its lift over the entire disk (upper swach plate) and therefore the altitude and/or the speed. It alternates the pitch angle of the main rotor blades uniformly or collectively, hence its name. During takeoff, the pilot lifts the collective lever to inccrease the pitch of all the rotor blades by the same amount.
- **The Rudder pedals** control the tail rotor (or anti-torque rotor) to alter the nose direction or heading direction and the symetry of the flight. A change in pedal position changes the pitch angle of the tail rotor to offset torque. As the torque varies with every changement of the flight conditions, the pilot is constantly requiered to change the position of the pedals. Pushing the right pedal deflects the helicopter tail to the left, the left pedal moves the nose to the left.

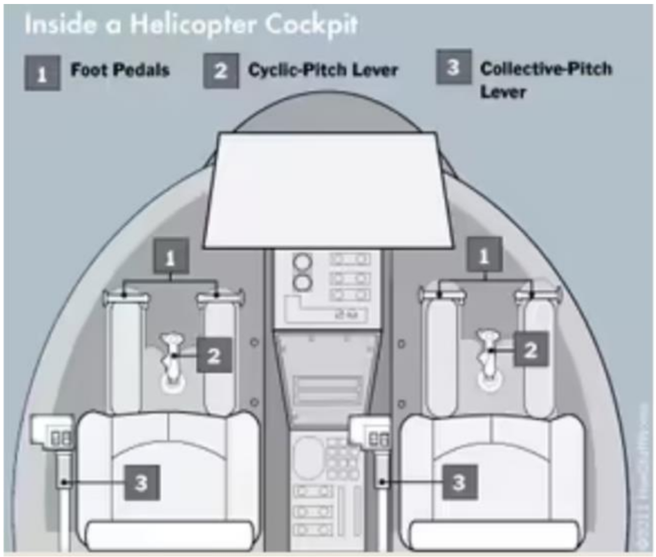

Figure 9: Main commands

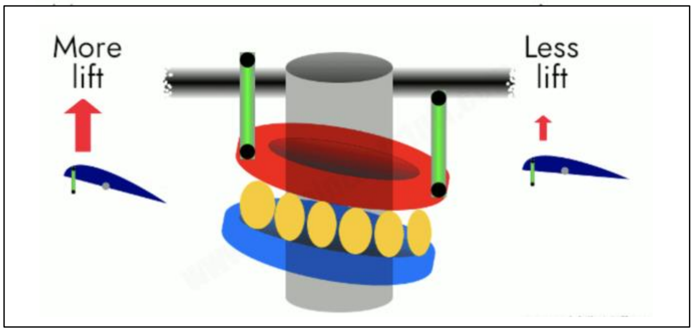

Figure 10: Illustration of the action of the cylic

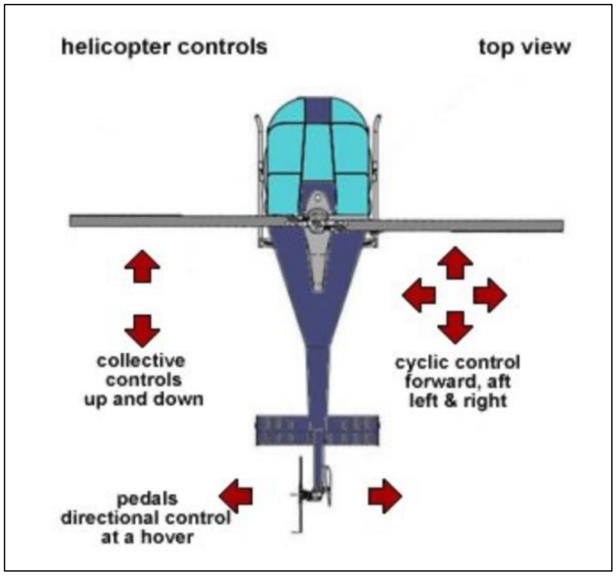

Figure 12: Controls and movements

4.2 Physical forces of rotatory wings

The main rotor creates a torque reaction on the fuselage, making it spin in the opposite direction. To prevent this gyration, a counter force is necessary. This is provided by the tail rotor -or anti-torque rotor- that keeps the cabin straight and provide directional control. So, the torque produced by the front rotor is offset by the torque created by the counter rotating rear rotor. However, to allow the cockpit to turn, the pilot adjusts the blade inclination and consequently the force delivered by the tail rotor. The imbalance in moments will then rotate the cabin. All these movements are strongly coupled, any action induced provokes a counter-reaction and sides effects that need to be corrected. Thus, the pilot always needs to adjust the parameters of the flight, which affects his position and results in stresses on his body.

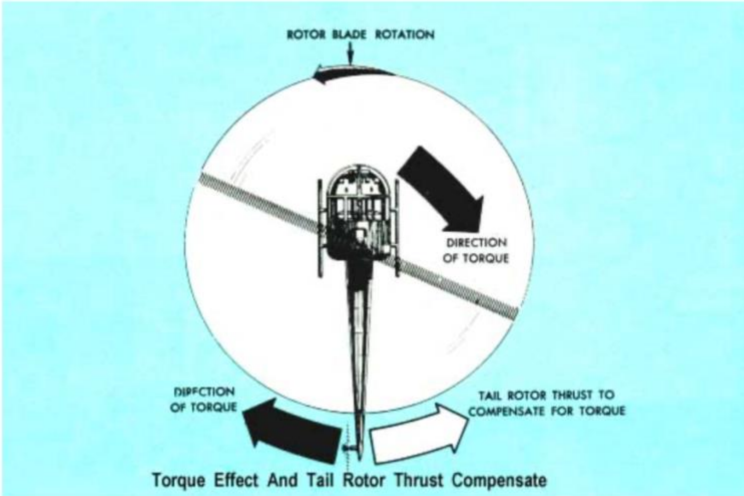

Figure 13: Rotatory forces and torque effect

4.3 Vibrations

Vibrations are a mechanical phenomenon producing oscillations occuring about an equilibrium point, and moving an object periodically into the 3 planes of space. They are characterised according to their frequency, displacement, velocity and acceleration.
The vibrations are a major disturbance for helicopters, they reduce the lifespan of its different components. The consequences of vibrations aboard can range from the discomfort of the crew to complete destruction of the aircraft. Control and reduction of the helicopter vibrations is a whole field of research and engineering to try to design new rotor blade, blades and tail rotor. Anti-vibratory materials and components are tested, as well as the improvement of the turbines. There are 4 types of vibrations generated by the different components of the machine. They are determined by their frequency: low, medium, and high.The general vibration level produces a force of the order of 0.05 to 0.25 g, which is about 5 times the level of vibration met in fixed wings conventional airplanes. They are felt throughout the fuselage in the three planes of the space, laterally, longitudinally and vertically.

Low frequency vibrations: Are provoked by the principal rotor, the main engines and the adjustment of the alignment of the blades. If the blades are not aligned into the same plane, that will generate vibrations. Their frequency range approximatively from 6 to 7.6 Hz (Hertz), with around 17 mm of displacement and a vertical load factor up to 3g.

Medium frequency vibrations: Are created by all the transmission mechanisms and the pistons of the small engines. They are about 15.2 Hz

High frequency vibrations: Are generated by the turbines, the tail rotor driveshaft, the cooling blower fan blades, all components spinning at high revolutionary speeds, and surprisingly by the air conditioning system. They have been recorded around 37.1 Hz

4.4 How do helicopters fly?

This paragraph will describe only the standard pilotage of helicopters with a tail rotor. Technology of double counter-rotating rotors is different.

The same physical principle than make the airplanes flying can explain the sustentation of the helicopters. Aerodynamic engineers developped the airfoil (or aerofoil) technology by changing the shape of the wing, the blades of the helicopter being considered as wings. The blades have an ovoid shape slightly higher to the front to offer a higher resistance, the leading edge; and smaller to the back, the trailing edge. By spinning the blades, a difference in air pressure is created, the pressure on the top becomes smaller and the pressure under the blades bigger. That slow moving high pressure under the blades creates a sustentation force pushing the machine into a vertical direction. This lifting force is perpendicular to the airstream and the dragging force created acts in the same direction than the airstream.

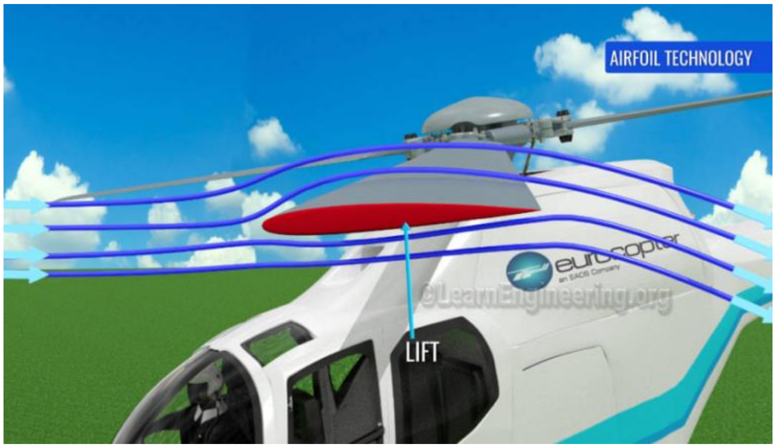

Figure 14: Illustration of airfoil technology

The pitch angle is the angle between the horizontal plane of rotation of the rotor and the chord line of the airfoil. A higher pitch angle increases the lift, and a lower pitch decreases it.

Once the spinning blades of the main rotor generates the lift, that overcomes the weight of the machine, pushing it up into the air. If the lift is greater than the weight, the chopper rises; if it is less than the weight, the helicopter drops. When the lift and weight are exactly equals, the machine hovers in mid-air. For takeoff, the blades need to have a steep angulation to produce maximum lift.

The main rotor speed also controls the lift: higher revolutions per minutes (rpm) increases the lift. This rpm varies from 225 rpm on big helicopters to 400-500 rpm on smaller machines. The tail rotor spin is five to six time faster than the blades rotor.

To move forward the pilot tilts the main front rotor disk slightly down in the front and up in the back. To realize this, the angle of the given blades is reduced when it is in the front to create less lift, and it is increased when it is at the back to produce more lift.

To same principle is used to direct the chopper laterally or backward to control the displacement in every direction. The tilt of the disc determinates the direction, and higher is its angle, the faster the movement.

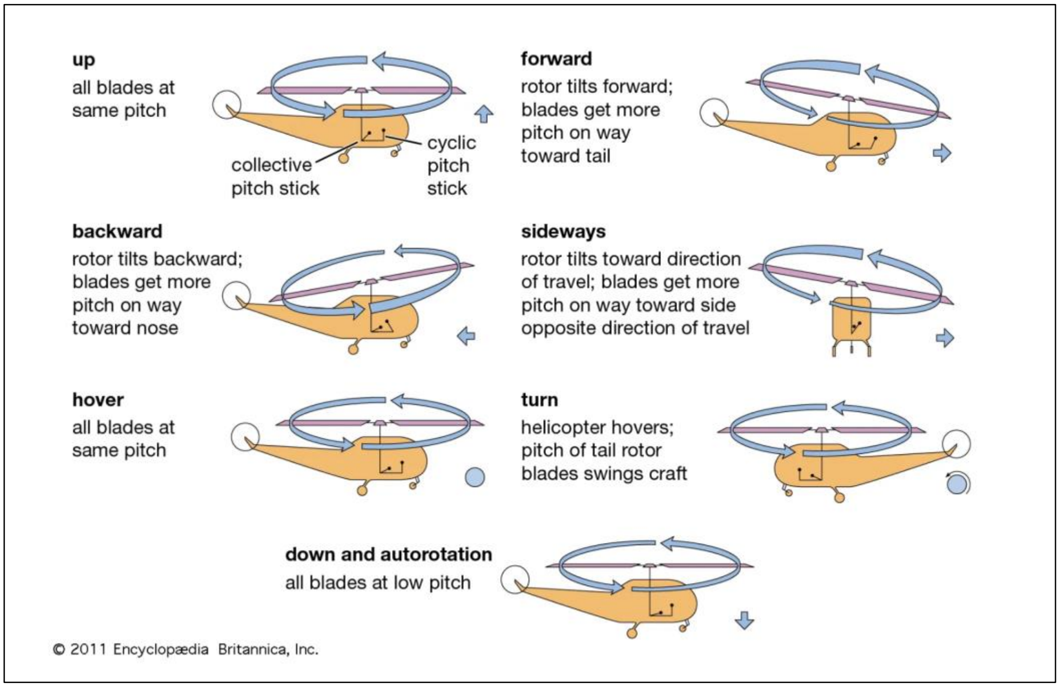

Figure 15: Illustrations of rotor and pitch variations

Meteorological conditions and altitude influence the air density (depending on the air temperature, humidity, and pressure), and affect the performance of the helicopter. High density generates more lift and the opposite. A change in the lift results in a change in drag. When the lift is increased by broadening the pitch angle and then the angle of attack of the machine, the drag increases and slow down the rotor rpm. The pilot needs to adjust the power to sustain the desired RPM. We understand that while a helicopter is altered like a convention airplane by the forces of lift, thrust, drag and weight, its mode of flight creates additional effects. The pilot needs constantly to correct theses parameters. His position and movements change permanently. We can start to discern now how these regular modifications of posture and moves can affect the whole body and its structural foundations.

5. Specificities of helicopter crew

In this chapter, we review and distinguish two types of helicopter crews can be distinguished: the civil and the military pilots. Albeit they are subject to the same physical and mechanical stresses, the military pilots -because of their specific equipment- might be slightly more exposed to physical complications. Evidently the age, physical condition, number of flight hours of the crew, model of helicopter, goal of the flight, external factors like the meteorology enter in consideration to create physical complications on the spine of the pilots.
As this occupation is highly stressful on the body and a profession at risk, pilots must pass regular medical visits (every six months in the military, every year for the civil), as well as flying tests (on simulators and in live trials) to obtain their clearance and renew their professional licenses.
All the information and data found and reported in this work are based on civilian and mostly military surveys and reports. As the goal of this redaction is to evaluate the impacts of helicopter fligths on the spine, we decided not to differentiate the military from the civil pilots. The sometimes surprising differences of prevalence can be explained by the model of helicopters that equip these different countries.

5.1 Epidemiology

5.1.1 Progressive onset

Lumbar pain

Lower back pains in helicopter pilots is a well known phenomenon for decades. They are signaled into the medical litterature as early as the sixties. Aircraft crews are more affected by this condition than the general population (civil or military).
Depending of the surveys, the rate of prevalence vary from 50 to 92% (2). 81% of civil and 83% of miltary pilots (of the Royal Air Force) (3) in the UK, 89,38% in Israel (4), 66% of pilots and 55% of onboard mechanics in France (5), 50.5% of Norwegian aircrew (6). It is the second cause of operational groundingin Canadian forces (7), whereas a survey in the Australian army demonstrated that only 8% of the pilots were back pain free. 57.6% of the Israeli Air Force helicopter pilots noticed lumbar pain during or directly after the flight versus 23.1% and 17.6%for fighter and transport pilots, respectively (8).
Medical investigations and imagery by Magnetic Resonance Imaging (MRI) in Israel noted a high rate of lumbar degeneration (9) in their helicopter pilots. Albeit pathology evidenced by medical imaging does not automatically coincide with symptoms, this study suggests that the high amount of lower back pain might correspond with degenerative changes. Another investigation highlighted that helicopter pilots have 4 times more spondylolisthesis than transport pilots (10).
Lower back pain are one of the major causes of flight restriction, and can also impact the concentration and the achievement of a mission. An Australian survey concluded that 54% of the pilots had focusing difficulties and that 7% refused to flight because of their pain (11). Aircraft crew noticed that the classical RW back pain starts during the flight or within hours of flying. It is located in the lumbar and gluteal area, and described as dull and achy.

The problem is nevertheless not only limited to the pilots; other members of the crew, the flight engineers, mechanics, divers and other staff are also affected by these pathologies.

Bongers et al. found that transient pain was connected with the daily flight hours, while chronic pain was associated with total hours of flight time, with a higher incidence of chronic pain beyond 2000 hours. They opined that the cumulative effect of vibrations and posture increase the spinal problem [12].

Thoracic pain

The thoracic spine is much less studied than the lumbar or cervical areas, and data are less publicated. However, some interesting findings were identified. In a three months cross-sectional study held in Austria from March to May 2018 [13] the findings demonstrated that 43.3% of the pilots and 30.8% of the crew members experienced shoulder and thoracic pain during a twelve months prevalence. During this period 37.8% of the pilots and 44.4% of the had reported 8 to 30 days of pain. A Swedish study on Air Force personnel [14] (AFP) concluded that 30% of the personnel with cervico-thoracic pain had impaired movements in the neck flexion test.

Cervical pain

The scientific literature shows a higher rate of cervical pain and disorders in the helicopter crew than for the general population. In the Netherlands, a 2010 survey demonstrated a prevalence of neck pain over one year of 43%, with 20% of constant or regular pain [15]. 80% of Canadian pilots signaled having suffered of their neck during flights [16]. In Sweden in 2006, the amount of cervical pain was of 57% for a three months period, with 32% of chronic pain [17]. In 2010 in Israel it was 47.3% of classic helicopters and 36.4% of fighting helicopter pilots who complained of this problem. It was more important than the fighter jet pilots (47.2%) and transport plane pilots (22.3%) [4]. Finally a Turkish study demonstrated the presence of higher changes in cervical osteo-arthritis (OA) [18].

5.1.2 Traumatological onset

Helicopter flights are one of the most dangerous modes of air transportation. In the oil ans gas industry, helicopters are the most common way to go to and from the offshore drilling rigs and vessels. Helicopters accidents are around 90% more likely to happen than airplane and are much more critical in terms of injuries or fatalities. In the US, the average mortality rate is 3.8 per 100.000 workers. This rate rises to 27.1 per 100.000 employees in the oil and gas industry, 75% of all transportation-related deaths were in helicopter accidents during the 2003-2010 time period [19]. Again American studies have shown that US Air Med & Recue reported 122 helicopter accidents in 2019, 24 of them fatal[20]. The United States Helicopter Safety Team (USHST) stated 96 accidents (17 fatal) in 2021[21].

Causes

The causes of these accidents can be numerous:

- **Operational pilot error:** the first cause of piloting accidents is too low flights that reduce the reaction time in case of problems. Errors can be due to tiredness, stress, pressure, dealing with complicated equipment and important amounts of information processings. Most helicopter require much more hands-on-flying than fixed-wings aircraft.
- **Mechanical malfunction:** we understood in the paragraph concerning the vibrations that every component of the chopper is vibrating. There is no other aircraft receiving more stress on its different parts than helicopters. Added to this is the risk of failure of the engines, rotors, rotor shaft, gearbox,…
- **Electrical and electronic malfunction:** new generations of choppers rely more and more on the electrical system but above all on its electronics. Any misfunctionning can end in an accident.
- **Environmental factors:** such as rain, snow, winds, fog, atmospheric pressure, mountains, or bird strikes can provoke accidents.
- **Military operations:** with the risk of impact by hostile weaponnery.

Injuries and Deceleration

Helicopter accidents can end in very serious injuries, sometimes in death. The seriousness of the injury depends of the deceleration the (part of the) body is submited during the accident. The frequentest cause of injuries in aircraft accidents is this sudden deceleration happening during the contact with the ground or water. The deceleration is measured as G-force. The G-force is the force of gravity or acceleration on the body. The tolerance to deceleration forces depends mostly of the direction of inertial forces, but also of the duration, magnitude and intensity of the forces.

Examples of decelerative forces to cause injuries:

- Vertebral body compression: 20-30G
- Nose fracture: 30G
- C1-C2 fracture-dislocation: 20-40G
- Mandible fracture: 40G
- Aorta (initial laceration): 50G
- Maxillary fracture: 50G
- Aorta (transection): 80-100G
- Pelvic fracture: 100-200G
- Vertebral body transection: 200-300G
- Fragmentation of the whole body: >350G

Injuries resulting from helicopter crashes can be varied and multiple. They are resulting from the sudden heavy contact of the body on the equipment or with the aircraft structure and the deceleration force as explained earlier. Every part of the body can be affected. They can range from lacerations to simple single fracture, multiple complex limb fractures, spinal cord injuries, cranial trauma with or without brain damages, soft tissues and thoracic or abdominal organs injuries, haemorrhage, amputations, burns injuries, drowning, asphyxia, Post Traumatic Stress Disorders among others.

Three orthopedic injuries are specific in the case of helicopter crashes: whiplash, T12-L1-L2 fractures and pelvis fracture.

Whiplash

The worst scenario that can happen to a helicopter is to lose his tail rotor, the torque force of the main rotor can not be counter-balanced anymore and the cabin starts spinning in the opposite sens of the rotation of the blades. The sudden uncommanded and uncontroled yaw applies tremendous centripetal force on the cockpit and its occupants. The lumbar and thoracic spine of the pilots and crew are harnessed and stabilized but the cervical portion is impacted by this brutal violent rotative force. It results by cervical ligament sprains and whiplash.

In studies performed at the University of Virginia, they analysed the risk of neck injuries from increased head mounted mass on dummy and cadaveric subjects. The results were announced at the IRCOBI conference in 2006 in Spain (22). The researchers reported that between 67 to 70% of the injured spinal structures were the posterior ligaments (83% of them between C5 and T2). The prevailing injuries were the supraspinous ligaments and ligaments flavum tears and transactions. The spinal cord became particularly vulnerable to fracture when the supraspinous, interspinous, ligamentum flavum and posterior longitudinal ligaments were torn or transected.

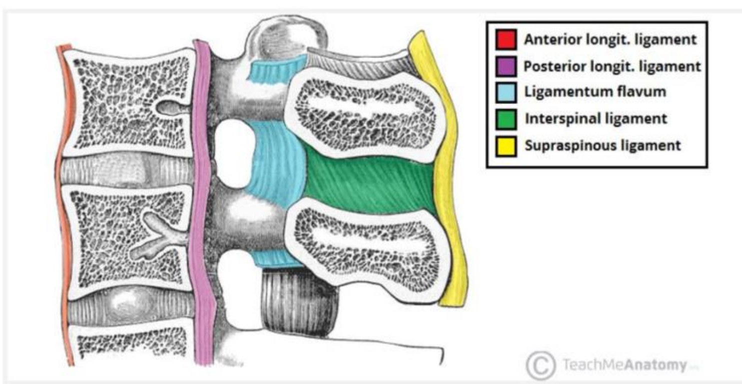

Figure 17: Ligaments of the spine

T12-L1-L2 Fractures

Within the whole spine, the thoracolumbar portion is the most impacted, L1 being the vertebra sustaining the highest rate of fractures. In a 1989 Shanahan and Shanahan survey (23), L1 appears to be the most fractured vertebra (30 of 547 total spinal injuries sustained during the study period in survivable and partially survivable mishap aircraft (5.5%). The second most injured vertebra was L2 (20 of 547 total spinal injuries, 3.7%), followed by T12 (9 fractures or 1.6 %). L1 was 1.5 times more likely to sustain a major injury than any other thoracolumbar vertebra (T11 to

L5). This can be explained by the harness and safety belts creating a fulcrum at this level of the spine.

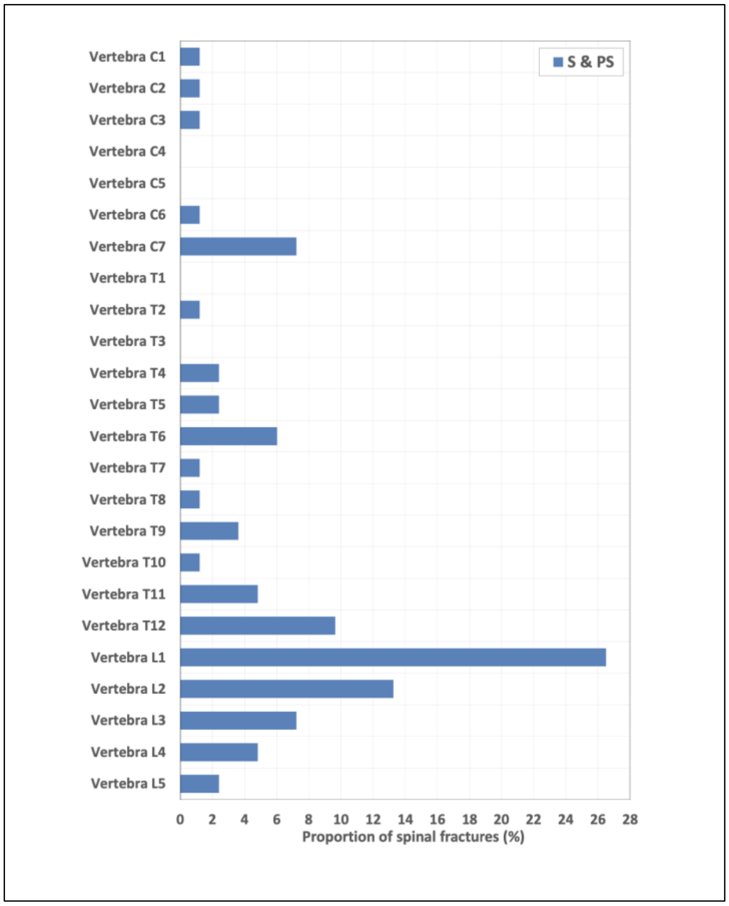

Figure 16: Spinal fracture frequency by vertebral level for survivable and partially survivable mishap aircraft from Shanahan and Shanahan (1989) [19]

Pelvis fractures

The pelvic girdle serves as the connection between the seat and the spine. During a vertical impact, deceleration forces are transmitted from the ground to the aircraft, next to he seat and finally through the pelvis and vertebral spine. In a 15 years survey ran by the US Army Aeromedical Research Laboratory (USAARL) [24], pelvic injuries happen more often in non-survivable impacts (57.8%) than in survivable and partially survivable accident combined (37.3%).

5.2 Specific associated risk factors

Several specific risk factors are associated with the predominance of spinal pain and pathologies. The Cunningham team reported in 2010 [25] that some of the causes of lumbar pain of Royal Air Force (RAF) helicopter pilots were related to issues such as the posture, the lack of lumbar support, the helmet, the night vision goggles (NVG), the combat protective gilet and the safety jacket. A 2007 French survey [26] concerning the cervical pain stated similar factors: the weight of the equipment, the seat, the posture during the flight, the vibrations, the combat or life jacket, and mainly the NVB.

5.2.1 Physical and mechanical stress

The main mechanical stress that pilots and aircrew undergo is the vibrations. Research demonstrated that a 5 Hz vibration is within the range a human's upper body presents resonance frequency (De Oliveira CD and Nadal J) [27]. Previous experiences on body vibrations and pathogenesis of disc degeneration in animals suggested that vibrations affect negatively the metabolism and nutrition of the disc, especially if the vibration coincide the resonant frequency of the spine (4 to 6 Hz). These vibrations then lead to an inflammation and degeneration of the joint structures, and premature deterioration of intervertebral discs.

5.2.2 Posture and ergonomics

We can comprehend with the description of the cockpit and the location of the three main commands (the cyclic, the collective, and the pedals) that the pilot's body is constantly in an asymetric position. This was determinated by Traccard in a 2010 survey [28] about the posture of the pilots and crew flying on Caracal EC275 and Puma AS330. This can easily be extended to any kind of aircrafts, especially where there is asymetric positioning of the flight controls.

Let us highlight that:

- The collective is located on the left side of the seat and is used by the left hand of the pilot in a vertical upward or downward motion. Some levers have a small range of amplitude while others have a bigger one, forcing the pilot to elevate his left shoulder and arm in an higher lateral abduction motion during takeoff or climbs. The opposite movements occur while descending or landing the chopper.
- The cyclic stick located between the legs is manoeuvred by the right hand. That brings the right shoulder forward and in left rotation. Anatomically this protraction and leftt rotation of the shoulder girdle ends by a retraction of the right Pectoralis muscles, abduction of the scapula and elongation of the Rhomboids and Upper Trapezius muscles that become weak. Another small degree of pelvic torsion to the left can be noted, and is followed by a left rotation of the lumbar spine.
- The rudder pedals are constantly operated (to control the rotation of the machine to the left and right) by movements of the feet and legs.

This piloting posture necessitates keeping the body in a permanent slight anterior flexion and left rotation of the trunk and shoulders, leading to a kyphosis of the thoracic spine, an effacement of the lumbar lordosis, and bigger efforts in compression on L3 and L5 (than in a neutral straight

siting position) [29], and right controlateral rotation of the cervical to keep the head and look straight. From the thoracic vertebrae misalignment, further complications can affect the ribs and the sternum anteriorly.
Several experimental studies highlighted with electromyography the increased activity and fatigability of the lumbar, cervical and Trapezius muscles on the right side, compared to the left muscles [30, 31, 32, 33,34] .

Figure 18: Posture of a pilot showing its asymmetrical position while piloting

Another postural issue depends on the size and the shape of the windshield. A pilot explained to us that depending of the type of helicopter, the windshield size and form can differ. If it is small and low in its height, the visibility of the upper sector is reduced and the pilot must lean forward and raise his head to be able to see this important part of the sky. This can be accentuated if the pilot is tall (and low in his seat) or if the seat is in a more backward position. That creates an anterior flexion of the thoracic spine and cervical extension with more loads on the vertebrae.

More complex and pathological postures appear when the pilot is doing aerial work, bringing heavy and large suspended loads to precise locations on construction sites. In addition to their asymetric posture, they need to side bend and rotate their trunk and head to the right to look through a lateral working bubbled window. That adds an inversed twist of their body to their initial wrong ergonomy and pilots are completely twisted.

In a (very intersting) 2011 article in the Helicopter magazine [35], Dr E. Roback, a practising aviation chiropractor in an Alberta sports rehabilitation firm, explained the complications and pain experienced by pilots in function of their posture, back stabilization, vibrations and spine hydration. We now understand that the asymetrical posture creates several problems in the pilots

but we would like to attract the attention on the (de)hydration point and its consequences on intervertebral discs.
Dehydration of the body decreases the blood pressure, which in turn reduces the “G” tolerance. It can affect especially high altitude flights where pilots need to breath dry oxygen, which exagerates the dehydration. Water deficiency in the body also desiccates the intervertabral discs, reduces the suppleness and flexibility of soft tissues, and thickens the blood.

A.G. Hadjipavlou published in a 2008 report on the physiopathology of disc degeneration (36) that intervertebral discs are the largest avascular tissues in the human body. The cells in their centre are about 8 mm away for the closest blood supply vessels. Cells at the external edge of the disc receive their nutrients from the large blood vessels of the neighbouring muscles and from a sparse diffusion of capillaries in the muscle’s furthermost areas. Intervertebral discs use a distribution system to pump water and nutrients into them. It seems that prolonged immobilization and compression of the spine deteriorate this flow of nutrients to the disc. That leads to an increased stress and cell death at the centre of the disc initially, later in the whole disc.
We can see that prolonged unsupported positions that helicopter pilots sustain sometimes for several hours can facilitate the deterioration of the intervertebral discs.

5.2.3 Repetitive movements

We understood that the main repetitive movements are those of the upper arms and legs. All the movements can’t be dissociated. Once you act on one command, the others must be adjusted. The left arm who is constantly manoeuvring the pitch lever of the collective in an upward and downward directions; the right arm controling the cyclic forward, abackward and latrally; and the feet pressing on the rudder pedals.

5.2.4 Equipment

Another factor that contributes to the dyscomfort, pain and more serious pathologies of the pilots’spine is the weight of the equipment they must bear. Albeit new materiels and enginnering techniques made the different components of the gear lighter and more comfortable, they still increase the amount of stress the body has to support.

Helmets

Helmets will differ in function of the category of pilots, military or civilian pilots. Military pilots will wear whole integral helmets while civilian will usually wear only the speaker-receiver helmet that mostly covers the ears (with a role of noise protection and communication). Military helmets vary depending of the corpse, mission and helicopter model. They are getting progressively lighter with time but still remain a 1-1.5 kg supplementary weight on the pilot head and cervical spine. It seems that the weight of the helmet is not associated with thoracic or lumbar pain, but with cervical pathologies. Contrary to a jet pilot fighter helmets which are constructed from a mold of the pilot’s head and integrated in the helmet shell, other (non-military) helicopter helmets are more standard and sometimes not perfectly adapted. They can slide slightly laterally or forward because of the vibrations or the weight of the attached binoculars.

Night Vision Goggles (NVG)

Night flights are difficult and can't be done without a light amplification system. For this, pilots use the Night Vision Goggles, a system attached on the helmet. They generate a supplementary weight of 800-1200 g in front of the eyes which pulls the head forward in a slight cervical flexion. It had been demonstrated that this equipment augments the loads on the Trapezius muscles [(37)]. To counterbalance this anterior weight, some crew place the battery of the NVG on the base of the back of the helmet. Nonetheless postural studies on the activity of the Trapezius showed contradictory results [(38)] . This added counter-weight increases the weight and modifies the center of gravity of the helmet. An increased in sternocleidomastoid electromyography (EMG) was notified by Knight and Barbar (1994) and Winter and Peles (1990), resulting in higher co-contractions of the agonist muscles to stabilize the neck and head.
The second problem caused by these NVG is that they reduce considerably the peripheral field of view (around 20 d° only) and force the pilot to rotate his head constantly to the right and left to be able to recreate the 3D image in his brain. A pilot eplained to me that was like looking into two small cardboars tubes of toilet paper rolls, with a very limited peripherical vision while they always need to visually scan the perimeter of the scan and the aircraft with the head in an uncomfortable non neutral position.
It is easy to understand that the superior cervical vertebrae and articulations (OAJ and AAJ) receive more strain to hold the head in a neutral position (OAJ) from the weight of the NVG, and during these regular lateral rotations to have a enlarge field of view (AAJ).
Cervical pain related to flights had been reported by 80% of Canadian helicopter pilots, 70% signaled experiencing it while flying [(39)]. During night flights, the percentage of work cycle spent in mild flexed posture raised to 74%, for 43% during the day. NVG demonstrated that they increase pilot's cervical pain and affect their professional and quality of life.

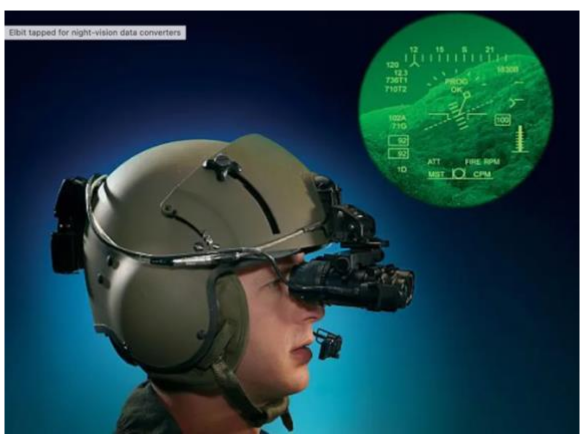

Figure 19: Night Vision Goggles
with an image of restricted field of view and counter-weight at the back

A different night vision system is the HUD or Head's Up Display. Its technology is much more complex, expensive, and is mostly used by the pilots of combat helicopters. The night vision system is integrated into the pilot helmet which delivers other information such as the current flight data, mission, target, weaponry,…


Figure 20: HUD helmet

Safety Jackets

Depending of the flight plan, pilots and crew flying over water must wear life jackets (Mae West). Albeit these jackets are mandatory and unvaluable to save life in case of crash, they unfortunately compress the spine by adding 1.5 kg with standard jacket and 3.5 kg with jacket equiped with an Emergency Breath System.

Combat protective Vests

Military pilots in field operations or in training wear ballistic vests which add up to 20 kgs more on the shoulder and compress more the spine. Military crew regularly complain about this excess of weight responsible for more muscular and spinal pain [(40)].

5.2.5 Types of helicopters

It is quite common to have pilots and crew reporting specific symptoms and pain depending on the model of helicopter they are flying in. Thomae *et al.* survey [(41)] demonstrated that 74% of pilots linked the apparition or worsening of symptoms to a specific aircraft. That could be explained by the age of the model, the quality of the seat, the posture and ergonomy, the location of the commands and controls, the vibrations, the accessibility of the cockpit, the shape of the windshield,….

New generations of helicopters benefit from aeronautic engineering that has developped new mechanisms, dynamic or passive anti-vibratory systems, composite material to attenuate all the loads and stress applied on the aircraft and therefore on crew's bodies.

It is clear that all data found and displayed in this thesis should be approached with the understanding that they depend of the model of chopper used by the pilots and crew members during the survey.

6. Treatment of spinal pathologies

In this chapter we will see the different options for treatment for spinal pain and complications helicopter aircrews have.

In the 2014, a medical thesis survey of Dr Dehez from the French army [(42)], 85.7% of the helicopter crew consulted a health professional for a spinal pain. French helicopter pilots who participated in this study visited medical doctors, osteopaths, physiotherapists, acupuncturists, and chiropractors. The most consulted practitioners were the osteopaths, physiotherapists, and medical doctors.
The interesting point in this thesis is the note attributed by the patients to the different therapists regarding the benefits of their treatment (note from 0 to 5):

Osteopaths: 4.11/5
Physiotherapists: 3.80/5
Chiropractors: 3.75/5
Medical doctors: 2.53-3.45/5
Acupuncturists: 2.74/5

We can notice that manual treatments proposed by osteopaths, physiotherapists and chiropractors are well appreciated by patients. It is not a real surprised as manual therapists can -in our opinion- assess more properly the cause of the ailment, and offer a higher holistic and individual personalized approach and treatments to their patients. They also are much more aware and better trained in musculo-skelettal troubles (MST) than medical doctors whose the studies don’t give them the same amount of education on this particular field.

6.1 Medical

While in pain, some pilots consult a medical doctor (general practitioner or specialist). Unfortunately the purely medical approach is a tendency too often to only provide medication to ease the pain (analgesics or anti-inflammatory drugs) without always looking for the initial cause of the problem. Some physicians who may be more aware of spinal pathologies will refer the patients for medical imaging or to health practicioners such as physiotherapists, osteopaths, chiropractors, acupuncturists,…
Other aircrew, who don’t consult a doctor, have a tendency to wait for the pain to disappear or to try to treat themselves. However medical authorities are aware about self-medication. A 2008 pharmaceutical industry French survey [(43)] revealed that 7 over 10 people in France uses self-medication, mainly for pain medication, respiratory ailments and digestive afflictions. These patients are usually young (30 to 50 years old) active people in relative good health, educated, and from the middle or upper classes. Helicopter pilots and crew belong to these categories. Self-medication in the air transportation industry can be hazardous, especially while combining different pharmaceutical molecules which can alter the vigilance and reactions of the pilot. Federal and governmental Aviation Administrations around the world have published lists of medicines counter-indicating flying, such as muscular relaxants pills that can provoke drowsiness.

6.2 Osteopathy

In this section we would like to describe briefly the different osteopathic techniques we used during our treatments of the helicopter aircrew who consulted us.

Assessment techniques

The goal of these techniques is to locate the pain and muscular hypertonicity, to assess the general posture, the active and passive Ranges of Motion (ROM), to determinate the vertebral mobility and the muscular strength, to check the neurological reflexes and irritation. They can be performed on the three segments of the vertebral column and on all peripheral joints.
This general and specific assessment include:

- Patient questioning and medical history check.
- General posture analysis to determinate any differences in the different body segments positions: forward head syndrome, elevation of one shoulder, ante or retropulsion of a shoulder, scoliosis, kyphosis, hyperlordosis, anterior or posterior innominate bone, asymmetric pelvis, rotations of the legs, varus or valgus of the knees, pronation or supination of the calcaneus, flat feet, muscular stiffness, skin and visual body inspection, and so on.
- Active and passive ROM in flexion, extension, rotations, and lateral side bendings.
- Reproduction of the pain or symptoms during the active and passive movements.
- Inter-segmental static joint play and palpation: posterior facet irritation test, Posterior to Anterior (PA) glides on Spinous Process and Transverse Processes.
- Skin roll.
- Upper or Lower limbs neural tissue evaluations: screening tests, neurodynamic provocative tests, nerve palpation, sensitization source identifications.
- Muscular strength and muscular imbalance.
- Reflexes.
- Dermatomes.
- Myotomes.
- Specific joint assessments tests.

Mobilization techniques

These different techniques aim to recover normal vertebral or articular mobility, to regain the gliding motions between the articular contact surfaces of the vertebrae or bones in a joint and therefore to increase the ROM, to stretch the capsules and soft tissues, to enhance the blood circulation, to reduce the inflammation, the sensitivity, the pain, and the muscular spasm.
Osteopathic mobilizations use low velocity and moderate amplitude forces to carry a dysfunctional joint through its full ROM. They can be preceded by thermogenic techniques to better prepare the tissues for the mobilizations.
There are so many different osteopathic mobilization techniques which all have the same goals. Here is a not exhaustive list of mobilization techniques that can be used: catwalk, cupping, double edge hands, pelvis pull, leg lift, SP traction, rocking thechniques (on the same or alternate vertebra(e)), cross hands, traction with double legs lift, lateral recumbent techniques on SP or TVP -with or without knee assist-, all peripheral joint glides and mobilizations.

Manipulation or High Velocity Low Amplitude Thrust (HVLAT)

Vertebral manipulation, or Grade 5 mobilization, or HVLA applies a rapid (high velocity) but short thrust over a small distance (low amplitude) on a rotational area within the anatomical barrier, without going beyond the physiological barrier of a joint. The goal is to engage the restricted barrier in one or several planes of movements to liberate the restriction and to regain a normal ROM by breaking the adhesions that limit the mobility of the joint.
These techniques can be very impressive in their efficiency but should be performed with great care and professionalism because they are more risky than softer mobilization techniques.
The "cracking" noise that can be heard is the result of a cavitation phenomenon, which is the liberation of a bubble of gaz produced by the sudden movement of the synovial fluid within the capsule joint.

Cranial Osteopathy Therapy techniques

We are using these very specific techniques mostly for the pilots presenting cervical pain and problems. We saw in the equipment section than military pilots wear helmets while flying and that the extra weight on their head is prone to cervical strain and injuries.
Classical cervical treatments can be optimized with cranial therapy techniques, especially for the upper cervical portion of the spine, but also for all medical issues occuring into the body.
The principle is to equalize the tension and circulation of the cerebro-spinal fluid to release the reciprocal pressure on the membranes of the meningeal system and the dural tube. For this, we mobilize the cranial bones and the sacrum (as levers) on the dural tube to extend and realign the fissures of the meningeal membranes. The technique uses the primary respiratory mechanism and balanced membranes tension that guides the function of the cranium, spinal cord, dura, sacrum, but also every cells of the body. Therefore cranial osteopathy is not limited to cranial or cervical problems, but on the contrary has effects on all parts of the body. This makes the osteopathic treatment completely holistic, it treats the whole body as an unit.

Soft Tissues Therapy (STT)

STT techniques are working on the soft tissues, essentially on the muscles, tendons and fascias to reduce the pain and the muscular spasm, to recover a normal length, a better flexibility and reactivity of the tissues. There also are many numerous methods to perform them. In our practice we are personally using the following ones:

- Strain – Counter Strain technique (SCS)
- Muscle Energy Technique (MET)
- Proprioceptive Neuromuscular Facilitation or PNF
- Facilitated Positional Release technique (FPR)
- Massage therapy techniques
- Visceral manipulation techniques (see below)

Visceral manipulation techniques

Some MST can have a visceral origin. Thoracic or abdominal organs present two kinds of movements: a general mobility of the viscera under the influence of external forces (movements of the diaphragm or the heart), and related to the surrounding organs and muscles, and an intinsic active motion of the organ itself (without the influence of extrinsic factors and other organs movements) that is named motility. The blockage and lost of general mobility and the reduced motility lead to an organic spasm and dysfunction but also to different MST. In effect, the spasm of the organ generates a pulling of the fascias which draws and stretches some attached muscles connected to the vertebrae and bones. The result is a reduction of the spinal or joints mobility and a provocation of the pain, and functional incapacity.
Restoring the mobility and motility of the concerned restricted organ with appropriated visceral manipulation techniques can sometimes be the key point of the treatment. It also can be used as a complementary technique to finalize a treatment [(44,45)].
We noticed improvements of the MST, pain and symptoms while using these techniques on our pilot patients who presented intestine, stomach or kidneys (see the paragraph concerning Renal colic in the Other Medical Complications chapter below) blockages.

6.3 Other therapeutic procedures

Physiotherapy

Physiotherapy or kinésitherapie (in French language) is a therapy by the movement (kinesis in Greek means movement). Physiotherapy uses different modalities of mobilizations, soft tissues releases, strechings, strengthening exercises, proprioception, and rehabilitation program, … But also the application of external physical agents to ease the pain, enhance the recovery of the tissues, regain normal organic, articular, muscular and neurological functions.
These external agents can be: thermic (heat or cold), infra or ultra-sounds therapy, short waves, radar waves, laser therapy, extra-coropral shock wave therapy, electrotherapy, hydrotherapy,…
Physiotherapists can work in almost all the different fields of the medicine from the very young age (in neo-natalogy) to very old patients in geriatrics, in most of medical departments, as well as in sportive activities.

Chiropractic

According to the World Federation of Chiropractic website, the definition is: "*A health profession concerned with the diagnosis, treatment and prevention of mechanical disorders of the musculoskeletal system, and the effects of these disorders on the function of the nervous system and general health. There is an emphasis on manual treatments including spinal adjustment and other joint and soft-tissue manipulation."*
Chiropractic treatments apply many manipulations on the misaligned joints, especially those of the spine, which could be the cause of neurological disorders and muscular or organic affections. They thus perform many spinal manipulations to re-align the vertebrae and liberate the neurological pathways.

Acupuncture

Acupuncture is an ancestral Traditional Chinese Medicine (TCM) whose the goal is to rebalance the different levels of energy to facilitate the circulation of the flow of the Qi. The Qi is the vital energy moving in the whole body. It can be influenced by the 5 elements that are the wood, fire, earth, metal and water. Each of them is associated to a Yin and a Yang organ, a sense organ and a fluid. An excess or a deficiency of energy in one of these elements leads to an organ disbalance and to several associated pathologies.

Element	Season	Yin organ	Yang organ	Sense organ	Fluid
wood	spring	liver	gallbladder	eyes	tears
fire	summer	heart	small intestine	tongue	sweat
earth	none	pancreas	stomach	mouth	saliva
metal	fall	lung	large intestine	nose	mucus
water	winter	kidney	urinary bladder	ears	urine

Figure 21: Chart of the 5 elements and associations

The body is divided in 12 meridians, plus 2 other central vessels that are passageway for the energy to circulate throughout the body. Each meridian corresponds to an organ and contains several strategic acupuncture points that are stimulated with needles inserted through the skin. Acupuncture is very efficient to treat pain and to restore organics functions. It can be a great help associated to other techniques, but it will not fix the mechanical or postural issues. Acupuncture is only one of the several methodes of the TCM that also offers moxibustion, cupping, acupressure, auriculopuncture, phytotherapy,…

6.4 Prevention

As health professionals specialised in musculo-skeletal disorders, we are well aware that prevention is a key point of our treatment plan. After determining the etiology of the problem, eliminating the pain and dyscomfort -which are the first reason of consultation-, correcting the different postural issues, establishing a program of muscular tonification, increasing the stabilization and proprioception, we believe that we have an important role in the education of the patients- role unfortunately too often neglected by health practitioners.

A Norwegian 2018 study from University hospitals [(46)] concluded that reduced lumbar trunk muscular function and akward position cause lower back pain (LBP), and that improving the tonification and endurance of the core muscles by specific training lessens the pain, improves the function and quality of life, and also reduces the number od sick leaves with the helicopter crew.

The Ergonomics International Journal (EIJ) article of January 2018 [(47)] presented several causes and possible solutions to reduce spinal pain in helicopter pilots and crew. We have attached below a recap board of their main ideas:

Etiologic Factors	Mechanism	Proposed Treatment	Expected Effect
Asymmetrical Posture	The trunk position in-flight (bend forward, twist to the left and bend to the left) is a great effort to the paraspinous muscles, leading to a fatigue	• Specifics exercises (stabilization and endurance) considering the muscles involved in the flight activity • Pre- and Post-flight stretching	• Increase the muscle strength and endurance • Produce a general muscle balance, improving the general posture
Static Position	This position leads to a great isometric contraction that leads a decrease in the blood supply, oxygen delivery, and deficient disc nutrition, producing fatigue and pain.	• Stretching exercises • Pre-, During and Post flight • Pre- and Post-sleeping	• Increase the length of the muscles • Improve blood supply process • Prevent fatigue • Improve disc nutrition
Prolonged Sitting Position	Shortens the lower limbs muscles, contributing to flat more the lumbar lordosis.	• Stabilizing exercises • Oriented flexibility exercises (FNP) • During flight stretching.	• Improve the co-contraction capacity • Improve posture, elongating the shortened, and strengthen the weakened muscles • Improve disc nutrition.
Vibration	It working in order to worsened the other three factors.	All Program	Improve the pilot specific physical conditioning, strength, endurance, flexibility, and the spinal stabilizer ability.

Figure 21: EIJ (2018) chart of causes, mechanisms, treatments, and effects

Solutions	Description of the actions/improvements
Redesigning of the Cockpit	• Bring the cyclic and the collective closer to the pilots body; • Developing a forearm support to the right arm (using the collective)
Improvement of the Seat Design	• Improvements in back design (more contours) with a good lumbar support • Improvements in thigh support (design and cushion to absorb vibration) • Improvements in the adjustment range in all axes, including arm rest and pedals
Personal Lumbar Support	• Making personal pilot-fitting lumbar support • Provide it to all helicopter pilots
Specific Exercises Program	• The program have to combine strength, stabilizing and flexibility exercises; • The strength, stabilizing and flexibility exercises must be under supervision and orientation;
	• Must be complemented by self-stretching exercises (pre-, in-, and post-flight, and a pre- and post-sleeping).
Management in flight duration	• Planning flights no longer than 2 hours (when it is possible); • Including the in-flight self-stretching exercises as an operational procedure.

Figure 22: EIJ (2018) description of proposed solutions to reduce spinal pathologies in helicopter crew

They concluded that in order to offer a comprehensive solution of LBP, a specific and personalized specific exercise program (immediate measure), the use of lumbar support (short term solution), and new design of the cockpit and the seat (long term goal) would help to reduce LBP in helicopter crew.

Another study from Patil University School of Sports and Exercise Sciences of Mumbai, India, held in 2018 [(48)], demonstrated that over the pilots who attended a 12-week structured exercises program to strengthen the core muscles and work on the mobility of the spine noticed a higher muscular endurance, improved function, and quality of life at the end of their program. 80% of the crew reported a better spinal muscular tone, 70% a gain in their back muscles, and 50% an improved spinal flexibility. Globally 70% of them found the course beneficial.

The US Naval Aviation studying the efficiency of standardized Preflight/Postflight Stretches (PPS) protocol on helicopter pilots [(49)] concluded that a simple 5 to 7 minutes stretching routine helps to reduce safely postflight cervical, thoracic, lumbar, and general pain. This PPS habit could limit conventional medical consultations, pharmaceutical prescription, and should be extended to other military and civilian aircrews.

The common main points in all the documents quoted are their insistence of muscular stretches and core muscles (Abdominals, Gluteus, Lumbar extensors) strengthening, which is not a surprise when we know the importance of these muscles to stabilize and protect the spine.

Stretches

Cervical, pectoralis, arms (triceps), lumbar, piriformis, gluteus, hamstrings, quadriceps, ilio-psoas, and adductors muscles should be stretched regularly before and after flying. We believe that Muscle Energy Technique (MET) is beneficial during the therapeutic sessions but also that teaching the aircrew how to perform the different stretches by themselves is an important part of the prevention.

Core strengthening

Three main groups of muscles should be targeted: the abdominals, the gluteus, and posterior erectors of the spine. Activities like yoga and especially Pilates propose a wider range of different exercises to increase the muscular tone of the spine and pelvis stabilizers.

Foam roller

Foam roller movements can be applied on the posterior muscles of the trunk, as well as on the lower body (anterior, posterior, and lateral thigh and leg muscles) to reduce muscular tensions and stiffness.

7. Statistic survey of spinal ailments in helicopter crews (personal clinical cases)

7.1 Goal of the survey

In this paragraph, we conducted a survey study of helicopter pilots we treated over the past three years in our international clinic In Myanmar. All these pilots were not military (although many of them were former militaries from the French army, navy and air force), but currently working for a private French company contracted by oil and gas companies. Their main flight missions were to bring workers and staff, and equipment to and from the offshore rigs.
This survey is only based on a small limited sample of patients from our private practice and the findings should therefore be taken with cautious.

7.2 General information

Pilots from HeliUnion private company operating in Myanmar are based in Yangon. The oil and gas rigs they are flying to and from have different locations in the Andaman sea, necessitating between 1 hour to 2 hours and 10 minutes, one-way journies. They do a minimum of two flights (one return tour) to a maximum of five (two return trips and one test flight) per day.
The French law authorize helicopter pilots to fly 185 days per year with a maximum of 8 hours a day, 35 hours a week. In Myanmar, they are flying up to 100-120 hours per month.
They are piloting Agusta commercial choppers which can transport up to 12 passengers per trip, but also are transporting professional equipment and components, and are in charge of medical evacuations in case of accidents.

Figure 20: Agusta Westland Leonardo AW139.

7.3 General characteristics

In our limited personal survey, we treated differents pilots over the past three years of private practice in our international clinic.
The average age of the pilots was 52 years old, running from 41 (for the youngest) to 64 years old (for the oldest).
Some of the pilots consulted us for only one acute pathology with a single course of treatment of a few consultations, others with more chronic problems came on a regular basis for different issues or combined pathologies. Consequently they attended several different course of treatments.
In total, we saw 24 differents patients for a total amount of 217 consultations. The minimum number of treatments was 2 sessions and the maximum was 15. The average number of consultations was 9 sessions per pilot.

7.4 Prevalence of pain

Cervical pain (and associated cervical pathologies: torticollis, cervico-brachialgia, cervicogenic headaches): 76 consultations over 217 consultations or 35% of the total amount of consultations.
Thoracic spinal pain: 18 consultations or 8.3%.
Lumbar pain: 78 consultations or 36% of the total consultations.
Shoulder pathologies: 23 consultations or 10.6%.
Other (right hip, right leg): 22 consultations or 10.1 % of the total number of consultations.

The data shows that cervical and lumbar complaints were the most frequent causes of consultations with a similar percentage of sessions received. In accord with the findings from other surveys, the thoracic spine seems to be the least impacted portion of the vertebral column, even if we add the shoulder pathologies that are linked to the thoracic column.

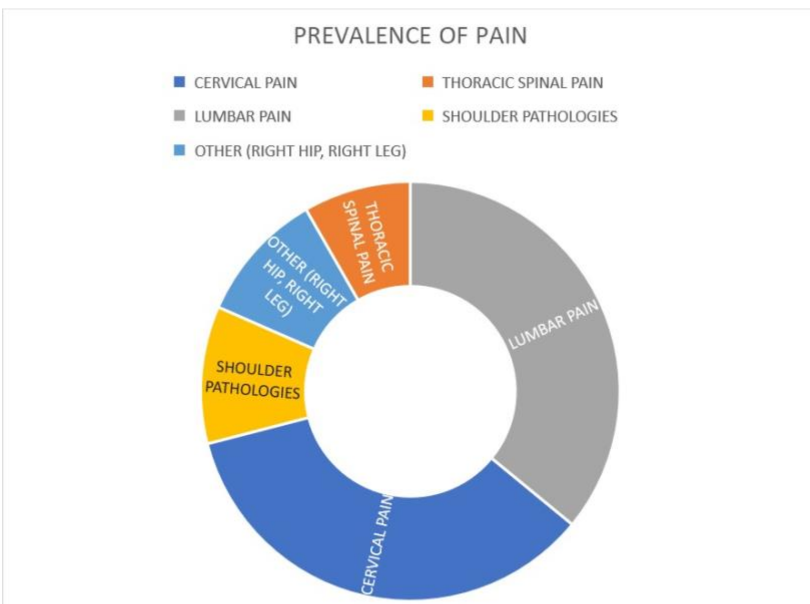

Figure 21: Chart of the prevalence of pain

7.5 Patient treatment

After assessing our patients to determinate the origin of the problems, we started to treat them using different techniques. These diverse therapeutic manual therapy methods will be described with more details in the next chapter but we thought useful to inform our readers about those we used in our practice with these pilots. Not all the procedures described below were used during a single consultation, we chose those we found the most appropriated or effective depending of the current condition of the patient at the present moment.
We would like to attract the attention of the reader that during our treatments we employed different manual therapy techniques (not only osteopathic) learned over almost three decades of practice.

Cervical treatments

- Local acupuncture points stimulated by acupressure: SI14, SI15, GB20, GB21
- Osteopathic mobilizations and sometimes manipulations (HVLA) on the OAJ, AAJ, cervical vertebrales and cervico-thoracic junction (C7-T1). We are using PA glides on the Spinous Processes (SP) or Transverse Processes (TVP).
- Natural Apophyseal Glides (NAG) or Sustain Natural Apophyseal glides (SNAG) performed with an antero-cranial (45 d°, along the plane of movements of the articular facets) PA glide on the cervical SP.
- Mobilizations with movements (MWM): articular glides along the axis of the articular facets (45 d° for the veretbrae of the lower cervical segment) during an active movement (flexion, extension, rotation or lateral flexion) performed by the patient.
  These NAG, Reverse NAG, and MWM are some of the techniques of Mulligan manual therapy concept [51].
- In case of cervicogenic headache or dizziness, patients can be relieved with an AP or PA glide on the OAJ.
- Traction of the cervical spine along its axis, or with slight rotation or lateral flexion to open the lateral foramina and decompress the nerve roots in case of upper limb paresthesia.
- Upper Limb nerve mobilizations and glides to desensitize them if necessary.
- Soft tissue release techniques: Strain – Counter Strain technique (SCS) or Facilitated Positional Release technique (FPR) on the different trigger points found in the cervical musculature.
- Muscle Energy Technique (MET) or Proprioceptive Neuromuscular Facilitation (PNF) to regain the full flexibility of the muscles.
- Niromathé technique to trick the brain by stimulating the skin neuroreceptors to regain the ROM, eliminate the pain, and “reprogram” the cutaneous and subcutaneous points that are “deprogrammed” by the osteopathic lesion.
- Ultra-Sounds Therapy (UST) or electrotherapy in the case of too algic patients who have difficulties to bear the mobilizations or manipulations.
- Occasional relaxing massage if the muscular stiffness is important.
- Strengthening exercises to stabilize and better protect the spine after eliminating all pains and stiffness, and regaining normal ROM.

Thoracic treatments

- Local acupressure points along the spine.
- NAG, Reverse NAG or SNAG performed along the 60 d° axis of the articular facets.
- MWM on SP or on TVP during active movements of the patient to recover the limited ROM.
- Osteopathic mobilizations: glides on the SP and TVP in flexion, extension, rotations and lateral flexions with active or passive movements of the patient, costo-vertebral mobilizations.
- Osteopathic HVLA on thoracic vertebrae in sitting, supine or prone position, costo-vertebral manipulations.
- Ribs or sterno-costal mobilizations.
- MET or PNF.
- SCS or FPR.
- Niromathé technique.
- Visceral manipulation on the diaphragm.
- UST or electrotherapy if hyperalgic patient.
- Massage therapy.
- Strengthening of the back extensors muscles.

Lumbar treatments

- Local acupuncture points: CV6, B23, B47, BL23, BL25, BL31, BL32, BL54, GB30
- Osteopathic mobilizations: catwalk, pelvic pull, cupping, double edge hands, SP traction, crossed hands, lateral recumbent on TVP (with or without knee assist, depending of the morphology and the limitation of mobilityof the patient), traction with double leg lift, AP or PA of the iliac bone (depending of its position and mobility) while stabilizing the sacrum.
- Osteopathic manipulation: mostly lumbar roll technique for the lumbar vertebrae or Sacro-Iliac joints (SIJ).
- MWM techniques with glide on the SP along the direction of the articular facets (in this case 90 d° or vertical).
- Lateral flexion of the spine in lateral recumbent position to open the ipsilateral foramina to decompress the nerve roots and stretch the Quadratus Lumborum (QL).
- As for the two superior segments of the spine, we use soft tissue release techniques: SCS or FPR on the different trigger points found in the lumbar or gluteal musculature.
- MET or PNF to regain the full flexibility of the muscles. We always target the Ilio-Psoas (IP) and QL, regularly the abdominal wall and lumbar extensor muscles (depending of their tightness).
- Lower limb nerves (sciatic or femoral) mobilizations and glides in case of neurosensitization.
- Niromathé technique.
- Visceral manipulation to release the eventual tensions and blockages in the abdomen that can pull the IP and restrict the lumbar mobility due to its vertebral attachment.
- UST or electrotherapy in the case of too much pain and hypersensitvity.
- Lumbar gymnastic exercises to regain more vertebral mobility and muscular suppleness.

- Strengtening of the core muscles (abdomninals, gluteus, and back extensor) to stabilize the spine and pelvis.
- Lumbar muscular proprioceptive exercises.

Shoulder treatments

- Local acupuncture points: LI15, LI16, SJ14, SI9, SI11, SI14, SI15, GB21
- Osteopathic passive, active, activo-passive mobilizations and stabilizations of the scapula, gleno-humeral (GHJ), acromio-clavicular joint (ACJ), sterno-clavicular joint (SCJ) to facilitate the movements.
- MWM with AP or PA glides of the head of humerus (with or without decoaptation) to regain a limited ROM.
- Pain Release Phenomenon techniques (PRPS) [(40)] to reduce the pain and tenderness in acute pathologies.
- Soft tissue release techniques: SCS or FPR on the different local trigger points found, MET or PNF to stretch the contracted muscles to regain their full physiological length.
- UST or electrotherapy if necessary.
- Massage therapy.
- Strengthening.
- Proprioception.

8. Other medical complications

During our researches and discussions with helicopter pilots, we have been informed about other medical problems RW aircrews can suffer from. Some of these complications were quite unexpected but finally not so surprising after we discovered and understood all physical and mechanical stresses pilots and crew members are subjected to.
As these medical complications differ from the subject of this thesis and will be too long to develop, we decided to only mention them. They can be the topic of another medical or osteopathic thesis (if not already done).

These other pathologies pilots can suffer are:

- **Shoulder pathologies** such as rotator cuff injuries, tendinitis, impingements, labral tear, misalignment,…
- **Cervicobrachialgia** that have a cervical origin (from the spine or the brachial plexus) and sensitize one of the upper arm nerves; or because of a nerve entrapment along its course.
- **Sciatalgia or Femoral nerve sensitization** due to the wrong ergonomy and vibrations leading to intervertebral disc degenerations and radicular compression or nerve entrapment along its pathway.
- **Dental amalgams or tooth crowns loosenig and falling down** due to the heavy constant vibrations of the engines and rotors.
- **Retinal Detachment** also because of the vibrations and myopia (short-sightedness that is pulling more on the retina).
- **Deafness** progressively provoked by the constant noises and vibrations that degenerate the 3 middle ear ossicles (malleus, incus, and stapes). It is not a permanent and total deafness but related to very specific frequencies.
- **Renal colic:** pilots are recommended not to drink too mineralized waters that can contribute -with the heavy vibrations- to the creation of kidney stones.
- **Barotrauma** due to the higher pressure inside the inner ear compared to the external pressure of the environment during too fast descents - that need to be controled. That lead to cochlear and vestibular pathologies.

9. Conclusion

At the end of the redaction of this enthralling thesis, we really do hope that you enjoyed reading it and that -like us- you were surprised to discover all the medical and spinal complications our pilot friends can suffer from, while learning interesting facts regarding their occupation.

We sincerelly do believe that manual osteopathic treatments are a very interesting therapeutic tool to help the different spinal ailments rotatoy wing airplane crews are suffering from. As for any vertebral therapy, a correct evaluation and diagnosis are vital to determinate the most appropriate technique. The combination of musculo-skelettal approach with visceral and cranial osteopathy can provide terrific results in only few consultations sometimes.

We also think that our role is not only to treat the pain and alignement issues produced by the incorrect piloting position but to prevent it from appearing. As we would have limited impact on the re-designing of the cockpit and advice on the anti-vibrations system, we can only focus more on the education of the pilots and creating customized gymnastic programs of stretches, flexibility and strenghtening exercises. As for many health issues and treatments, we consider that prevention and education are a very important part of our work. We are here to help and treat our patients who are in pain and needs, but educating them about their musculoskeletal disorders will help them to prevent these problems to appear.

A friendly pilot was emphasizing the analogy between the mechanical fatigue of the different components of the machine and the pathological degradation of the aircrew bodies. Mechanical parts of the helicopter are regularly inspected, removed and replaced on a strict planned calendar. Unfortunately the aircrew who is an integral part of the machine doesn’t have the possibility to have his “defective” anatomical and physiological body parts to be replaced. He therefore relies on his therapist -and his treatment and prevention program- to be able to continue his activity.

Integrating manual therapists in a program of education into the RW airline companies to prevent the different pathologies (reversible or not) to keep the pilots in a good condition and allow them to continue their career safely could be an intersting approach. That would be beneficial for everyone.

10. References

(1) Humzah, M.D.; Soames, R.W. Human intervertebral disc: Structure and function. *Anat. Rec.* 1988, *220*, 337–356.

(2) Gaydos SJ. Low back pain: considerations for rotary-wing aircrew. Aviat Space Environ Med. sept 2012;83(9):879!89.

(3) Cunningham LK, Docherty S, Tyler AW. Prevalence of low back pain (LBP) in rotary wing aviation pilots. Aviat Space Environ Med. août 2010;81(8):774!8.

(4) Grossman A, Nakdimon I, Chapnik L, Levy Y. Back symptoms in aviators flying different aircraft. Aviat Space Environ Med. juill 2012;83(7):702!5.

(5) Seynaeve A, Burlaton JP, Dollet-Ferraton D. Les rachialgies du pilote d'hélicoptère de l'ALAT. Résultats d'une enquête à propos de 560 réponses. Méd aéronaut spat. Soframas, Chantilly; 1998. p. 262!9.

(6) Hansen OB, Wagstaff AS. Low back pain in Norwegian helicopter aircrew. Aviat Space Environ Med 2001; 72:161–4.

(7) van Leusden AJ, Prendergast PR, Gray GW. Permanent grounding and flying restrictions in Canadian Forces pilots: a 10-year review. Aviat Space Environ Med 1991; 62:513–6.

(8) Froom P, Barzilay J, Caine Y, Margaliot S, Forecast D, Gross M. Low back pain in pilots. Aviat Space Environ Med 1986; 57:694–5.

(9) Landau DA, Chapnick L, Yoffe N, Azaria B, Goldstein L, Atar E. Cervical and lumbar MRI findings in aviators as a function of aircraft type. Aviat Space Environ Med 2006; 77:1158–61.

(10) Froom P, Froom J, Van Dyk D, Caine Y, Ribak J, et al. Lytic spondylolithesis in helicopter pilots. Aviat Space Environ Med 1984; 55:556–7.

(11) Thomae MK, Porteous JE, Brock JR, Allen GD, Heller RF. Back pain in Australian military helicopter pilots: a preliminary study. Aviat Space Environ Med. mai 1998;69(5):468!73.

(12) Bongers PM, Hulshof CTJ, Dukstra L, Boshuizen HC. Back pain and exposure to whole body vibration in helicopter pilots. Ergonomics 1990; 33:1007–26.

(13) Markus Posch, Alois Schranz, Manfred Lener, Werner Senn, Björn O. Äng, Martin Burtscher and Gerhard Ruedl. Prevalence and potential risk factors of flight-related neck, shoulder and low back pain among helicopter pilots and crewmembers: a questionnaire-based study. 2018; 4-7.

(14) Matthias Tegern, Ulrika Aasa and Helena Larsson. Cervico-thoracic pain and associated impairments in air force personnel: a cross- sectional study. 2021; 2-4.

(15) Van den Oord MHAH, De Loose V, Meeuwsen T, Sluiter JK, Frings-Dresen MHW. Neck pain in military helicopter pilots: prevalence and associated factors. Mil Med. janv 2010;175(1):55!60.

(16) Forde KA, Albert WJ, Harrison MF, Patrick Neary J, Croll J, Callaghan JP. Neck loads and posture exposure of helicopter pilots during simulated day and night flights. Int J Ind Ergon. mars 2011;41(2):128!35.

(17) Ang B, Harms-Ringdahl K. Neck pain and related disability in helicopter pilots: A survey of prevalence and risk factors. Aviat Space Environ Med. juill 2006;77(7):713!9.

(18) Aydog˘ST, Turbedar E, Demirel AH, Tetik O, Akin A, Doral MN. Cervial and lumbar spinal changes diagnosed in four-view radiographs of 732 military pilots. Aviat Space Environ Med 2004; 75:154–7.

(19) Lamber, Zainey, Smith and Soso. Common helicopter accidents injuries. Retrieved from https://lambertzainey.com/maritime-injury/helicopter-accidents/common-helicopter-accidents

(20) AirMed&Rescue. (2020, February 13). US helicopter accident rate analysis. Retrieved from https://www.airmedandrescue.com/latest/news/us-helicopter-accident-rate-analysis

(21) United States Helicopter Safety Team. (2021, November). Monthly Safety Report United. Retrieved from https://ushst.org/wp-content/uploads/2021/11/USHST-Safety-Report-2021Nov.pdf

(22) Cameron R. 'Dale' Bass, Lucy Donnellan, Robert Salzar, Scott Lucas, Benny Folk, Martin Davis, Karin Rafaels, Chris Planchak, Kevin Meyerhoff and Adam Ziemba.University of Virginia – Center for Applied Biomechanics. A New Neck Injury Criterion in Combined Vertical/Frontal Crashes with Head Supported Mass. 2006; 5-6.

(23) Shanahan, D. F. & Shanahan, M. O. (1989). Injury in U.S. Army Helicopter Crashes October 1979-September 1985. *The Journal of Trauma*, *29*(4), 415-422.

(24) Frederick T. Brozoski, Valeta Carol Chancey, Joseph R. Licina, & B. Joseph McEntire, USAARL. Retrospective Review of Spinal Injuries in U.S. Army Rotary-wing Mishaps: January 1990–December 2014

(25) Cunningham LK, Docherty S, Tyler AW. Prevalence of low back pain (LBP) in rotary wing aviation pilots. Aviat Space Environ Med. août 2010;81(8):774!8.

(26) Heraudeau-Fritsch A. Pathologies ostéo-articulaires du personnel navigant. Enquête multicentrique par questionnaire anonyme portant sur 1732 navigants. [médecine générale]. [Bordeaux]: Bordeaux II; 2007.

(27) C. De Oliviera, J. Nadal. Transmissibility of Helicopter Vibration in the Spines of Pilots in Flight. Aviation, Space, and Environmental Medicine (2005).

(28) Traccard C. Rachialgie du personnel navigant sur hélicoptère de combat. Etude des postes de travail, examen myofascial et traitement ostéopathique. 2010.

(29) Gaydos SJ. Low back pain: considerations for rotary-wing aircrew. Aviat Space Environ Med. sept 2012;83(9):879!89.

(30) Lopez-Lopez JA, Vallejo P, Rios-Tejada F, Jimenez R, Sierra I, Garcia-Mora L. Determination of lumbar muscular activity in helicopter pilots: a new approach. Aviat Space Environ Med. janv 2001;72(1):38!43.

(31) De Oliveira CG, Nadal J. Back muscle EMG of helicopter pilots in flight: effects of fatigue, vibration, and posture. Aviat Space Environ Med. avr 2004;75(4):317!22.

(32) De Oliveira CG, Simpson DM, Nadal J. Lumbar back muscle activity of helicopter pilots and whole-body vibration. J Biomech. oct 2001;34(10):1309!15.

(33) Harrison MF, Neary JP, Albert WJ, Kuruganti U, Croll JC, Chancey VC, et al. Measuring neuromuscular fatigue in cervical spinal musculature of military helicopter aircrew. Mil Med. nov 2009;174(11):1183!9.

(34) Balasubramanian V, Dutt A, Rai S. Analysis of muscle fatigue in helicopter pilots. Appl Ergon. nov 2011;42(6):913!8.

(35) Dr. Emily Roback and Helicopters' staff, Flying Against the Odds, Helicopters, July 18, 2011. Retrieved from https://www.helicoptersmagazine.com/flying-against-the-odds-2886/

(36) A.G. Hadjipavlou et al. The pathophysiology of disc degeneration. Journal of Bone and Joint Surgery (Br). 2008

(37) Thuresson M, Äng B, Linder J, Harms-Ringdahl K. Neck muscle activity in Helicopter pilots: Effect of position and helmet-mounted equipment. Aviat Space Env Med. cover date 2003;74(5):527!32.

(38) Harrison MF, Neary JP, Albert WJ, Veillette MDW, Forcest C, McKenzie NP, et al. Physiological effects of night vision goggle counterweights on neck musculature of military helicopter pilots. Mil Med. août 2007;172(8):864!70.

(39) J. Adams. Results of NVG-induced Neck Strain Questionnaire Study in CH-146 Griffon Aircrew. (2004)

(40) Nevin RL, Means GE. Pain and discomfort in deployed helicopter aviators wearing body armor. Aviat Space Environ Med. sept 2009;80(9):807!10.

(41) Thomae MK, Porteous JE, Brock JR, Allen GD, Heller RF. Back pain in Australian military helicopter pilots: a preliminary study. Aviat Space Environ Med. mai 1998;69(5):468!73.

(42) Dehez E, Rachialgies chez le personnel Navigant sur hélicoptère. Enquète multicentrique par questionnaire anonume portant sur 231 navigants sur hélicoptère français. 2014; 44-45

(43) Raynaud D. Les déterminants du recours à l'automédication. Rev Fr Aff Soc. 2008;(1):81!94.

(44) JP. Barral & P. Mercier. Visceral Manipulation, Revised Edition. 2005, 1-18

(45) Eric U Hebgen. Visceral Manipulation in Osteopathy. 2011, 3-8

(46) Knut Andersen, Roald Baardsen, Ingvild Dalen and Jan Petter Larsen. Long-term effects of exercise programs among helicopter pilots with flying related LBP. Journal of Back and Musculoskeletal Rehabilitation 31 (2018) 1–13

(47) Gilvan V da Silva. Helicopter Pilots and Low Back Pain: How to Manage the Risk Factors? Ergonomics International Journal. 2018; 7-9

(48) Mishra S, Krishnan A, Sharma KK. DY Patil University School of Sports and Exercise Sciences. An Interventional Study to observe the Impact of Back and Core Body Strengthening Program among Helicopter Pilots. Ind J Aerospace Med. 62(2), 2018

(49) LCDR James B. Walsh, MC, USN; Andrea F. McGlynn, MS; CDR Curtis L. Hardy, MC, USN; LCDR George C. Armas, MSC, USN; LCDR Hadley M. Sulpizio, MSC, USN; LCDR Martin R. Wright, MSC, USN (Ret.). Stretching and Self-Myofascial Release in Helicopter Aircrew to Reduce Neck and Back Pain (Phase 1). MILITARY MEDICINE, Vol. 00, Month/Month 2023

(50) Stanley R. Mohler. Lower Back pain is a Common Complaint, But Precautionary Practices Help Pilots Cope. Flight Safety Foundation, Human Factors & Aviation Medicine, Vol. 47 No.3. May-June 2000

(51) Brian R. Mulligan. Manual Therapy, NAGS, SNAGS, MWMS, etc. 2006; 10-31, 132-137

11. Glossary and Acronyms

AAJ	Atlanto-Axial Joint
ACJ	Acromio-Clavicular Joint
AFP	Air Force personnel
AP	Anterior to Posterior
Cpt	Captain
d°	degrees
D	Dimension
EIJ	Ergonomics International Journal
FPR	Facilitated Positional Release
G	Gravity force
GHJ	Gleno-Humeral Joint
HUD	Head's Up Display
HVLAT	High Velocity Low Amplitude Thrust
Hz	Hertz
IP	Ilio-Psoas
IRCOBI	International Research Council On Biomechanics of Injury
LBP	Lower Back Pain
MET	Muscle Energy Technique
MM	Millimetre
MRI	Magnetic Resonance Imaging
MST	Musculo-Skeletal Troubles
MWM	Mobilization with movement
NAG	Neutral Apophyseal glides
NVG	Night Vision Goggles
OA	Osteo-Arthritis
OAJ	Occipito-Atlantal joint
PA	Posterior to Anterior
PNF	Proprioceptive Neuromuscular Facilitation
PPS	Preflight/Postflight Stretches
PRPS	Pain Release Phenomenon techniques
PTSD	Post Traumatic Stress Disorders
QL	Quadratus Lumborum
RAF	Royal Air Force
ROM	Range of Motion
RPM	Revolutions Per Minute
RW	Rotatory Wing
SCJ	Sterno-Clavicular Joint
SCS	Strain – Counter Strain
SIJ	Sacro-Iliac Joints
SNAG	Sustain Neutral Apophyseal glides
SP	Spinous Process
STT	Soft Tissues Techniques
TCM	Traditional Chinese Medicine
TVP	Transverse Process

UK	United Kingdom
US	United States (of America)
USAARL	United States Army Aeromedical Research Laboratory
USHST	United States Helicopter Safety Team
UST	Ultra-Sounds Therapy