Harness suspension: review and evaluation of existing information

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A personal fall protection system comprises at least a body holding device, i.e. a harness of some type, a lanyard and a reliable anchor. A well thought-out system will seek to minimize the effects of any potential fall. If a fall does occur, that system will arrest the fall with a limited impact force. At this stage, the harness (and the rest of the components in the system) will have stopped the fall, hopefully, without it causing any injury.

The fall and the arrest of it are only part of the story, and not necessarily the most dangerous. After the fall and its arrest comes the suspension phase, when the casualty either rescues him or herself, if capable, or awaits rescue by another person or persons. After a fall, the body is likely to be in a state of shock. If the casualty is badly injured or unconscious, there is unlikely to be any movement of the legs and there can be serious consequences. The orientation of the body and the comfort of the suspended person, determined to a large extent by the design of the harness and the position of its attachment point to the system, also play their part in the outcome.

This review looks at the potential problems of the suspension phase of a fall, how the position of the attachment points on various harnesses play an important role in the comfort and survival of a casualty, and how a selection of harness standards address the issues surrounding suspension. The review reports on existing literature, gives background information to assist the reader, raises issues for discussion and gives recommendations for further work.

ACKNOWLEDGEMENTS

CONTENTS

EXECUTIVE SUMMARY

The objective of this review was to locate and study literature dealing with the effects of being suspended in a harness and evaluate and report on them, together with attendant issues regarding various types of harnesses, including the position of their attachment points. In addition, selected harness standards were to be examined to see if and how they addressed the topic of suspension.

Over 50 documents were located from sources in the United Kingdom, Germany, France and Australia and the Internet. These form the basis of the report.

Much of the literature deals with fall arrest and post-fall suspension, and the problems associated with being upright and motionless. The problems of being upright and motionless are well known and understood in the medical field, where it is known as orthostatic syndrome or orthostatic shock. It is not, however, generally realised by persons using personal fall protection equipment that in certain circumstances the same problems can apply when suspended in a harness. This condition is known as suspension trauma and has potentially fatal consequences.

Although it was commonly thought that research into suspension trauma was very limited, it was discovered during the course of this review that work had been carried out and papers published in 1968, 1972, 1978, 1979, 1982, 1983, 1984, 1985, 1986, 1987, 1990, 1991, 1997 and 1998. All these documents are reviewed, revealing ample evidence of the existence of the condition.

Injury, pain, shock and possibly stress caused by the fall can exacerbate the onset of suspension trauma. The posture of the body during the suspension phase of a fall is largely controlled by the location of the harness attachment point, which typically contributes to the degree of comfort while suspended. Checking on the fit and comfort level of a harness before first use is strongly advocated. The orientation of the body after the fall also has a bearing on the position of the head, specifically in relation to maintaining an open airway. The report provides background information on some aspects of the principles of personal fall protection and on personal fall protection systems. It then presents perceived advantages and disadvantages of various harness types and the location of their attachment points.

An important part of the suspension phase in any fall is rescue, either self-rescue or by another person, and the treatment of the casualty during and after the rescue. It is essential that a rescue plan and resources are in place at the worksite and that they are continually assessed and updated. Advice is extracted from various papers, quoted, and a summary is given. Some of the advice appears to conflict.

A study of eleven harness standards reveals a surprising lack of attention to the suspension phase of a fall and its inherent dangers. Only one standard incorporates a suspension test, using real people, to ascertain comfort and adjustabilty to ensure a good fit, and only two standards require the manufacturer to recommend such a suspension test before purchasing or using the harness for the first time.

Recommendations for further work are included.

INTRODUCTION

When, in Australia in 1999, a rescuee on a training exercise took his full body weight on a harness, he felt "excruciating pain", became nauseated and unable to react or communicate with the rescuer. Details of the incident were communicated via email to interested parties all over the world [1]. This re-awakened an interest in the subject of suspension trauma. Suspension trauma, which is also known as harness induced pathology, appears to occur particularly in those subjects who are immobile while suspended in a harness, and can result in loss of consciousness and death.

Information on suspension trauma appeared to be sparse. The Health and Safety Executive felt that, in the interest of the safety of persons working in harnesses, there was a need to try to find out more. This project was commissioned to locate existing literature on harness suspension and its problems, and to review and evaluate it. At the same time, the advantages and disadvantages of existing harness types and their attachment points would be examined. Finally, a comparison would be made between different harness standards with regard to the requirements on harness suspension and the information required to be supplied by the harness manufacturers.

Although the information gained in this research project is intended primarily for persons in a work environment, the literature search and review have not been confined to just suspension trauma related to the workplace. Much highly relevant information has been obtained from the fields of mountaineering and caving. This project, therefore, could be of benefit to the climbing and caving community, as well as those using harnesses in the workplace.

The reviewer commissioned for this report was involved in the manufacture of fall protection equipment for over 30 years and has been involved with the development of standards in this field for many years, most actively in the last twelve. The many contacts in the fall protection field gained during these periods were utilized, with valuable contributions from colleagues in Australia, France, Germany and the United Kingdom. These were added to the reviewer's own library on the subject. Papers or reviews of papers referred to within these documents thought to be of possible value were located. Literature searches were made on the World Wide Web and several documents were downloaded. The British Library was approached and some documents were obtained through it. The Health and Safety Executive undertook the translation into English of several documents in French and German, some of them, it is thought, for the first time. A questionnaire was placed on the website of the Industrial Rope Access Trade Association (IRATA), asking for information on any incidents pertaining to suspension trauma. This is reproduced as an appendix. If not already in the reviewer's possession, relevant national, international (ISO) and European Standards (CEN) were obtained for the third part of the project.

The report is in four sections. Section 1 explains the effects of being upright and motionless, reviews existing literature and provides evidence of the existence of so-called suspension trauma gained from the literature obtained. It looks at the medical conclusions of the research in the reviews and more closely at the underlying reasons for the dramatic consequences of motionless upright suspension. Finally, it provides information and advice on the management of suspension trauma. Section 2 looks at the advantages and disadvantages of the types of harness available, the position of their various attachment points and the convenience of the location of the attachment point for the user. Section 3 looks at how several standards and legislation address the ergonomic issues of harnesses, e.g. comfort when suspended. Section 4 gives recommendations and suggestions for further work.

Many medical terms are used in the reviews, which may be unfamiliar to readers. To facilitate understanding, a brief definition or explanation is given in parentheses immediately after the medical word or term used in the text, or as a footnote where the inclusion of explanations in parentheses would affect the flow of the sentence or possibly cause confusion. In addition, a glossary of medical terms is provided at the end of the report and information on the body's circulatory system is provided as an appendix.

References are given by number and are enclosed in square brackets, e.g. [15]. A list of references is provided towards the end of the document, as is a bibliography, which provides a route to many other sources of background information.

1 SUSPENSION TRAUMA

1.1 INTRODUCTION

Outside the medical world, it is commonly thought that little is known about the effects and potential consequences of being upright and motionless (orthostasis), for example, as one would be if unconscious and suspended in a harness. Section 1 first explains what these effects are. It then provides a more-or-less chronological look at the evidence of the existence of orthostatic syndrome (symptoms caused by being upright and still) when in suspension, and the research that has been carried out to date. When related to suspension in a harness, orthostatic syndrome and its effects are known as harness induced pathology or suspension trauma.

The amount and degree of detail in the reports reviewed varies. Consequently, so does the detail in the reviews of the reports. Many of the reports reference earlier work carried out by other people, which are themselves the subject of review in this project. Details of the earlier work in those reports are generally omitted in this review.

1.2 ORTHOSTATIC SYNDROME AND ORTHOSTATIC SYNCOPE

Orthostatic syndrome and its causes are well known in the medical field. Standing up quickly or for periods without moving can cause a person to feel dizzy, nauseous, to have hot flushes and unusual sweating and to faint. When fainting occurs in this kind of situation it is known as orthostatic syncope. Orthostatic syncope is quite common and is said to be related to the current state of evolution of the human being, in that we have not yet totally adapted to standing upright. In certain circumstances, the effects can be serious and can lead to death.

A well-known example of orthostatic syncope is that of the soldier who faints while stood to attention for any length of time. The moment the soldier loses consciousness, he collapses and becomes horizontal. Therefore, the time spent in a vertical position while unconscious is minimal. This has a significant bearing on the result of the collapse. Assuming no injuries caused during the collapse of the soldier, return to consciousness will ensue quickly and recovery is likely to be rapid.

If a person is suspended in a harness in a situation in which the legs are immobile, for example, due to injury after a fall, there is no such "natural" move to the horizontal. The time spent in this unmoving suspended position, with the legs below the heart can have fatal consequences.

The fundamental cause of orthostatic syncope seems to be venous pooling.

1.2.1 Venous pooling

Venous pooling is the accumulation of blood in the veins (typically in the legs) due to gravity. Some venous pooling when a person is stood up is normal. Muscular action in moving the limbs, together with one-way valves in the veins, normally assists the return of blood in the veins back to the heart. If the legs are completely immobile, these "muscle pumps" do not operate and an excess of blood accumulates in the veins, which are capable of considerable expansion and, therefore, considerable capacity. Retention of blood in the venous system

reduces the circulating blood volume available to the heart. Thus, the circulatory system is disturbed. During excessive venous pooling, cardiac output and arterial pressure fall, which may critically reduce the quantity and/or the quality of (oxygenated) blood flowing to the brain and precipitate syncope.

1.2.2 Syncope

A common term for syncope is fainting. Syncope is described as the temporary loss of consciousness and postural tone (balance and ability to stand) due to a decrease in the quality and/or quantity of blood flow to the brain. The brain is not good at coping with low blood oxygen or low glucose levels and, in such circumstances, syncope can occur. The warning symptoms that are given before syncope, such as palpitations, nausea, dizziness, sweating and confusion are known as pre-syncope. When a person is upright, for example, stood up or suspended in a harness, blood has to be forced against gravity to the head, which requires special blood pressure regulation. The body does not take kindly to anything that interferes with its blood circulatory system, such as venous pooling, and sets off a series of intended compensatory reactions at the first signs of any imbalance, the result of which are the symptoms experienced in pre-syncope. The body is now in a state of (orthostatic) shock.

1.2.3 Further effects

Loss of consciousness assures that a suspended person will not be moving his or her limbs, so venous pooling will increase, which will in turn reduce the circulating blood volume even further. In addition, any restrictions of the femoral arteries and veins[1] caused by the harness straps could be a contributory factor to venous pooling. Thus, the detrimental effects are increased. These include not only a potentially fatal reduced blood flow to the brain, but also the effect on other vital organs, such as the kidneys. The kidneys are also very sensitive to blood oxygen levels and renal failure as a result of excessive venous pooling is a real possibility.

Unless the casualty is rescued very quickly and unless the rescuers follow a particular procedure, the effects of venous pooling and syncope are likely to lead to death, as the brain and kidneys are deprived of vital oxygen. Moving the casualty quickly into a horizontal position, a natural reaction, is likely to cause a massive return of deoxygenated (and possibly toxic) blood to the heart, which is unable to cope, causing cardiac arrest.

Tolerance to the effects of orthostasis appears to vary between individuals. However, evidence shows that given sufficient time, orthostatic shock, pre-syncopal effects and syncope will occur [2]. The onset of these effects can be exacerbated by various factors. These include the shock of experiencing the event that caused them to be suspended and immobile in the first place, the injuries suffered by the casualty, their harness comfort level, and possibly their psychological state.

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[1] *Arteries and veins running down the thighs*

1.3 SUSPENSION TRAUMA: EXPERIENCES IN THE FIELD AND IN RESEARCH

The condition "orthostatic shock while suspended" acquired a more acceptable name in the communities that use harnesses: *suspension trauma*. Another term used is *harness-induced pathology*. For the rest of this document, the term *suspension trauma* will be used generally in the text, but will not replace other terms in any quoted text.

In *Death from orthostatic shock caused by hanging on the rope,* J-D Toledo Y Ugarte (1972) [3] goes back to early days:

"We have known the effect of orthostatic shock for a long time from experiments (Hill, Eppinger, 1935; Toledo, 1965). This is also familiar to us from history and the death of Christ on the cross."

A crucifixion victim would be in exactly the right position and situation to suffer excessive venous pooling and orthostatic shock: upright with no movement of the legs.

Early tests

In more recent times, a limited number of fall arrest and suspension tests involving human subjects were conducted as early as 1968, in the United Kingdom (Beeton et al). This is mentioned in *Fall arrest and post-fall suspension: literature review and directions for further research* (1984) [4 p8]. Subjects underwent a period of post-fall suspension but it is reported that the details are sketchy and not of much value.

Also in 1968, the Harry G Armstrong Aerospace Medical Research Laboratory at the Wright-Patterson Air Force Base, Ohio, USA conducted tests in which five volunteer subjects were suspended in a parachute/torso retraint harness for approximately 30 minutes (Baumann 1968). This was reported by Orzech et al (1987) [5] in *Test Program to evaluate human response to prolonged motionless suspension in three types of fall protection harnesses* (p5):

"Four of the five subjects tolerated a 30-minute static suspension with only minor discomfort…. Three of the subjects noticed marked discomfort of the lower legs and feet associated with numbness during the exposures. This discomfort subsided spontaneously with repositioning of the buttocks and leg straps. One subject lost consciousness at 27.75 minutes after the start of the test. He was lowered, treated, and regained consciousness at 28.50 minutes. He remained in a semi-conscious state for three to five minutes before becoming fully alert. His loss of consciousness was attributed to venous pooling caused by forward body positioning and an inadequate pre-test diet."

1972 conference of mountain rescue doctors

The Second International Conference of Mountain Rescue Doctors in 1972 focused on "falls into the rope" and skull injuries in alpine regions. The papers of this conference [6] give details of accidents in the Austrian Alps from 1955 to 1972.

To aid understanding of the references to climbers hanging from the rope in the papers, it should be explained that in the 1960s and early 1970s, continental European climbers and mountaineers tended to tie on directly with the rope at chest level. Harnesses were only in the early stages of development, and had not been adopted by the majority. F Scharfetter (1972) [7] discusses the pressure paralysis of the brachial (arm) nerves suffered by a number of climbers due to hanging

on the rope after a fall. After a short time hanging in such a fashion, the climbers were unable to help themselves, due to the paralysis.

G Flora and H R Hölzl (1972) [8] outline the deaths of a number of climbers who had not seriously injured themselves in the fall, but found themselves hanging free after it. Sometimes they had support from footloops and sometimes not.[2] Eight out of ten of the climbers managed to survive periods hanging free from half an hour to eight hours, and after they were rescued alive, they survived from half an hour to 11 days. But all eight died. Information on how long the other two climbers were suspended before they died is not available. To keep things in perspective, in the period 1964 to 1972, 13 climbers were suspended for periods of five minutes to three and a half hours, and survived. Two of them were wearing a sit harness [8] (pp9-10).

H Patscheider (1972) [9] states:

"Between 1957 and 1968, a total of 137 post mortems were carried out on persons killed during mountain climbing in the summer.[3] [4] In 11 of these cases, the fall was terminated by hanging on the rope. Six of these climbers died from strangulation or injuries caused by the fall. Hence they must be excluded from the narrower question. The remaining five fallen climbers, who remained hanging on the rope, exhibited only slight external injuries and occasionally internal injuries unimportant with regard to their survivability."

Examination of the liver and the heart established that the casualties had suffered from hypoxia (oxygen depletion). Although asphyxiation as a result of compression of the thoracic cage caused by pressure of the rope was considered, it was ruled out, because the fallen climbers hanging from the rope were still able to call out, and because of other factors. Also, the question of whether reduced oxygen in the atmosphere because of altitude played any part in the symptoms of hypoxia was ruled out. There was no evidence of circulatory disorders or clots or other mechanical obstacles (prior to the incident) that could have been responsible for the hypoxia.

There remained only the assumption that death caused by hanging on the rope was based on a general circulatory disorder, with an attendant reduction of circulating blood quantity. Such a condition coincided with the concept of shock. The circumstances allowed only orthostatic shock to be considered.

"The protracted vertical hanging with support of the body exclusively in its upper third leads to reduction of the load on the abdominal wall and to relaxation of the leg muscles. However, the motor for return of the blood from the veins in these areas, which can absorb up to 60% of the extrathoracically present blood, fails. The unhindered effect of centrifugal force leads to an increase in the hydrostatic pressure in the veins, possibly also in the arteries, probably to their widening, and thus to the sinking of the blood in the lower parts of the body."

"As in all forms of shock, a fall in blood pressure also occurs in this case, the consequence of which is cardiovascular hypotonia[5] with inadequate blood supply to the heart muscle, which in turn reduces efficiency and thus leads to reduced blood supply to other organs. The release of catecholamine,[6] which occurs when the blood pressure falls, is intensified by fear and anxiety

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[2] *A footloop is a sling, typically made from webbing or rope, which is attached to the suspension rope or harness so that when the suspended person steps into it, the pressure from the harness straps on other parts of the body, e.g. the thighs and waist, is alleviated.*
[3] *Although not stated, it is assumed from the text that this refers to the alpine regions of Austria.*
[4] *See page 11 of Patscheider's report [9]*
[5] *Diminished resistance of muscles to passive stretching*
[6] *E.g. adrenaline - see glossary*

and leads to vessel contraction in the periphery and thus to circulation centralisation, probably plays a certain role in this respect. This process may produce certain regulatory compensation in the initial phases of free hanging, so that the onset of shock is perhaps prevented in this way."

The conclusion was that protracted orthostatic shock had led to a fatal circulatory collapse.

W Stulinger, P Dittrich, G Flora and R Margreiter (1972) [10] explain that three of 20 climbers who were rescued alive after prolonged free hanging on the rope died immediately after detachment from the rope. Acute kidney failure occurred in two victims, although one survived. A further three climbers died between the first and eleventh day, despite intensive therapy, from a clinical state that could best be described as generalized peripheral circulatory insufficiency. The doctors realized that they were confronted by a syndrome (group of concurrent symptoms), the cause and clinical symptoms of which had not yet been fully clarified. This led to an attempt to carry out circulatory and renal function tests under similar conditions to those hanging free on a rope.

Twenty suspension tests were conducted on ten volunteers from the Innsbruck Mountain Rescue Service and climbers, who were suspended in a chest harness used by orthopaedic surgeons on the first test day and in a climbing sit harness or in a foot sling on the second test day.

During free hanging in the chest harness, all the test subjects suffered from venous congestion in the upper and lower extremities after a short time, which was intensified. After the fifth minute, the test subjects reported paraesthesiae (tingling and numbness) in the hands and legs, in some cases also a total loss of feeling in the hands.

"Imminent circulatory collapse, which was indicated by pallor, cold sweat, dilated pupils, ringing in the ears, giddiness and incipient nausea, caused the doctors to remove the test subjects from the hanging position before the end of the planned test time (30 minutes), i.e. between the eighth and twenty-second minute, and lay them in a horizontal position. They were completely normalized subjectively after a few minutes in the horizontal position."

"Hanging in the sit harness and standing in the foot sling was tolerated substantially better by the test subjects. Seven out of ten test subjects were suspended by the rope for over 30 minutes under these conditions without showing significant shock symptoms. However, the test had to be interrupted between 22 and 28 minutes in three cases."

The circulatory changes measured during the tests adequately explained the subjective adverse effect on the test subjects during suspension, such as flashes of light in front of the eyes, ringing in the ears, giddiness and nausea.

W Bernard, H Haselbach, H Scharfetter, A Aigner and R Michaeler (1972) [11] were interested in some changes in the lungs and heart in the harness suspension tests that they carried out. Ten volunteers were used in the tests, who were instructed to remain quite still, without any kicking movements. Suspension, made difficult by the instruction not to move and by unaccustomed breathing due to the instrumentation attached to measure the volume of air inhaled and exhaled, was tolerated for between 2.35 and 7 minutes. Any forcing of the suspension time was strictly avoided. The reasons for stopping the tests were, in particular, pains in the shoulder, increasing parasthesiae in the hands and, in two cases, signs of collapse. Because of the essential avoidance of risk, the measured changes were only early symptoms of the specific endangerment of being suspended.

During the suspension tests, held in front of an x-ray screen, changes in the shape and the size of the heart of the test subjects were observed. The transversal and depth diameter of the heart

diminished, with a correspondent increase in lung/heart quotient. "Respiratory excursions of the thorax" were observed, which became more rapid, but less productive. It was noticeable that the abdomen was drawn in and the front outlet of the thorax was raised and projected. Hardly any abdominal respiration was visible and it was obvious that the respiratory auxiliary muscle of the neck and shoulders were blocked. Pallor, together with lip cyanosis, sweating and giddiness after suspension were present as symptoms of incipient collapse in two test subjects. There was an increase in pulse rate up to 155.

The increase in breathing rate, respiratory minute volume and oxygen consumption with simultaneous reduction of the vital capacity were recorded. The blood gas analysis revealed a small fall in the PCO2 (partial pressure of carbon dioxide) and even a smaller one in pH (degree of acidity or alkalinity), with the fluctuations remaining within the normal values.

Bernard et al interpreted their findings and observations as follows:

"The respiratory mechanism is adversely affected, viz. this restriction is so severe; because the stiffening of the thorax cannot be compensated in the usual way by activity of the auxiliary muscular system and abdominal breathing; this combined respiratory obstruction is apparently specific to the pathophysiology of hanging on the rope. The most easily measurable expression of this respiratory obstruction is the reduction in vital capacity. Increases in the respiratory minute volume and oxygen intake are vain compensation attempts by the body; they lead to an increase in the respiratory dead space and cannot improve the alveolar hypoventilation." [7] [8]

"The PCO2 fall is an expression of the hyperventilation;[9] the simultaneous pH fall may already be evaluated as indication of oxygen debt. The drop-like reduction of the heart corresponds to reduction of stroke volume; with acceleration of the cardiac action, the body nevertheless attempts to maintain the minute volume: if this compensation is no longer possible, the general inadequate circulation of orthostatic shock is achieved."

"Our results emphasize the opinion that orthostatic shock makes a significant contribution to endangerment of life when hanging on a rope. As far as we know, a new feature is the proof of a severe and typical respiratory obstruction."

In their concluding remarks on the papers of the Second International Conference of Mountain Rescue Doctors, (1972) [6] H Scharfetter and G Flora say:

"Orthostatic shock and typical respiratory obstruction may lead to death when hanging on a rope; the probability of survival after hanging two hours is small; death may occur during hanging or after detachment from the rope when rescued."

Tests in human tolerance to suspension in 1978

Noel et al (1978) [12] carried out several tests to determine human tolerance to suspension in various harnesses.

This research involved the static suspension (i.e. suspension without moving) of five human test subjects in three types of full body harness (A, B and C), a parachute harness (which is also a

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[7] *Hypoventilation: breathing at an abnormally shallow rate. See glossary for alveolar hypoventilation.*

[8] *It is not clear what kind of harness was being worn. If it were a chest harness or similar, respiratory problems would be expected, due to restrictions by the harness straps. However, the problem could be connected with orthostatic syndrome, i.e. be a manifestation of venous pooling.*

[9] *Hyperventilation: breathing at an abnormally rapid rate at rest*

full body harness), a chest harness and a waist belt with shoulder straps. All the harnesses and the belt utilized a back attachment.

Types A and B full body harnesses were similar in design, with a sub-pelvic harness with leg loops and integrated shoulder straps. Type A had a horizontal cross strap at the front, just below waist height, attached to each leg loop. There did not appear to be a front cross-strap on the Type B harness. The type C harness was similar in design to types A and B but incorporated an adjustable waist belt. None of these incorporated a chest strap. The parachute harness had a sub-pelvic harness with leg loops and an incorporated chest strap, but no waist strap or front cross strap.

The age and mass in kilograms of the subjects were: 59/82, 32/72, 31/63, 28/72 and 18/59.

Suspension times varied from a maximum of 45 minutes with no problems (subject 28/72, harness type C) to a minimum of eight minutes where the test was stopped because of nausea (subject 32/72, harness type A). These figures exclude those for the waist belt and chest harness, as the authors stress that they should be prohibited. None of the five subjects tolerated the waist belt or chest harness for more than two minutes.

Of the 18 tests on the full body harnesses, including the parachute harness, eight were stopped due to pain, five were stopped due to nausea and five caused no problem (except increased pulse rate).

In each test, the pulse rate of the subjects increased, varying between 11% (subject 31/63, harness type A) to 177% (subject 18/59, harness type A) and did not seem to follow any pattern.

The authors concluded that:

- the tests lead to a posing of questions rather than definitive conclusions, e.g. what would be the result after a "brutal" fall arrest; what if the casualty were unconscious;

- tolerance in suspension varies considerably from subject to subject;

- maintaining someone who has fallen in a state of suspension may be as critical as the fall itself;

- it would be difficult to propose a reasonable test standard for suspension;

- harness design should attempt to "satisfy all needs" i.e. not only to arrest the fall but to allow the casualty to position him/herself correctly (and comfortably) and which would not cause asphyxiation if unconscious [12] (p24).

Changing climbing techniques

The climbing and mountaineering routes being attempted in the 1960s and early 1970s caused a change in climbing techniques. This change demanded a greater reliance on equipment and a requirement for relatively comfortable harnesses in which the climber could rest. The development of technical climbing equipment led to the introduction of commercial climbing harnesses. Harnesses of the type that have a waist belt with sub-pelvic straps for support became popular. They became known as sit harnesses, because the wearer could "sit" in them and rest.

In 1979, B A Nelson published the results of suspension tests by experienced climbers in an article in the American climbing magazine *Off Belay* [13]. Four different models of sit harness

and one full body harness were used, plus a self-made sit harness formed from 25 mm wide webbing, known as a Swiss seat harness and also a direct tie-in to the climbing rope using a bowline-on-the-coil. The subjects were told to avoid moving while suspended.

A total of 65 tests were carried out. The mean suspension times ranged from 24 seconds for the bowline-on-the-coil to just over 17 minutes in one of the sit harnesses. The maximum suspension time for any test subject was 28 minutes in a (different) sit harness.

A variety of adverse effects were experienced in the 65 tests. These included lower body numbness (25 cases), intense pain (21 cases), respiratory distress (8 cases), uncontrollable shaking (4 cases), change in blood pressure (3 cases), loss of consciousness (2 cases), weak pulse (1 case), and upper body numbness (1 case). The two cases of loss of consciousness occurred despite efforts to terminate the suspension prior to loss of consciousness. The suspension tests were also terminated in the event of severe pain, abnormally rapid heart rate, numbness of the extremities or narrowing of the pulse pressure. Narrowing of the pulse pressure was caused by harnesses that caused pain in the groin area, which was almost universally after hanging vertically, but especially in the case of the full body harnesses.

This study concluded that hanging vertically in a harness could cause loss of consciousness without prior trauma or blood loss. It further concluded that an unconscious climber who remains vertical is in danger of brain damage and eventual death from reduced blood flow to the brain within four to six minutes of fainting.

It is suggested that climbing harnesses should permit a horizontal body orientation during suspension and goes on to say:

"The argument in favor of vertical suspension is that the climber's head should be upright during a fall to avoid hitting it on the way down. But this is not realistic because a climber falling head first will not be pulled upright until *after* the fall is over. There is no assurance that the climber will fall in an upright position."

Orzech et al (1987) [5] reported that, in 1982, M Amphoux studied five subjects between the ages of 18 and 59 during passive suspension, using a torso harness, a parachute harness, a waist belt with shoulder straps and a thoracic belt. Subjects suspended in harnesses that supported the whole torso were able to tolerate suspension for longer durations than those who were in waist belt systems. The longest suspension time for the torso harness was 43.25 minutes. The parachute harness was tolerated for 28.17 minutes; the thoracic belt for one minute. Two subjects who were suspended using the waist belt with shoulder straps lasted one minute and three minutes respectively. The medically adverse effects that were encountered included lower extremity numbness, difficulty in breathing, nausea, dizziness, tachycardia (abnormally rapid heart rate), bradycardia (abnormally slow heart rate) and premature ventricular contractions. There was also abdominal, shoulder and groin pain. Dr Amphoux suggested that the mechanism responsible for the adverse effects might have a respiratory, cardiac and circulatory basis.

Changing caving techniques

In the early seventies, cavers began to adopt new techniques for descending and ascending shafts (known as pitches or pits) in caves. Instead of the traditional method of climbing up and down flexible ladders, they modified and developed mountaineering techniques, using fixed ropes in place of the ladders. The cavers now wore sit harnesses and connected to the rope via descending and ascending devices. The former is a type of controllable friction inducing device, which allows a controlled descent and the latter a type of clamp that allows movement along the rope in one direction (upwards) but clamps firmly onto it in the other direction, thus enabling

the caver to climb the rope. After a few years, a new phenomenon appeared: the deaths of cavers while hanging on the rope. At first, this was generally assumed to be caused by exhaustion hypothermia. Instances over a short period of time of 12 cavers dying while suspended on rope[10] prompted a study of the deaths in 1983 by the Medical Commission of the French Federation of Speleologists. A report by the Commission [14] describes these 12 deaths.

The ages of those who died ranged from 15 to 50 and from inexperienced to experienced cavers. ten out of 12 accidents took place in a wet shaft or pitch. Although it is not stated, wet shafts are normally cold and windy due to the turbulence of the water. Eight accidents took place on the return journey, bringing into play the importance of the fatigue factor in a situation of prolonged suspension. In four cases, cases 1, 2, 9 and 11, the casualties were stuck on the rope, unable to progress due to technical reasons. In the first case, there was rapid loss of consciousness; in the second, a series of losses of consciousness after about 15 minutes, then a final loss of consciousness. In case 11, the caver was freed quite quickly by his friends, but was in a very confused state. He was placed in the recovery position at the bottom of the shaft for 20 hours, but died. In two other cases, cases 3 and 4, the cavers had poor thermal equipment. The first said that his arms were stiff and that he was too cold to climb. His "state of mind was very rapidly catastrophic and he said he was going to die." He lost consciousness very rapidly and died. In the second of these two cases, the subject felt unwell. He was hoisted to the top of the 20-m shaft still alive (in a state of confusion) and placed in the recovery position. He sank rapidly into a coma and died five hours after initially feeling unwell.

The authors comment that the presence of water is a factor precipitating exhaustion; that the panic factor could also play an important role, and that in the majority of cases, a hypoglycaemic coma (coma caused by low blood glucose), which is seen in normal cases of exhaustion, could not be ruled out.

Tests by the Medical Commission of the French Federation of Speleologists

The report led the Commission to consider the possibility of a new factor potentially responsible for the cause of death: suspension in a sit harness. A test programme, sponsored by the Medical Commission, was set up in 1984. The programme, carried out by M Amphoux, J Bariod, B Théry et al, was to study the effects of hanging motionless while suspended in a harness, in the same way that a caver, climber, or worker would be, if exhausted or unconscious [15], [16].

The results of the first few tests were so dramatic that they were stopped before they were completed. "The first two volunteers fainted and experienced serious difficulties, one after only six minutes of hanging." [15], [16].

In this experiment, according to Bariod and Théry (1997) [17], two cavers were suspended with instructions to avoid any movement. In each case, the onset of unconsciousness was observed after 30 and seven minutes respectively, which necessitated brief resuscitation. The potential for serious consequences following the phenomenon observed forced the interruption of the other experiments that had been planned.

For the first time, they said, it could be confirmed that hanging motionless in a safety harness used for caving could cause serious physiopathological disorders alone.

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[10] *Numerous articles refer to 15 deaths, but only 12 deaths while suspended from a rope are described in the Commission report [14].*

After this study, it was concluded that it was no longer possible to interpret all the deaths on the rope as exclusively the result of simple exhaustion.

The test programme was re-established in 1986, this time in the Laboratory for Sports Physiology of the University Clinic of Besançon/Doubs in France, with the full use of its facilities. It was possible to monitor pulse, blood pressure, continuous electrocardiogram,[11] electroencephalogram,[12] and to conduct blood tests, including blood gases.

There were three human test subjects. The first was positioned in what would be a "real" situation for an unconscious caver in a sit harness: his head in hyperextension (extension beyond its normal limit), with his legs dangling under the level of his heart. The second test subject wore a surgical collar to exclude the hyperextension and the third test subject had his legs horizontal but with his head in hyperextension like the first.

After a period of between 12 and 30 minutes, all three subjects experienced considerable difficulties. The first felt faint after ten minutes. The pulse had increased and blood pressure, normal at 120/80, increased to 180/120. The subject felt faint, with hot flushes, paleness, sweating and breathlessness. The hyperextension of the head was painful, and led to a quicker faintness. A manual correction of the head hyperextension eased the problems, but within five minutes the pulse accelerated again as well as blood pressure. The subject was released. In the second case, the subject managed 20 minutes before becoming faint and the decision was taken to disconnect him.

In the third case, the subject fainted, in spite the medical attention around him. This happened even though the legs were in a high position.

According to Bariod and Théry [17] reporting on the tests much later, in 1997:

"Despite the precautionary measures taken when the experiments were being planned, namely removing the test subject from the suspended state before any worsening of the disorders, in several cases we were unable to prevent the onset of unconsciousness. It was impossible to conduct any experiment concerning the study of the minutes that follow after the onset of unconsciousness with the person not removed from the suspension state. Developments leading to death appear to be unavoidable if the test subject remains suspended in this situation."

The project was filmed and a video produced called *Pathologie induite par le harnais* (Pathology induced by the harness) [18].

The conclusion of this work was that:

"Fainting (in these circumstances) is a complex medical matter. Whatever the type of harness, motionless suspension is not physiologically safe and will eventually lead to very serious blood circulation problems. It seems useless to try to invent a preventative harness."

This important work by the Medical Commission of the French Federation of Speleology is quoted extensively, either directly or indirectly, or referenced in later publications by other individuals and organisations, e.g. [14], [15], [16], [17], [19], [20], [21], [22] and [23].

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[11] *Recording of the electrical activity of the heart on a moving paper strip by means of an apparatus called an electrocardiograph*
[12] *Recording of the electrical activity of the brain into a tracing*

Tests at the University of Sports Science, Innsbruck, Austria

In 1985, Dr Norbert Schauer and Christian Damisch of the University of Sports Science in Innsbruck, Austria, in association with the Austrian Mountain Association, carried out a study of mountaineering harnesses and their relative safety, in accordance with the UIAA (International Federation of Climbing Associations) standard for mountaineering harnesses. The results were published in a magazine called Bergsteiger und Bergwanderer in an article *Wie sicher sind Anseilgurte?* (How safe are body harnesses?) (1985) [24].

Sixteen test subjects took part in 46 suspension tests involving a variety of harness types. The harnesses were tested as a combination of chest and sit harness. The test subjects were told to simulate unconsciousness during the tests, i.e. to relax fully whenever possible. Only the limp falling back of the head was omitted. Symptoms that were experienced during the ten-minute motionless suspension included diaphoresis, pallor, a decrease in measurable blood pressure, an increase in heart rate, dizziness, intense strap pressure and numbness in both arms and legs. Three test subjects had to be removed prematurely from the hanging position: in two cases (after five and nine minutes) the blood pressure was no longer measurable and there was noticeable facial pallor, giddiness, and flashes in front of the eyes. In the third case, perspiration, anxiety and severe pains in the area of the inner thigh occurred. Virtually all the test subjects reported pains in the inner thigh and numbness in the legs or arms, to a varying extent. It was found that even in a safety harness with webbing straps around the pelvis and the seat, the unconscious person is at risk of shock due to circulatory problems. The use of a "stepping sling" is recommended (a sling attached to the harness into which the person can put his/her feet and thus relieve the tension from the harness straps on the body and allow movement of the legs).

The conclusions were that a motionless subject in a chest harness/sit harness combination is subject to orthostasis with pooling of the blood in the lower extremities, subsequent irreversible protracted shock, and mountain climber's "rescue death". Rescue death is believed to be a result of an acute overload of the right ventricle, resulting in right ventricle failure, due to a sudden return of blood from the lower extremities, where it had pooled, back to the heart. It was noted during these tests that as the time in suspension increased, the subjects felt an easing of the pain from the strap pressures. The researchers believed that the decrease in pain was probably due to superficial cutaneous nerves being temporarily damaged by the pressure to the extent that pain stimuli could no longer be transmitted.

Testing at the Wright-Patterson Air Force base in Ohio, USA

In September 1987, the Harry G Armstrong Aerospace Medical Research Laboratory at the Wright-Patterson Air Force Base, Ohio published *Test program to evaluate human response to prolonged motionless suspension in three types of fall protection harnesses* (Orzech et al) [5]. The United States Department of Labor Occupational Safety and Health Administration (OSHA) had requested that the laboratory at the Wright-Patterson Airbase in Ohio, USA undertook a research programme aimed at developing the relative effectiveness of various types of fall protection harness. The programme's objectives were to "evaluate the relative capabilities of three types of fall protection harness to provide occupant support and restraint during post-fall suspension" and to use knowledge and data gained from the study to assist the design of fall protection equipment. In 1988, a paper by James W Brinkley [25] based on this work was presented at the International Fall Protection Symposium in Orlando, Florida, called *Experimental studies of fall protection equipment.*

In the first phase of the research, three body-holding devices were used: a body belt, a chest harness and a full body harness. The objectives of the first phase were to determine the post-fall capabilities of three types of body-holding devices; to assess the physiological effects of

prolonged motionless suspension; and to simulate the state of an individual who might be unconscious or injured prior to or as a result of a fall. The second phase was to investigate the differences in post-fall suspension capabilities of four different styles of full body harness.

Thirteen volunteer test subjects took part in phase 1, 12 males and one female. Their weights ranged from 48 to 91 kg. They were told to remain motionless during suspension and to stay that way for as long as possible. They were suspended until their tolerance was reached or until symptoms of hypotension or syncope developed. Each test subject was tested with each of the three body-holding devices. Suspension of each subject occurred no more frequently than once in a 72-hour period, to allow time for recovery.

The body belt, which was worn around the waist and was adjustable, consisted of a 100-mm wide padded belt with D-ring for the rear attachment of a lanyard. The chest harness was constructed of 45 mm webbing and in fact consisted of two belts, one worn around the waist and the other around the chest, with shoulder straps connecting the two belts to a suspension D-ring located between the shoulder blades. The full body harness was also constructed of 45-mm webbing and had a D-ring for attachment of a lanyard located between the shoulder blades.

The time range for the three body-holding devices were as follows:

- body belt: 0.35 to 4.76 minutes;

- chest harness: 0.62 to 13.13 minutes;

- full body harness: 5.08 to 30.12 minutes.

This gives a mean of 1.63, 6.08 and 14.38 minutes respectively.

A medical decision was more frequently the reason that the suspension test had to be stopped in the cases of the full body harness and the chest harness. These decisions were based on symptoms of light-headedness, nausea, head/body flush and drowsiness. Reasons for voluntary termination included numbness and tingling in the extremities, strap pressure and difficulty in breathing.

The decisions were as shown in table 1.

Table 1 Reasons for termination of tests in phase 1

Decision	*Body belt*	*Chest harness*	*Full body harness*
Medical	3	9	11
Voluntary	10	4	2

One case of syncope (loss of consciousness) occurred in a subject suspended in a full body harness as he was being lowered after requesting termination of the test. The subject was unconscious for approximately 30 seconds and recovered quickly when placed in the supine position. The electrocardiogram revealed a significant bradycardia in which the heart rate decreased to approximately 30 beats per minute. The bradycardia persisted for approximately 20 seconds before returning to a normal sinus rhythm and rate.

In almost all cases, the heart rate and respiratory rate increased during suspension of the subject. This was variable among the subjects and body-holding devices. Tachycardia and premature ventricular contractions were observed, as well as bradycardia.

The primary causes of termination of the tests were:

- body belt: difficulty in breathing and pressure;

- chest harness: cardiovascular symptoms and pressure;

- full body harness: cardiovascular symptoms and nausea.

In phase 2 of the programme, nine males and one female took part as test subjects, using four designs of full body harness, all with back attachments. The weights of the test subjects were from 59 to 88 kg. Again, the subjects were told to hang without moving, and suspension was continued up to a maximum period of 60 minutes or until either a voluntary or medical decision was taken to terminate the test.

In all, the ten test subjects carried out a total of 40 suspension tests.

The time range for the four full body harnesses were as follows:

- harness A: 3.47 to 32.00 minutes;

- harness B: 5.50 to 37.50 minutes;

- harness C: 10.20 to 49.80 minutes;

- harness D: 4.33 to 60.00 minutes.

This gives a mean of 17.05, 18.36, 28.36 and 26.66 minutes respectively.

A medical decision was more frequently the reason that the suspension test had to be stopped in the case of harness B. The medical decisions were based on symptoms of light-headedness, nausea, decreased heart rate and drowsiness. Reasons for voluntary termination included numbness and tingling in the extremities, strap pressure and nausea.

The decisions are shown in table 2.

Table 2 Reasons for termination of tests in phase 2

Decision	Harness A	Harness B	Harness C	Harness D
Medical	4	7	3	3
Voluntary	6	3	7	6
Time limit	0	0	0	1

The occurrence of light-headedness, nausea, breathing difficulty and sweating are shown in table 3.

Table 3 Occurrences of symptoms in phase 2

Symptom	No of occurrences
Light-headedness	9
Nausea	18
Breathing difficulty	10
Sweating	20

There were many occurrences of numbness and tingling in the upper and lower extremities. These are shown in table 4.

Table 4 Occurrences of numbness and tingling of upper and lower extremities in phase 2

Symptom	No of occurrences
Upper extremity numbness	13
Upper extremity tingling	19
Lower extremity numbness	25
Lower extremity tingling	25

Tachycardia, bradycardia and premature ventricular contractions were observed, but there were no episodes of syncope (fainting). However, if a subject developed a progressive bradycardia, the test was terminated. Thus, the risk for development of syncope was reduced.

A few subjects experienced visual problems such as greying of the visual field. One subject lost vision before the test was terminated. These symptoms were attributed to decreased blood flow to the arteries supplying blood to the eyes.

In the discussion of findings, the author stresses that the test subjects were young, healthy individuals and that application of the test results to the general population should be done with care. The test subjects were required to pass a rigorous medical evaluation prior to taking part: it is unlikely that workers would be required to undergo such detailed medical evaluation. Workers, therefore, could be more susceptible to a more rapid onset of the effects experienced in the tests. In addition, individuals who may be exposed to periods of motionless suspension are probably those who are incapacitated or injured prior to or during a fall, which could have a bearing on the results.

"These experiments have demonstrated potentially adverse physiological effects of prolonged suspension in a supra-normal population. The experiments have also demonstrated clear

differences in relative effectiveness of body belts, chest harnesses and full body harnesses, as well as different styles of full body harnesses."

The authors concluded that:

- the body belt was the least tolerated, due to abdominal pressure and restriction of the subjects' breathing;

- the chest harness caused upper-extremity symptoms, due to strap pressure concentrated at the axilla (armpits);

- the full body harness style that was tested was superior to both the body belt and chest harness and had the longer mean suspension duration (14.38 min compared with 1.63 min for the body belt and 6.08 min for the chest harness);

- statistically significant differences in suspension durations were found among some of the full body harness styles that were evaluated. Prolonged motionless suspension may result in potentially adverse cardiovascular responses, including tachycardia and bradycardia, with subsequent loss of consciousness;

- the heart rate and respiratory rate tended to increase with suspension duration.

Research for the German Federal Post Office

Around 1990, following a fatal accident, the German Federal Post Office was ordered to develop a system for the rescue of accident victims from locations such as communications towers. Work carried out by Peter Weber and Gerlinde Michels-Brendel, *Physiological limits of suspension in harnesses,* was published in 1990 [26]. Importance in this project was given to "orthostatic circulatory collapse as a result of being suspended in the harness, which causes a damming of blood into the peripherals." "This syndrome", the introduction continues, "is announced by… the occurrence of subjective shock indicators (paleness, cold sweat, noises in the ear, blurred vision, dizziness and incipient nausea etc.) and is characterized in the relevant literature by typical changes in the circulatory system, changes in breathing patterns and by displacement of the blood volume."

The inquiry considered free hanging after falling over the edge of a platform (suspended from the back attachment point of the harness) and free hanging after falling from a ladder (suspended from the front attachment point or points of the harness system).

In addition to the contracted work, the project attempted "to determine the wearability of the harnesses, starting with the known fact that the willingness to use the harnesses in the manner meant is largely determined by the wearability during normal use."

In the first series of tests, (phase 1) three harnesses were used (A, B and C), with twelve male and three female human test subjects. Free-hanging tests were carried out using full body harnesses with back attachments. The back attachments were located in approximately the same place on all the harnesses, i.e. between the shoulder blades. Tests were also carried out using the front attachment points on the harnesses (used for work positioning). These attachment points were located at waist level and positioned at the sides. In an additional phase, (phase 2) two more full body harnesses (D and E) were added to the programme. These had back attachments located as harness types A, B and C and front attachment points located at sternum height. Six male and four female human test subjects took part in these additional tests.

The current state of health of the subjects was evaluated, as well as relevant work-medical data such as sicknesses, injuries, medication, and alcohol, drug and tobacco consumption. Anthropometric data, such as weight, height, stomach and thigh girth, were taken, although this information is not given.

Before the suspension tests started, each subject had to undergo a task-related course, which involved 12 ground and three ascending ladder tasks. Data were recorded regarding wearability of the harness during normal wear and pressure/pain complaints in the extreme positions, and movements required of the subjects in the course.

Each subject had to wear each of the three harnesses in the first phase and the two harnesses in the second phase, in the task-related course and in the two suspension positions.

Before the suspension tests, each subject was fitted with electrodes to monitor electrocardiogram (ECG), a flex-band to register breathing patterns, and a collar to monitor blood pressure and to measure thigh circumference.

The subjects were told to stay suspended without moving for as long as possible.

Pulse frequency, breathing rate, blood pressure, and thigh circumference were measured. Also measured were the subjective state of health during suspension, such as nausea, blurred vision, troubled breathing, numb feelings, tingling in the extremities, pressure and pain spots caused by the harness, and observable signs of shock, e.g. the amount of blood in the capillaries, whiteness of the skin, sweating, etc. The tests were stopped when one or more of the following were observed:

- unbearable pain;

- subjectively related orthostasis indications;

- objectively observed orthostasis indications;

- orthostasis indications substantiated by physiological measurements.

Suspension duration

In the suspension tests using types A, B and C harnesses (phase 1):

- the suspension duration from the front (waist level, work positioning) attachment points varied between five minutes (harness type A) and 26 minutes (harness type B). It is not clear whether suspension was from both front attachment points (normal, when two side attachment points are provided) or one of them: this would undoubtedly make a difference to the comfort provided by the harnesses;

- the suspension duration from the back (shoulder-blade level, fall arrest) attachment points varied between four minutes (harness type A) and 53 minutes (harness type B).

In the suspension tests using type D and E harnesses (phase 2):

- the suspension duration from the front (sternal, fall arrest) attachment points was better than that for the front waist level attachment points of harnesses types A, B and C (minimum/maximum 14/24 minutes for harness types D and E and minimum/maximum of 5/9 minutes for harness types A, B and C).

To make a direct comparison between the median suspension durations of the two phases, table 5 was composed. Times were rounded off to the nearest minute and no differentiation was made between male and female test subjects.

Table 5 Median suspension durations for phase 1 and phase 2 combined

Suspension type	Harness A (minutes)	Harness B (minutes)	Harness C (minutes)	Harness D (minutes)	Harness E (minutes)
Front suspension waist level	7	15	7		
Front suspension sternum level				22	16
Back suspension	27	27	23	26	20

Although the majority of the test subjects broke the tests off due to other complaints, the majority of persons exposed to suspension trauma due to longer suspension duration, it was observed by the authors, were not protected by the customary physiological measuring procedures, because orthostatic circulatory collapse occurs so suddenly.

Pulse frequency

In the front waist-attachment suspension tests, there was an increase in the pulse frequency by more than ten beats in 40% of the test subjects. The pulse rate for the remaining 60% remained steady. The pulse frequency for the front sternum-attachment suspension tests is not given.

In the back-attachment suspension tests, there was an increase in the pulse frequency by more than ten beats in 41% of the test subjects. The pulse rate for the remaining 59% remained steady.

There was "no recognizable tendency towards a change in breathing rate" during the tests. Changes "were usually quick, chronological deviations up or down with amplitudes of about five breaths."

Blood pressure

Blood pressure was taken before suspension, immediately at the start of suspension, at 2, 5, 10 and 15 minutes after the start of suspension, then every five minutes until completion of the test. It was taken again immediately after completion of the test, then at two and five minutes after it.

No prevailing tendencies could be found. However, both suspension situations differed markedly regarding the blood pressure changes.

▪ In the front waist-attachment tests, ten results showed an increase in the blood pressure amplitude, six showed constant and 22 showed decreasing blood pressure;

▪ In the back-attachment tests in phase 1, one result showed an increase in blood pressure, 26 were constant and 18 showed decreasing pressure.

Weighted blood volume

This was carried out by measuring the circumference of the right thigh at intervals similar to those carried out for blood pressure. The results are summarized in the report as follows:

"After a relatively strong increase in thigh circumference during the first three to five minutes, there is a slower increase, which then, between roughly ten and twenty minutes, levels into a sort of plateau. In so far as a correspondingly longer suspension time was achieved, frequently a slight new increase of the thigh circumference was observed."

Using the data outlined above, the authors found it possible to conduct tests predicting the suspension duration for front and back attachment. According to the authors, this "can be predicted with amazing accuracy." Of particular importance to the prediction were body weight, body height, shoulder width and stomach girth. Gender had insignificant influence.

The most remarkable result of the tests, in the authors' opinion, is the short suspension duration times, which for front waist-attachment suspension were just a few minutes and for front and back attachment suspension, less than half an hour.

Major research in Germany

In 1991, extensive research was carried out by Deutsche Montan Technologie (DMT) on many aspects of falling from a height and published in an extensive document entitled *Optimisation of intercepting devices - Biomechanical stress limits of humans.* The section relevant to this review is Appendix 5: *Part III: Investigation of personal safety equipment to protect against falls* by R Mattern and R Reibold [27].

In *2.1.3, Hanging in the safety harness - until rescued*, it states:

"Hanging in the harness causes, beside pain through pressure along the webbing straps, states of shock caused by circulation, so-called orthostatic syndrome, which can go along with drop in blood pressure, dizziness, pallor, and can lead to death in circulatory shock."

4.6, Preliminary trials for hanging in safety harnesses of type A describes tests that were carried out to investigate the tolerability of free hanging in a harness, with regard to the possible impairment of health. (A type A harness is a full body harness with a back attachment in accordance with the then draft European Standard, prEN 361.) Two human test subjects were used, one male and one female. Both subjects were aged 30, and weighed 76.5 kg and 63 kg respectively.

Before each experiment, after the harness was fitted, a short trial suspension was carried out. It was noted that the fitting of the harness straps led to different hanging postures in the two test subjects.

Initially, the male subject complained of a painful restriction of breathing, due to some of the metal fittings. The harness was refitted. After 8.5 minutes of suspension, the male subject suffered cold sweats and became pale, and the test had to be abandoned. There was full recovery after ten minutes of lying flat. No further suspension tests were carried out using this subject.

During the pre-test suspension, the female test subject complained of "pain that could not be borne for long" along the chest straps, across the collar bones and along the leg straps at the inner surfaces of the thighs. The harness was refitted to achieve a relatively comfortable fit. This resulted in a posture resembling squatting, "with the seat extended far to the rear". The subject

still "complained of bearable pain, respectively over the webbing straps located over the collarbones and at the seat. There were no problems on the insides of the thighs; the harness straps there were not under strain."

According to the Doppler sonograph, the venous return flow was unrestricted. Dorsalis pedis pulses (artery in the feet) were present at all times during the tests.

However, the summary results found that:

- "in individual cases a collapse can occur suddenly - in this case in just over eight minutes - with the threat of loss of consciousness, even if the harness is properly fitted";

- "in individual cases the most comfortable position for suspension conforms little to the position following deceleration in such a harness";

- in order to be able to make a more comprehensive statement about hanging in the harness, additional trials under precisely defined conditions were necessary.

The evaluation refers to work by P Weber [26] and to more work by A Thomas et al. These authors "observed that even subjects with strong pain reached a hanging duration of 30 minutes without collapse and concluded that there were highly variable tolerances of pain and tendency to collapse among individuals." However, ultimately, they say, "it is merely a question of time until vagovasal[13] syncope[14] occurs, even in a subject tolerant of pain."

In January 1997, M Petermeyer and M Unterhalt reported in an article published in Der Notarzt, entitled *Das Hängetrauma* (Suspension trauma) [19], that "healthy volunteers, who hung motionless in a leg loop harness as part of suspension tests, reported ringing in the ears, dizziness and nausea after between five and 22 minutes."

Tilt table and double-strop suspension tests

The latest original research seems to be that of P Madsen et al in 1996 or 1997 and published in Aviation, Space and Environmental Medicine, in 1998 [2].

The research was concerned with the tolerance of human beings in general to orthostasis (not just those suspended in a harness). Although, according to the authors, "orthostatic hypotension is usually a benign event, some patients are disabled by frequent syncopal events." In plain English, this means that although low blood pressure caused by being in a vertical plane and not moving is usually not a problem, some patients faint (which can lead to death).

A case report is given of a 25-year-old soldier who, during first aid training, was suspended from a wall with a strop around his thorax in order to simulate hanging. He was left unobserved for about six minutes and was subsequently found lifeless and taken down. He died, with signs of ischaemic brain damage. There were no signs of strangulation, e.g. no marks on his neck, and he did not suffer from any disease prior to the incident, nor was he taking any medication.

The research programme consisted of two sets of trials. The first involved the human test subject lying on a tiltable board equipped with a pillow and a bicycle saddle fixed to the board, the latter providing support when the angle dictated it to be necessary (see figure 1). The second

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[13] *This is quoted directly from the German to English translation, but is probably a mistake and probably should say vasovagal: see glossary.*
[14] *Loss of consciousness after symptoms including nausea, pallor, sweating, slow heart rate and low blood pressure*

set of trials required the subject to be suspended in a double padded strop arrangement. One strop was placed around the thorax and connected to a rope, and the other strop was passed under the legs just behind the knees and connected to the rope in the same place as the first strop (see figure 2). On lifting the subject into a suspended position, a sitting position was assumed, so that the upper part of the legs was roughly just above horizontal.
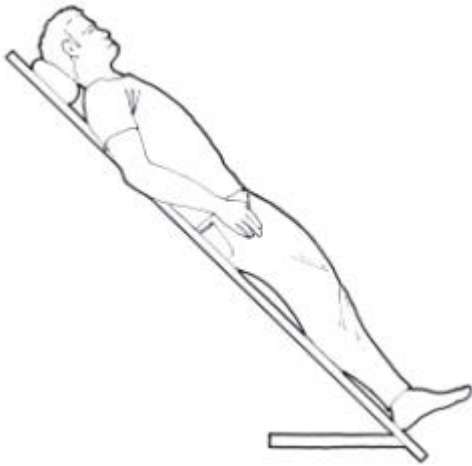
Figure 1 Head-up tilt to 50° from horizontal (after Madsen)
The subject is supported by a bicycle saddle

Figure 2 Suspension with a double-strop device (after Madsen)
The thorax is upright and venous return is secured by elevation of the legs

In the first set of trials, 79 volunteers were subjected to a 50° passive head-up tilt with respect to the time required until hypotension and near fainting occurred. The subjects consisted of 64 men and 15 women aged between 20 and 41, weighing between 57 and 90 kg and with a height of between 1.65 and 1.95 m. "The subjects were first kept supine for 60 minutes in order for cardiovascular variables to stabilize. Tilt to the 50° position was interrupted at each 10° increment to allow time for measurements. Subjects remained tilted without moving for one hour or until pre-syncopal symptoms (nausea, light-headedness and feeling hot) or signs (pallor, relative bradycardia and hypotension) appeared."

Passive head-up tilt to 50° resulted in pre-syncopal symptoms within one hour in 69 of the 79 subjects. Seven subjects sustained one hour of tilt and three were taken down due to discomfort other than near-fainting after 25, 35 and 45 minutes respectively. Half of the group experienced

pre-syncopal symptoms within 27 minutes. Six subjects experienced pre-syncopal symptoms within five minutes and 17 within ten minutes. One subject near-fainted after only two minutes.

In the second set of trials, nine subjects took part. There were eight men and one woman, aged 21 to 35, weighing 71 to 82 kg and with a height of 1.70 to 1.87 m. Like the tilt tests, the subjects were first kept supine for 60 minutes in order for cardiovascular variables to stabilize. And again, like the tilt tests, subjects remained suspended without moving for one hour or until pre-syncopal symptoms or signs appeared.

During the double-strop suspension study, only the female subject experienced pre-syncopal symptoms and was taken down after 50 minutes. This subject also took part in the head-up tilt tests where she experienced pre-syncopal symptoms after only five minutes.

Under the heading "Discussion", the paper finds that "leg elevation prevented vasovagal reactions in eight out of nine subjects", and that "although an increase in the heart rate of approximately eight beats per minute (bpm) was noted, since the central blood volume was unchanged, this could probably be explained by discomfort in the awkward position." However, there was an abnormal reduction of blood pressure and slowing of the heart rate in one subject (preceded by an increase of 25 bpm and a reduction of the central blood volume). Thus, even in a position with the legs elevated, a critical reduction in the central blood volume may be experienced, albeit with a much lower risk of pre-syncope than during the head-up tilt test.

The paper concludes: "the data supports the notion that the upright position results in bradycardia and hypotension, mainly by way of central blood depletion."

1.4 THE CAUSES OF SUSPENSION TRAUMA

The many examples of the effects of being suspended upright and motionless given in 1.3 establish without doubt the existence of so-called suspension trauma. This section looks at the conclusions of the research reviewed in 1.3 and other documents, and at the underlying reasons for the dramatic consequences of motionless upright suspension.

In *The medical effects of being suspended in safety harnesses* (1997) [17], Bariod and Théry discuss pathology caused by safety harnesses for cavers, which actually applies to all persons suspended in a harness. Extracts from this paper set the scene:

"All cavers know from experience that one can remain suspended in one's safety harness for several hours with no problems other than those arising from pain due to pressure in the region of the harness straps and with no risk to life. A single feature distinguishes this situation from those in the experiment:[15] the presence or absence of voluntary movements in order to adjust the body to the pressure of the harness straps and fastenings of the harness.

In all situations in life, our organism changes its support points continually and unconsciously. If this mechanism is blocked, e.g. in the event of paralysis, skin injuries at the support points and difficulties with the return of venous blood from the lower limbs appear after a few hours. It is in this way that circulatory problems occur.

The pathology caused by safety harnesses only occurs in the special context of a person hanging suspended and motionless.

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[15] *Refers to the testing carried out by Amphoux, Bariod, Théry et al in 1986, described earlier in [17] and also in [18].*

This situation occurs necessarily if unconsciousness occurs more or less due to skull trauma or a medical incident, e.g. fainting or cardiac dysrhythmia. The situation deteriorates very rapidly due to the hindrance of the movement apparatus and psychological impairment (panic), whereupon there is a very rapid loss of consciousness together with the body tilting backwards.[16] In some instances described, death appears to have occurred very quickly, possibly at the time of the body tilting backwards."

The symptoms of pre-syncope are then listed (see 1.2.2) and then:

"In all, the series of experiments with our test subjects are characterized by the occurrence of pain and pronounced loss of feeling in the limbs, confirmed by a particularly high level of endorphins.[17] For a certain period of time the person affected can attempt to respond, but the substantial increase in unease undermines with each impact any attempt at movement, and fainting occurs very quickly."

"…The fact that the body is overstretched when it tilts back is a serious influencing factor. No harness can actually prevent this. During our experiments, manual correction of this factor did not prevent the trend that was generally observed or the onset of nausea. Active movement of the legs may for a time improve these symptoms, but this does equally little to prevent the tendency towards a strong sense of unease. Although systematic blocking of the arterial blood does occur, it does so only to a limited extent: the pulse can be felt fully throughout the experiment.

The unpleasant feeling when the venous blood flows back is indisputable, but it can only be measured with difficulty. Horizontal arrangement of the lower limbs does not prevent the onset of a feeling of unease. During our short series of experiments, the wide scatter of the measured gas values of capillary blood (from the ear) did not permit interpretation. The same applies to the metering of the lactate values. Only a significant increase in endorphin values was recorded. We still do not know the medical explanation for the feeling of unease described, although its onset in reality is fully proven. There is a strong possibility that certain fatalities observed when a person remains suspended from a rope arise due to this relation (alone or in combination)."

All the collated research points to a primary cause of suspension trauma: venous pooling. The main problem is that excessive blood pooled in the legs means that the amount of blood in the circulatory system is considerably reduced and so the heart has less blood to pump. This leads to abnormalities such as an unusually rapid heart rate which is then followed by an unusually low heart rate with low pulse pressure, and symptoms such as dizziness, nausea, sweating, ringing in the ears and loss of vision. Loss of consciousness (orthostatic syncope) can occur, followed by death, due to lack of blood to the brain.

However, there is another possible reason for syncope to occur: vasovagal attack. This is an excessive activity of the vagus nerve, resulting in a slowing of the heart rate and a fall in blood pressure, which leads to fainting. One trigger for the vagus nerve to come into action is the lowering of blood pressure, which is an effect of venous pooling.

In *Physiological implications of findings* in section 5 of Orzech et al's work in 1984 [5], it states:

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[16] *Cavers use sit harnesses, typically linked to a type of chest harness that provides support higher than just the sit harness alone, but not as high as a properly adjusted full body harness. Hence the reference to tilting backwards.*
[17] *Chemical compound occurring naturally in the brain that has pain relieving properties*

"Another mechanism which can cause some of the clinical findings associated with motionless suspension is the vasovagal (vasodepressor) response. During a vasovagal event, individuals may experience hypotension, bradycardia and loss of consciousness in response to environmental stresses. The bradycardia is the result of vagal stimulation. In addition, other authors have suggested that profound vasodilation[18] of skeletal muscle arterioles[19] occurs, which results in an accompanying drop in blood pressure (Goldstein et al 1982). The prodromal[20] symptoms of a vasovagal attack are pallor, nausea, sweating and abdominal discomfort arising from sympathoadrenal[21] and vagal responses. Loss of consciousness occurs as a result of cerebral ischaemia from hypotension."[22]

Probably the most famous incident attributed to a vasovagal attack is that of the president of the United States of America, George W Bush, known to have low blood pressure, who, in January 2002, fainted while eating a pretzel. It is thought that the vagus nerve was stimulated [28], an effect of which is a lowering of the heart rate and blood pressure, which itself would lead to a reduction of blood to the brain, thus triggering the syncope.

The primary cause of syncope is a decrease in the quality and/or the quantity of blood flow to the brain. Examples of reasons for this occurring are:

- pooling of blood in the veins of the legs and abdomen (venous pooling);

- abnormal response to stimuli (e.g. vasovagal effects);

- inappropriate distribution of the blood, with less going to the brain and more elsewhere (e.g. during exercise);

- hypoglycaemia (low blood glucose levels);

- hypoxia (low blood oxygen levels);

- hypocapnia (low blood carbon dioxide levels).

It is also possible that restrictions of the femoral arteries and veins by harness straps can exacerbate venous pooling and the pain caused by these straps can aid the onset of shock.

There is an increase of toxins in the pooled blood [23]. Small amounts of toxins are normal in the veins and are usually carried away safely. Without the action of the muscle pumps, these toxins remain in the pooled blood and begin to build up.

Death can occur during or just after rescue caused by the casualty being moved to a horizontal position, resulting in a massive return of venous blood to the heart, which is unable to cope and fails (cardiac arrest). It is possible that the unusual level of toxins in the venous blood plays a part in the effect on the heart. Death can also occur some time after rescue, due to renal failure. This is caused by the lack of blood oxygen to the kidneys due to the effects of venous pooling.

The underlying causes of suspension trauma are examined by referring to the findings of the literature already reviewed and other literature.

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[18] *Increase in the diameter of blood vessels, especially arteries*
[19] *Small branch of an artery leading into many smaller blood vessels, i.e. the capillaries*
[20] *Early warning*
[21] *Relating to effects of the responses of the sympathetic nerves and associated catecholamines (e.g. adrenaline)*
[22] *Inadequate flow of blood to the brain caused by abnormally low blood pressure*

Scharfetter and Flora (1972) [6] say:

"Orthostatic shock and typical respiratory obstruction may lead to death when hanging on a rope; the probability of survival after hanging two hours is small; death may occur during hanging or after detachment from the rope when rescued. The cause of this death, generally occurring suddenly, soon or some time after detachment from the rope, is ascribed to protracted shock, but also to acute heart failure. The latter can perhaps be explained by the inability of the heart to cope with the blood which had sunk into parts of the body in orthostasis, but flows back in excess to the heart after the victim is laid flat. Failure of the kidneys damaged by shock may lead to death much later."

Amphoux, Bariod, Théry et al in their work for the Medical Commission of the French Speleological Federation (1986) [18] and also see [20] say that "the physiological mechanism of the malaise[23] is complex but can be expressed as follows: disruption of the equilibrium of the cardiovascular system leading to a failure of the circulatory system with cerebral ischaemia, leading rapidly to death."

The text of a recorded lecture entitled *Hanging after a fall: an extremely urgent rescue* (1998) [15] by Dr Amphoux, based on his earlier work, highlights the lack of understanding by climbers and cavers of the potential danger of "hanging passively in a harness". It discusses the subject of suspension trauma in general terms and hypothesizes on the causes:

"In fact several hypotheses have been raised to explain the observed troubles. It was possible to invoke the inevitable compression of the tops of the thighs on most harnesses tried. Even if that compression was light, it was possible that there was a disturbance of the return (blood) circulation and cardiac depression caused by the accumulation of the waste products. But the troubles occurred just as much with certain harness models in which the buttock straps are kept in place by straps which did not compress at this level. This type of compression is, however, to be feared even with a well-adapted harness, if it shifts during the fall. A second hypothesis has been raised during some trials where the hanging straps were in lateral contact with the neck and could have stimulated the carotid baroceptors.[24] But this arrangement is unusual."

"The most probable hypothesis, therefore, is that absence of muscular contractions more than the compressions lead to an important blood stasia at the level of the lower limbs. Besides there exists constantly a certain local cyanosis.[25] The lowering of the amount of circulating blood may determine a certain degree of cerebral anoxia [26] aggravated by the trouble of the cardiac rhythm, which stems from the same mechanisms. This hypothesis has been largely confirmed by basic knowledge in resuscitation anaesthesia. Surgical operations under general anaesthesia are only carried out in the low legs position for certain special types, more particularly the intra-cranial operations. Anaesthetists know that the moment when a patient is brought back to the horizontal position is often delicate and must be especially watched, often necessitating hyper-oxygenation and cardiac support."

Petermeyer and Unterhalt (1997) explain the reasons [19] (p3-4):

"The first reports from the 70s of bodies of mountaineers recovered from ropes expressed surprise at the lack of external trauma…[27] Post mortems found no evidence of external or

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[23] *Suspension trauma*
[24] *Collection of sensory nerve endings specialized to monitor changes in blood pressure. Also see baroreceptors*
[25] *Bluish discoloration of the skin and mucous membranes resulting from an inadequate amount of oxygen in the blood*
[26] *Condition in which the brain receives inadequate amounts of oxygen*
[27] *See [6]*

internal injury. First indications of the cause of death came from histological results from individual tissues: the changes observed in the heart, liver and kidneys were identical to those produced in experiments on animals through acute shortage of oxygen. Small platelet agglutinates,[28] obstruction and endothelial oedema[29] in the capillaries testified to intravascular coagulation."[30] Injury caused by hypoxia was assumed to be the cause of all the changes observed.

The assumption of hypoxia as the cause of the changes provided the initial clue that formed the basis of some suspension tests. During these tests, "healthy volunteers who hung motionless in a leg loop harness as part of the tests reported ringing in the ears, dizziness and nausea after between five and 22 minutes. A drop in systolic blood pressure[31] with accompanying tachycardia[32] and a fall in the glomerular[33] filtration rate indicated the onset of shock. The symptoms improved as soon as the test subjects exercised their leg muscle pump."

Petermeyer and Unterhalt go on to say that the results can all be explained by relative hypovolaemia[34] resulting from an orthostatic shock. Hanging on the rope causes the blood to accumulate in the legs. "A vicious circle is created where failure of the muscular pump and constriction of the legs by the harness accelerate the development of shock" (see figure 3).

"Declining cardiac output due to relative hypovolaemia is responsible for causing the microcirculatory disorders. Inadequate perfusion pressure leads to the symptoms described, such as dizziness and nausea. Compensatory catecholamine release may delay circulatory breakdown for a certain time. However, following the onset of irreversible damage, it leads to deterioration in microcirculation with development of endothelial[35] damage and disseminated intravascular coagulation.[36] The brain and kidneys are the organs that are sensitive when the body is in a state of shock."

In *Morphological findings in the case of death after hanging on a rope for four hours*, J Fodisch (1972) [29] goes into detail about the cause of death of a 23-year-old woman who fell about four metres and died four hours later at the moment of rescue. He found that after an initially compensated phase when hanging freely, sinking of the blood and thus reduction of the circulation volume occurs as a result of disturbance of the circulation dynamics, above all on the venous vascular system. A considerable time later there occurs respiratory hypoxia, and thus also reduction of the oxygen tension of the blood, as a result of additional impedance of the respiratory mechanism. Both mechanisms intensify the fall in the oxygen tension in the tissue, lead to insufficiency of the oxidising metabolism in the individual cell and finally to visible oxygen deficiency symptoms such as vacuolisation,[37] fatty degeneration, necrobiosis[38] and necrosis[39] (see figure 4). The duration and degree of severity of this disturbance determine the extent of damage.

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[28] *Adhered cells*
[29] *See 'endothelium' and 'oedema' in the glossary*
[30] *Clotting within the blood vessels*
[31] *Pulse pressure high value*
[32] *Abnormally rapid heart rate*
[33] *Tiny blood vessels in the kidneys*
[34] *Decreased circulating blood volume*
[35] *Cells lining the blood vessels, heart and lymphatic glands*
[36] *Scattered clotting within the blood vessels*
[37] *The taking in of material into a space formed in a cell*
[38] *A gradual process by which cells lose their function and die*
[39] *The death of cells caused by disease, physical or chemical injury, or interference with the blood supply*
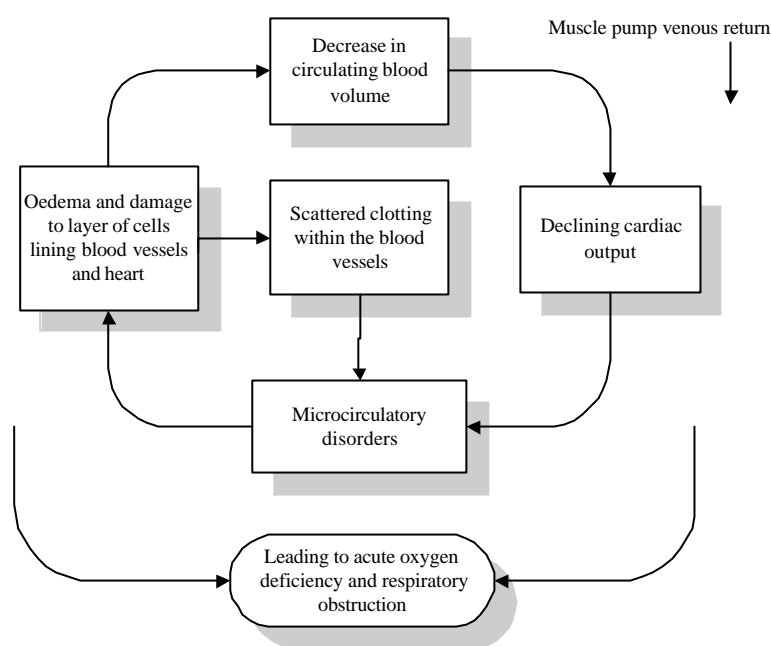
Figure 3 Suspension trauma: pathogenetic mechanism (after Petermeyer and Unterhalt)

Further findings revealed additional pathogenetic criteria, including fibrin clots in the sinusoids of the liver, which could be regarded as evidence of circulatory shock and coagulation effects in the blood. "Both shock and coagulopathy follow seamlessly from the above comments, because hypoxidosis[40] as a phenomenon of a general oxygen deficiency itself becomes, after a specific stage, an important pathogenetic principle, which is further intensified in three ways (see figure 5): firstly, via a hypoxidotically induced neurogenic[41] or cardiogenic[42] shock with all its resulting conditions in the sympathico-adrenal system and the peripheral vascular region; secondly, (as shown histologically) via the acidotically induced activation of the coagulation system with formation of fibrin clots in the terminal vascular system, and thirdly, on the basis of the glucose consumption as a result of increasing substrate deficiency."

Fodisch concludes: "the patho-morphological findings in the case of death after hanging freely on a climbing rope represent the visible substrate of a general hypoxia relating to the entire organism, whereby primarily both the disturbance of the circulation dynamics (sinking of the blood, reduction of the circulation volume etc.) and disturbance of the respiratory mechanism should be regarded as the cause. Finally, the hypoxidosis — itself now the important pathogenetic principle[43] — is continuously intensified via three control systems." Central neurogenic shock, metabolic acidosis with activation of the coagulation system and substrate deficiency as a result of glucose consumption intensify themselves in the sense of mutual reinforcement, which finally leads to an insufficiency of oxygen to the vital organs.

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[40] *Acute oxygen deficiency*

[41] *Arising in nervous tissue*

[42] *Relating to the heart*

[43] *Manner of development of the disease*

Figure 4 Causal genetic development of hypoxidosis when hanging on a rope (after Fodisch)

Figure 5 Hypoxidosis as central pathogenetic principle for induction of further pathophysiological control systems with the result of self-intensification (after Fodisch)

Hearon and Brinkley (1984) [4] concluded that the mechanism involved in post-fall suspension had not yet been defined experimentally. However, they suggested that venous pooling occurred in the lower extremities during motionless, prolonged suspension, which contributed to a decreased cardiac output and venous return to the he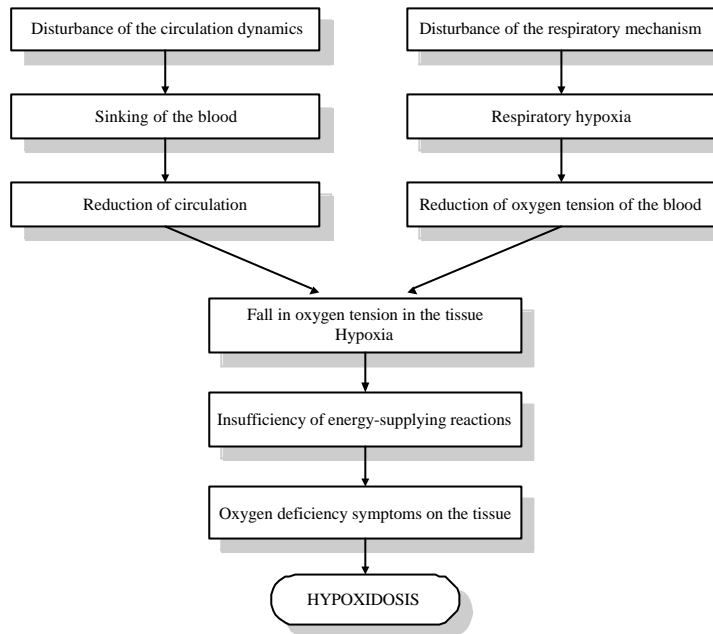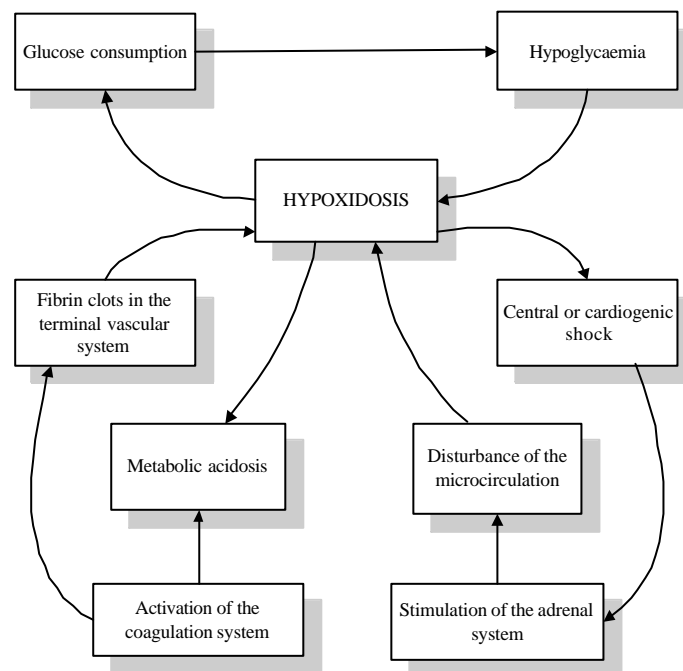art. Orzech et al (1987) [5] refer to this work by Hearon and Brinkley, and state: "The decreased cardiac output may explain the symptoms of light-headedness and hypotension observed in previous experiments. Pathophysiological consequences attributed to venous pooling in the lower extremities include decreased right atrial pressure, decreased venous return to the heart, and a decrease in the cardiac stroke volume."

Interestingly, the work of Mattern and Reibold (1991) [27] found that in their tests with two human subjects in suspension in harnesses, according to the Doppler sonograph connected to the two subjects, the venous return flow was unrestricted and that dorsalis pedis (artery in the feet) pulses were present at all times during the tests. Even so, after 8.5 minutes of suspension, the male subject suffered cold sweats and became pale (sure pre-syncopal signs), and the test had to be abandoned.

Damisch and Schauer (1985) [24] concluded that a motionless subject in a chest/seat strap harness combination is subject to orthostasis with pooling of the blood in the lower extremities, subsequent irreversible protracted shock, and the possibility of death during or just after rescue (so-called rescue death). Rescue death is said to be a result of an acute heart failure (in particular of the right side of the heart) immediately after the rescue of a person in shock from the hanging position, because the blood, which has sunk to the lower half of the body, flows back too quickly to the heart.

Patscheider (1972) [9] provides a probable order of processes leading to death (see figure 6).

Hearon and Brinkley (1984) [4] conclude in their work that:

- heart rate and respiratory rate tended to increase with suspension duration;

- prolonged motionless suspension may result in cardiovascular responses, including tachycardia and bradycardia, with subsequent loss of consciousness.

Madsen et al (1998) [2] reported in their research that passive head-up tilt resulted in hypotension, bradycardia and pre-syncopal symptoms in 69 of 79 subjects (87%) within one hour and tolerance to sustained orthostasis decreased almost linearly with time. In contrast, suspension with elevated legs using a double strop system was associated with near-fainting in only one of nine subjects (11%).

Madsen et al found that head-up tilt reduced the central blood volume. Central venous pressure was also reduced but returned towards the resting value during the sustained tilt. In the pre-syncopal (near fainting) subjects, the cardiovascular response to central hypovolaemia (decrease in central blood volume) included a normotensive-tachycardic (high heart rate with normal blood pressure) phase followed by a hypo-tensive-bradycardic (low heart rate with low blood pressure) episode. The double-phased heart rate response relates to increased sympathetic and parasympathetic[44] activity, respectively.

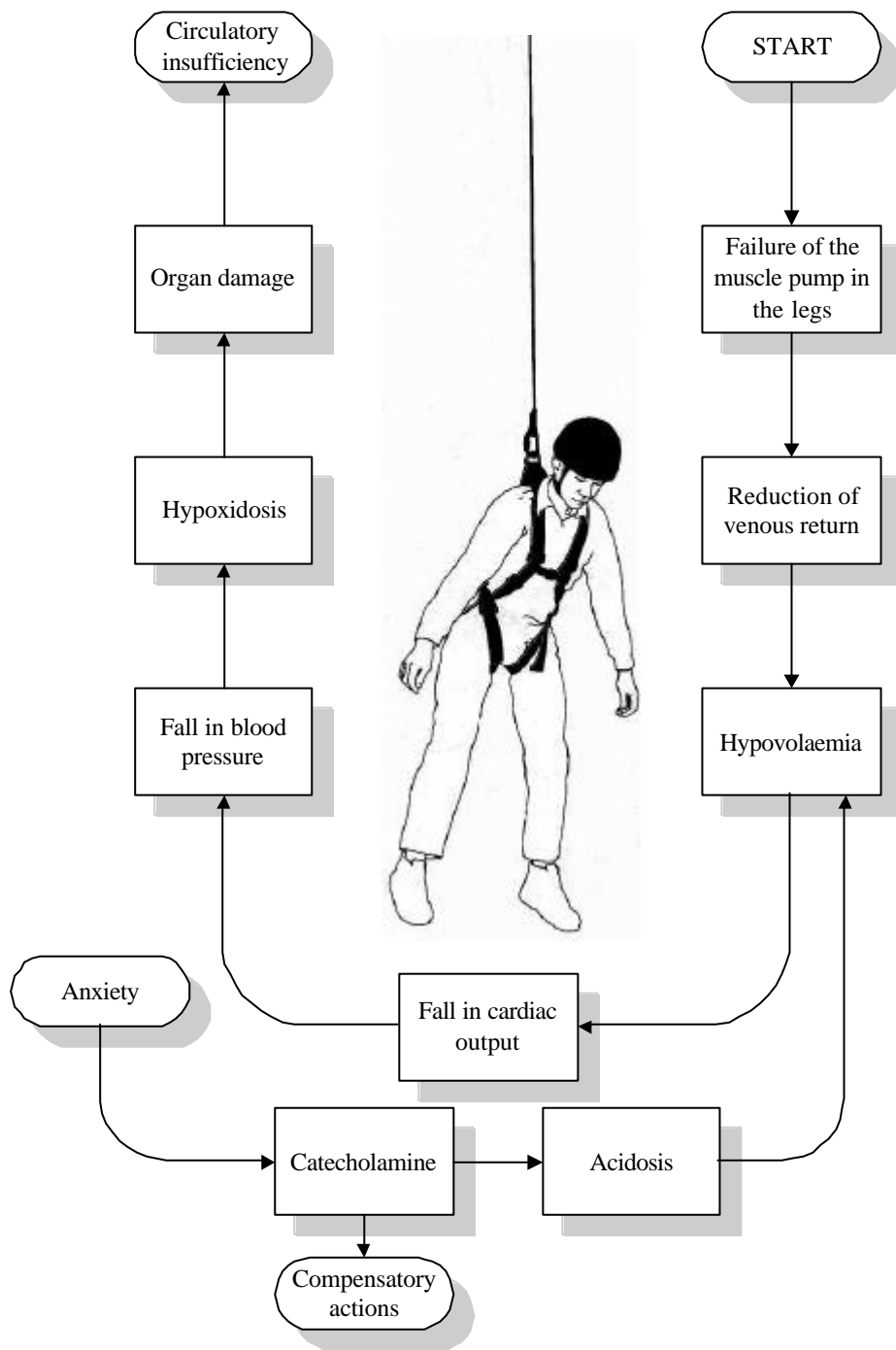[44] *Part of the autonomic nervous system: see glossary*

Figure 6 Probable order of processes leading to death from protracted orthostatic shock (after Patscheider)

Arterial hypotension (abnormally low blood pressure) is elicited by reduced sympathetic outflow and arterial dilatation, which in turn increased muscle oxygen saturation. The increase in heart rate is probably mediated by way of central volume receptors as mean arterial pressure and pulse pressure were elevated, and therefore arterial baroreceptors (blood pressure sensors) are unlikely to contribute. Hypotensive-bradycardic (vasovagal) episodes maybe triggered by cardiac mechanoreceptors (sensory receptors that respond to mechanical stimuli) due to poor filling of the heart and increased contractility.

However, in *Orthostatic Intolerance Syndromes* (2001) [30] it states that arterial baroceptors, particularly those in the carotid sinus area, play an important role in the regulation of blood pressure and the response to positional changes. A drop in venous blood pressure for whatever reason will trigger a compensatory response to increase blood pressure. Any disruption in any of the processes, or their co-ordination, can result in an inappropriate response to the upright position, and can lead to a series of symptoms, and may include syncope.

It should be remembered that Madsen et al's test subjects were not suspended in harnesses: they were either supported by a bicycle saddle or a double strop arrangement that held their legs high (see figures 1 and 2). Had harnesses been used, the restricting effects of the straps could have affected the results detrimentally.

In an article in Technical Rescue magazine called *Suspension trauma: a medical perspective* (2000) [31], Dr R Dawes describes in layman's terms the physiology associated with suspension trauma, extracts from which are given here. This, and the information by Lloyd following these extracts provide a summing up of what is thought to cause suspension trauma.

Dr Dawes first explains that "some form of pump is required in order to move fluid against gravity, and it is no different in the legs. The heart is an efficient organ, but with up to 20% of the blood volume being in the legs at any one time, it would have to work extremely hard at all times to maintain adequate venous return". Additional methods are required. These are provided by one-way valves in the veins and by the contraction of the calf muscles, which squeeze blood upwards towards the heart. If someone stood still for a number of minutes, up to 20% of the blood volume would be in the legs. This would place the body into class 2 shock (there being four classes, increasing by ascending number in severity), which could lead easily to loss of consciousness. He gives the analogy of the soldier fainting while on guard duty, described earlier in 1.2, and his rapid return to consciousness as the blood flow to the brain is restored. Having made the point that an unconscious person suspended in a harness would not automatically assume a horizontal position, he continues: "There are a number of factors that make suspension trauma in a climber/casualty different from that in our soldier:

- The harness can effectively become a tourniquet, thereby decreasing venous return even further.

- There is a possibility of exhaustion.

- There is a possibility of injury (and therefore more blood loss).

- Further physiological effects altering brain blood flow, such as hanging of the head (hyperextension) when unconscious in a harness.

- The possibility of dehydration (reducing effective circulating blood volume).

- Hypothermia, with adverse effects on conscious levels, blood clotting and exhaustion.

The normal blood pressure in the foot on walking (and therefore with the muscle pump working) is approximately 25 mm Hg. On standing still, without the muscle pump, this can rise to over 90 mm Hg. Couple this with the addition of a harness impeding venous return, and the additional effect of increasing the hydrostatic pressure, which essentially forces the water component of the blood out of the veins, causing oedema or swelling of the legs.

The body's response to falling blood pressure is to increase the tone of the arteries and veins in an attempt to increase the blood pressure, and this increased pressure against the harness 'tourniquet' further contributes to the oedema and increases the volume of blood in the legs. All of the above results in a vicious circle and downward spiral of increasing venous pressure, reduced venous return, decreasing central venous pressure and decreasing levels of consciousness.

When the blood pressure in the brain stem reaches an unacceptably low level, a response known as the Central Nervous System Ischaemic Response is initiated. This is one of the most powerful of all the body's responses to low blood pressure. It shuts down kidney perfusion and can increase the blood pressure to as high as 250 mm Hg in ten minutes. What this does, however, is force even more blood into the legs, continuing the downward spiral.

To further complicate matters, after 20 or 30 minutes of the harness directly compressing tissue, the condition known as 'crush injury' will result. This causes the release of large proteins (myoglobin) from damaged tissues and when the harness (or bodyweight) is removed can be very damaging to the kidneys."

C Lloyd, in comments on a web-based article called Harness-induced pathology (2001) [23], which is in fact a repeat of Ampoux, Bariod and Théry's work in 1983 to 1986, refers to compression syndrome or crush injury:

"Any caver who has been involved with a rescue of someone trapped by falling or collapsed rocks is familiar with this one.[45] The causes here are more obvious as you can easily see that the rock is cutting off the flow of blood to the affected limb. The problem then is when that circulation is restored and that stale blood is able to return to the rest of the body. If careful measures are not taken, the patient will then die from the stress of this blood hitting the rest of the body. What has happened while the blood has been pooled in the limb is that the normal exchanges between blood and tissue have not been able to proceed. This causes a change in the chemical balance in the blood and the small quantities of toxins that the blood normally carries away are now much more concentrated.

That is the problem with the blood part, but is not the whole story. The circulation of blood also ensures a balance of watery fluid in the muscles and other cells of the limb. When the blood does not circulate, that balance gets out of balance as well, and this watery fluid leaves the cell where it normally lives and flows into the inter-cell areas. This is what causes the swelling seen in these situations. The normal solution for dealing with that problem is to physically cut the affected areas, allowing the fluid to drain, because you don't want that being re-cycled back into the body either.

While the above compression syndrome could be evoked on some vertical rope accidents, it is not the same thing. Hanging in a sit harness may, or may not, adversely affect the circulation of blood to the legs by compression, depending on the harness and the particular person. The point is that just the non-movement of the legs is enough to significantly decrease that circulation.

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[45] *Crush or compression syndrome*

If the legs and arms aren't moving, there is no pumping action, and blood tends to stagnate in the arms and the legs. This means that there is less blood return to the heart, and the arms and legs may even get puffy (oedema) from the extra fluid there. The lessened blood flow to the heart, and then subsequently to the head, is what leads to the faintness" (experienced in pre-syncope).

1.5 MANAGEMENT OF SUSPENSION TRAUMA

Prevention is better than cure. This adage applies very aptly to the management of suspension trauma. Ideally, systems of work and rescue plans should be set up so that no one will be in a position where they are likely to suffer the condition. A good start is to ensure that the harness chosen is appropriate for the work to be undertaken, is a good fit and has an adequate comfort level. This does not guarantee that a person suspended motionless in such a harness will be exempt from suspension trauma, but it should at least delay the onset.

In 1997, Bariod and Théry wrote [17]:

"To date, there is no ideal safety harness, but it is likely that — whatever the appearance of the safety harness — a relatively long period of time spent suspended motionless can lead to death. In the meantime, it is recommended as a matter of urgency that when a safety harness is purchased, it be tested while suspended so that one can find the model which best fits the shape of the body. No safety harnesses should be used that do not adjust to the body….

Safety harnesses must have a good anatomic fit so that a person can remain conscious if suspended in one for a relatively long period of time. If a person loses consciousness, there is a risk to life after only a short period of time.

If a person falls into a safety harness, restriction of movement or loss of consciousness must be anticipated. A person who has suffered an accident must therefore be rescued extremely quickly, i.e. rescue technology must be to hand and must be rehearsed routinely."

The following is extracted from *Suspension Trauma* (2000) [32] by A Sheehan, an Australian senior vertical rescue instructor:

"Suspension trauma is life threatening. Whatever the type of harness, motionless suspension is not physiologically safe and can lead to very serious blood circulation problems, including death.

Anyone who uses a harness for work or recreation may be at risk of suspension trauma if they were to hang motionless in the harness.

Anyone sustaining a head injury while on a rope is particularly at risk, especially if they lose consciousness. Casualties immobilized in a stretcher in a vertical lift or head-up position may also be at risk." (This could also apply to an immobilized 'pretend' casualty during rescue training.)

Sheehan continues:

"Factors that can affect the degree of risk are:

- the inability of the person to move their legs to assist circulation;

- dehydration;

- hypothermia;

- shock;

- fatigue;

- the degree of inclination of the body;

- unconsciousness."

A web-sourced article called *Suspension Trauma - Serious Risk to Subject* (1999) by Rob Thomas [20] (which is in fact a review of the work of Amphoux, Bariod, Théry et al in 1986 [18]) raises the potential problems for rescue and rescue training with the casualty in the vertical position. Thomas recounts an experience with a team member in a stretcher during a rescue practice involving a vertical haul. The "casualty" started changing colour and feeling faint after eight or ten minutes of vertical haul. A nearby group of cavers had also experienced similar problems during a similar rescue practice.

Sheehan [32] gives warning signs of suspension trauma:

- faintness;

- breathlessness;

- sweating;

- paleness;

- hot flushes;

- increasing pulse rate and blood pressure;

- unconsciousness.

All these symptoms were observed while carrying out research into suspension trauma.

Other symptoms not mentioned in Sheehan's work, but observed during the research covered by this literature search and review are:

- nausea;

- dizziness;

- unusually low pulse rate and blood pressure (usually occurring after the incidence of increased pulse rate);

- loss or "greying" of vision.

Sheehan advises that:

- "Time should be spent stabilizing the casualty before handling to make them more robust and less susceptible to suspension trauma. The more the casualty is suffering from hypothermia, dehydration or shock, the greater the increase in susceptibility to suspension trauma.

- Vertical lifts should be avoided, wherever possible, or the time spent in a vertical lift position minimized. Casualties should assist, wherever possible, by flexing the leg muscles.

- The casualty should be kept horizontal." *(But see the advice below, marked with an asterisk, which conflicts with this. [6], [14], [19], [22] and [33].)*

- "Suspension trauma can develop extremely quickly. Therefore, vital signs should be closely monitored. The casualty can assist, if capable, by telling the rescuer how they feel or if there are any changes at all."

R Dawes, in *Suspension trauma - a medical perspective* (2000) [31] advises:

"The basic principles of trauma management must always be followed whatever the injury, namely ABC.[46] Bringing the head into neutral alignment[47] if possible, the use of 100% oxygen and appropriate circulatory support with warmed IV (intravenous) fluids and appropriate use of MAST[48] during extrication can all negate the deleterious effects of suspension trauma and crush injury" (which, Dr Dawes says, will result after 20 or 30 minutes of the harness directly compressing tissue). "This obviously means that you will have to have at least a paramedic as a team member.[49] These particular skills can be almost impossible to administer in some situations, so the best advice as stated in Al Sheehan's article[50] has to be to remove the patient from the harness and the state of suspension as soon as possible and get them flat." *(But see the advice below, marked with an asterisk, which conflicts with this. [6], [14], [19], [22] and [33].)*

H Scharfetter and G Flora in their concluding remarks of the Second International Conference of Mountain Rescue Doctors (1972) [6] offer the following advice. The advice on positioning the casualty appears to conflict with the advice given by Sheehan [32] and Dawes [31]:

"1. Combating of shock by carefully placing the casualty in the squatting position (***do not lay flat**), careful volume supply, combating of acidosis, if necessary assisted breathing, whereby concentrated oxygen supply could also be indicated, digitalisation.[51]

2. Ensuring and noting of adequate diuresis, if necessary use of an artificial kidney.

Basic requirements, which should also be fulfilled by the layman, are as follows:

- prevention of hanging trauma[52] by a tying-on method in which the main tension passes to the pelvis;[53]

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[46] *Airway, breathing, circulation*
[47] *Natural, normal alignment*
[48] *Medical anti-shock trousers*
[49] *In a rescue team*
[50] *Technical Rescue, Issue 27 [21], essentially the same as [32]*
[51] *Administration of the drug digitalis or one of its derivatives*
[52] *i.e. suspension trauma*
[53] *In 1972, when this was written, it was normal to tie on directly with the rope at chest level. It was subsequently discovered that suspension trauma could also occur when suspended in a harness, so this advice is partially invalid.*

- dissemination of the knowledge of the danger of hanging trauma;

- awareness of the possibility of death after rescue. Hence, the casualty should be given adequate time to recover before transport to hospital. Bear in mind that despite apparent absence of injury the casualty is in great danger;

- awareness of the possibility of later death. Hence, anyone who was hanging freely for more than half an hour should be taken to hospital."

Advice in *Rescuing people who have fallen and first aid following suspension in a safety harness* by M Lieblich and W Rensing (1997) [33] is:

- "Everybody who is suspended in a safety harness runs the risk of shock and unconsciousness due to blood flow insufficiency. Unconsciousness can become life threatening after only a few minutes. Shock, caused by a lack of blood flow, is due to the blood accumulating in the lower parts of the body as a result of the musculature of the legs relaxing and the so-called "muscle pump" stopping.

- In order to maintain this function in good order, the victim of a fall must be made to keep his or her legs moving. In this way, blood circulation can be activated and the accumulation of blood in the legs prevented. The victim of a fall must be released from the suspended situation as quickly as possible.

- *Important! The accident victim must never be laid down after being rescued from the suspended position, not even in the stable side position.* The victim should be positioned with the upper body very well raised, i.e. in a seated, or possibly squatting or crouched posture. All restrictive belts and clothing should be unfastened. A doctor should be called immediately.

- Laying the victim down horizontally could be life threatening. The blood that has accumulated in the legs flows abruptly into the heart creating a risk of heart failure due to overstrain. Transfer to a horizontal posture should take place only gradually. Continuous monitoring of the respiration and circulation is necessary. In the event of unconsciousness, the air passages should be kept open."

However, Thomas [20] refers to a British Medical Journal report from 1966 entitled "Hypothermia in walkers, climbers, and campers: report to the medical commission on accident prevention" by L Pugh. This paper, one of the first medical reports on hypothermia, describes how one patient, who was hypothermic and probably dehydrated, seized and died as soon as he or she was tilted head-up in the stretcher. And in the same paper, a comment on Thomas's article by Dr K Conover states:

"…However, we know that people who are tired tend to be dehydrated, too. And we also know that cold stress, even without true hypothermia, causes significant dehydration….

…In the WEMSI Wilderness EMT course we teach that dehydrated/hypothermic patients should NOT be tilted in the head-up position if at all possible — and if you have to tilt such a patient, i.e. to get up a narrow pit in a cave — rehydrate first, and consider putting the MAST garment on the patient, inflation prior to the vertical lift, and deflating after the vertical portion's done."

Nevertheless, a comfortable harness is likely to delay the inevitable onset of suspension trauma in the right circumstances.

Rescue and prevention in caving and cave diving (1990) [14] recommends, in the case of an unconscious caver, where the pulse can be felt and respiration is spontaneous: place in the classic recovery position (cf cave rescues) with one point in particular for the unconscious subject: lateral safety position. *However, Phelps, in the same paper, recommends "progressively straightening out the subject after some minutes in the foetal position. This thereby avoids a sudden overload of the right side of the heart." Phelps also gives the same advice for a conscious caver where the causes of the distress persist. It is also stressed in this paper that any subject who has been suspended for more than 30 minutes must be transported by helicopter (i.e. very quickly) to a hospital provided with a dialysis centre.

M Petermeyer and M Unterhalt in their paper *Suspension trauma* (1997) [19] state under the heading *Rescue*:

"There may be a number of different reasons why the person pauses motionless on the rope:

- exhaustion;

- hypoglycaemia;

- hypothermia;

- rock fall; cranio-cerebral trauma;

- technical problems;

- mental problems.

Leaving an unconscious person on a rope can cause death in less than ten minutes!

If the patient is still responsive, he or she should be encouraged to exercise his or her muscular pump. If he or she is hanging free, this can only be done by hanging up a foot loop, which can be improvised with the hanging rope.[54] It is also extremely important to reassure the person hanging helpless on the rope. If the scene of the accident cannot be reached with a turntable ladder[55] then experience shows that rescue time is around five minutes from reaching the scene. In principle, the patient should primarily be transported in the direction of gravity, before being stabilized and applying actual first aid measures.

Treatment

The most important step in treatment is to consider the possibility of suspension trauma. Despite low blood pressure, the classic shock condition can lead to acute right ventricular failure. There are cases of victims dying a few minutes after being rescued. Although not appropriate, the term 'rescue death' has become accepted. *It is therefore recommended initially to prop up the upper body and increase blood volume carefully; the circulatory system is stabilized with sympathomimetic drugs. Only after between 20 and 40 minutes should a more generous volume therapy (Ringer's solution) be introduced with adjuvant diuretic administration as kidney failure is the most common complication. Concomitant hypoglycaemia should be treated with higher-percentage glucose solution. The patient should be hospitalized even in case of apparently minor symptoms, e.g. numb legs or transitory

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[54] *Or lanyard*
[55] *Or a mobile elevating work platform*

respiratory and circulatory problems. Possible delayed damage, such as kidney failure as mentioned earlier, cannot be assessed at the scene of the accident."

Petermeyer and Unterhalt summarize the treatment of suspension trauma as follows:

- *Prop up upper body for 20 - 40 minutes.[56]

- Stabilize circulatory system, then increase blood volume carefully.

- Determine blood sugar level.

- Administer oxygen.

- Hospitalize, even with minor symptoms.

- Transport with upper body raised.

- Diuretics: kidney failure most common complication.

The advice in an article entitled *Rescuing accident victims* in the German Trade Journal for the Protection of Labour, the Protection of Health and Accident Insurance (1997) [22], which describes rescue from masts and towers etc., discusses the problem of deciding how the casualty should be treated:

"Positioning the accident victim

A certain dilemma arises with respect to the administering of medical first aid after a person is rescued from a suspended position, particularly if there is a loss of consciousness. On the one hand, the lack of blood circulating through the brain must be eliminated and this can be achieved by laying the accident victim flat. On the other hand, lying flat can endanger the life of the person who has been rescued, as the volume of blood that has flowed down into the legs suddenly flows to the shock-damaged heart, which may fail due to overload as a result of too much blood flowing into it all at once ('rescue death'). *We recommend a compromise whereby the accident victim is positioned so that the upper body is definitely uppermost at first (sitting or huddled position). Only then should any injuries be tended to. The accident victim should only be moved gradually until he is lying flat. It is essential that breathing and circulation be monitored constantly. If the person loses consciousness, the respiratory tracts must be kept open.

If the accident victim is conscious, then, while hanging freely, he should keep moving his legs to activate the so-called muscle pump for circulation, in order to prevent flooding by the blood."[57]

Australian/New Zealand Standard AS/NZS 1891.4:2000 *Industrial fall-arrest systems and devices Part 4: Selection, use and maintenance* states in appendix A, Suspension trauma [34]:

"Although the condition is still being researched, it is recommended that certain measures be taken to reduce the effects of this condition or delay its onset. It appears to help if the person is suspended in a substantially horizontal position or with the knees elevated, and with an opportunity to 'pump' the legs, ideally with the feet against a firm surface. The person should be

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[56] *To protect against failure of the right ventricle*
[57] *The translation "flooding by the blood" will be referring to venous pooling.*

encouraged to maintain leg activity by moving the legs and where possible pushing with the feet against a firm surface at regular intervals until retrieval can be effected."

British Standard BS 7985:2002, *Code of practice for the use of rope access methods for industrial purposes* states in annex D, Suspension trauma [35]:

"It seems that steps can be taken to minimize the risk of rope access operatives experiencing the condition. Frequent 'pumping' of the legs, preferably against a firm surface, will activate the muscles and should reduce the risk of venous pooling. Harness leg loops should be well-padded and as wide as possible to spread the load and reduce any restrictions. The use of a workseat might be advisable if work in one position is to be sustained for an extended period.

An injured person hanging in a harness awaiting rescue might be better off in a substantially horizontal position or with the knees elevated. During rescue, it could be advisable not to allow the casualty to become totally horizontal, but to be in a sat-up position, with the knees bent, to avoid a rapid return of venous blood to the heart. The eventual movement of the casualty to the horizontal position should perhaps be carried out only very slowly over an extended period of around 30 min to 40 min. It could be necessary to consider dialysis to protect the kidneys. Medical advice should be sought on all these points."

Sheehan [32] offers more advice on the prevention of suspension trauma:

- "Rope access workers and rope rescuers should not attempt long or difficult ascents when fatigued, dehydrated, hypothermic or low on energy.

- Tasks should be avoided that require a long period suspended in a harness with little leg movement.

- Workers should never be allowed to work at height alone where there is the possibility of immobile suspension, either in an emergency or otherwise."

Details of systems to rescue casualties suspended on a rope upwards in a caving situation are given in *Extrication Techniques: Unhooking a caving team member in difficulty on a rope* (1992) [36]. It is usually quicker and safer to lower a casualty to the ground, but sometimes there is no alternative to rescuing upwards. The systems described might usefully be adapted to certain rescue situations in difficult circumstances other than just those experienced in caving.

The danger of a casualty remaining suspended for more than a few minutes is recognized in European law. The so-called *Temporary Work at Height Directive* [37], which in fact is an annex to *89/655/EEC Council Directive concerning the minimum safety and health requirements for the use of work equipment by workers at work*, was formally adopted by the European Council of Ministers and European Parliament on 14 June 2001 and was published on 19 July 2001. It states in 4.4, *Specific provisions regarding the use of rope access and positioning techniques:*[58]

"(e) the work must be properly planned and supervised, so that the worker can be rescued immediately in an emergency;

(f) in accordance with Article 7, the workers concerned must receive adequate training specific to the operations envisaged, in particular rescue procedures."

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[58] *The Directive does not cover the use of fall arrest systems, so there are no requirements for these in the Directive.*

The Temporary Work at Height Directive has to be transposed into the national legislation of Member States of the European Union by 19 July 2004.

1.6 SUMMARY OF ADVICE ON PREVENTION OF SUSPENSION TRAUMA, RESCUE AND TREATMENT OF CASUALTIES

1.6.1 Prevention

The first action in helping to prevent the onset of suspension trauma is in the choice and adjustment of the harness. Before using a harness for the first time, users should carry out a suspension test in a safe place, to ensure that their harness is the correct size, has sufficient adjustment and is of an acceptable comfort level for the intended use [35, 8.3.6.2] and [38, 5.8]. A comfortable, properly adjusted harness could delay the onset of suspension trauma.

Steps should be taken to ensure as much as possible that a person using a harness will not be put in a position where they will be at serious risk of suspension trauma. There should always be a well thought-out and practised rescue plan in place appropriate to the workplace, and appropriate rescue facilities should always be on hand to enable an immediate and safe rescue should the need arise [35, 12.3.7]. Knowledge of and adherence to the following points should minimize the risk:

- Awareness that anyone who is suspended in a harness may be at risk of suspension trauma if they were to hang motionless in the harness [33].

- Awareness that suspension trauma is life threatening. Whatever the type of harness, motionless suspension is not physiologically safe and can lead to very serious blood circulation problems, including death [32].

- Awareness that anyone sustaining a head injury while on a rope is particularly at risk, especially if they lose consciousness. Casualties immobilized in a stretcher in a vertical lift or head-up position may also be at risk [32].

- Awareness of the symptoms of suspension trauma (i.e. the symptoms of pre-syncope) and precautions (see 1.6.2);

- Awareness that leaving an unconscious person suspended on a rope can cause death in less than 10 minutes [19].

- Release of a casualty from the suspended position as quickly as possible [33].

- Rope access workers and rope rescuers should not attempt long or difficult ascents (or descents) when fatigued, dehydrated, hypothermic or low on energy [32].

- Tasks should be avoided that require long periods of suspension in a harness with little support of the legs or movement of them [32].

- Workers should never be allowed to work at height alone where there is the possibility of immobile suspension, either in an emergency or otherwise [32].

- Frequent "pumping" of the legs, preferably against a firm surface will activate the muscles and reduce the risk of venous pooling. This applies to workers in a normal working

environment, e.g. rope access workers, and to conscious persons suspended after a fall [34] and [35].

- For suspended persons, the use of a footloop will alleviate pressure (and therefore pain) on parts of the body such as the waist and thighs. [19] Reducing pain could delay pre-syncopal symptoms and syncope. The footloop would also provide support to facilitate "muscle pumping".

- If possible, conscious casualties awaiting rescue who are unable to perform "muscle pumping" should arrange themselves or be arranged so that their legs are in a substantially horizontal position or with the knees elevated [35].

1.6.2 Pre-syncopal symptoms

For a person suspended in a harness, experience of any of the following symptoms should be taken to be possible pre-syncopal symptoms and steps should be taken urgently to move into a non-suspended position:

- faintness;

- breathlessness;

- sweating;

- paleness;

- hot flushes;

- increasing pulse rate and blood pressure;

- nausea;

- dizziness;

- unusually low pulse rate and blood pressure (usually occurring after the incidence of increased pulse rate;

- loss or "greying" of vision.

Unless adequate steps are taken, these conditions are likely to develop into syncope (unconsciousness).

1.6.3 Factors that can affect the degree of risk of suspension trauma

Persons suspended in a harness will be at increased risk of suspension trauma if they experience any of the following conditions:

- the inability of the person to move their legs to assist circulation;

- pain;

- dehydration;

- hypothermia;

- shock;

- fatigue;

- individuals with cardiovascular or respiratory disease.

The risk of suspension trauma to an injured person will be further increased if he or she is unconscious, as there will be no movement of the legs and therefore no muscle pumping. The risk could be exacerbated by the angle of the body in suspension: a substantially horizontal position could be of benefit. However, other factors should be borne in mind, such as possible blockage of the airway caused by the position of the head.

1.6.4 Rescue and treatment

The following points should be taken into account during the rescue and treatment of persons suspected of suffering from suspension trauma or being at risk of it:

- It is extremely important to reassure the person hanging helpless on the rope [19].

- The basic principles of trauma management must always be followed whatever the injury, namely ABC (airway, breathing, circulation as an order of priority) [31].

- Time should be spent stabilising the casualty before handling to make them more robust and less susceptible to suspension trauma. The more the casualty is suffering from hypothermia, dehydration or shock, the greater the increase in susceptibility to suspension trauma [32].

- However, in principle, the casualty should be released from the suspended position as quickly as possible [33] and should be rescued in the direction of gravity, where possible, before being stabilized and applying actual first aid measures [19].

- Vertical lifts should be avoided, wherever possible, or the time spent in a vertical lift position minimized. Casualties should assist, wherever possible, by flexing the leg muscles [32].

- Signs of pre-syncopal symptoms should be closely monitored at all times. If capable, the casualty should assist by advising the rescuer how they feel or of any changes in how they feel [32].

- *Important! The casualty must never be laid down after being rescued from the suspended position, not even in the recovery position.* The casualty should be positioned with the upper body raised, i.e. in a seated, or possibly squatting or crouched posture [6], [19], [22] and [33]. All restrictive belts and clothing should be unfastened. A doctor should be called immediately. Laying the casualty down horizontally could be life threatening. The blood that has accumulated in the legs flows abruptly into the heart creating a risk of heart failure due to overstrain [33]. However, conditions other than suspension trauma should be borne in mind, e.g. hypothermia and dehydration. See 1.8, *Discussion*, for more on these points.

- Transport the casualty with the upper body raised [19].

- Continuous monitoring of the respiration and circulation is necessary. In the event of unconsciousness, the air passages should be kept open [33] and [31].

- With the casualty in the sat-up, squatting or crouched position, the blood volume may be increased carefully; the circulatory system is stabilized with sympathomimetic drugs. Only after between 20 and 40 minutes should a more generous volume therapy (Ringer's solution) be introduced, with adjuvant diuretic administration as kidney failure is the most common complication [19].

- The possible use of digitilisation [6].

- Concomitant hypoglycaemia should be treated with higher-percentage glucose solution [19].

- Administer oxygen [19] and [31].

- The patient should be hospitalized even in cases of apparently minor symptoms, e.g. numb legs or transitory respiratory and circulatory problems. Possible delayed damage, such as kidney failure as mentioned earlier, cannot be assessed at the scene of the accident [19].

1.7 SUSPENSION TRAUMA IN A NORMAL WORKING ENVIRONMENT

It is clear from the evidence provided by the research covered in this review that any person who is suspended in an upright and motionless position is at risk of excessive venous pooling and, therefore, suspension trauma. However, evidence is not apparent of suspension trauma in a normal working environment, where workers are suspended in harnesses while working, e.g. in rope access, (as opposed to workers who are suspended motionless or relatively motionless after a fall and/or have been injured). To investigate this further, a questionnaire was prepared and placed on the website of the Industrial Rope Access Trade Association (IRATA) and members advised of it by email. IRATA has approximately 50 members and approximately 7,000 trained technicians, all of whom had access to the questionnaire. The website is not restricted to IRATA members and technicians; it is also open to the general public. Approximately 15,000 pages a week are read on the site.

If suspension trauma is a problem in a normal working environment, IRATA technicians are likely to know, as millions of hours have been spent by them suspended in harnesses. By the end of 1999, over a period of 11 years, over 5.8 million recorded hours were spent by IRATA qualified rope access technicians actually "on rope".

The questionnaire was placed on the IRATA website on or around 09 August 2001 and reminders of its existence, further requests for information and details of the symptoms of pre-syncope were emailed to members on 18 October 2001 and again on 03 December 2001. The request for information remained on the website until 31 January 2002. Not one incident of symptoms of pre-syncope or syncope had been reported at that date. Details of the questionnaire and the reminders are given in appendix B.

Direct requests for up to date information on incidents of suspension trauma resulted in one response (December 2001).[59] This was from Western Australia and occurred during rescue training, the very subject that initiated this report. Two mild cases had been seen of what was believed to be hypovolaemic shock. These cases had arisen under controlled circumstances during tower rescue training. The "casualties" were suspended by their harnesses awaiting a rescue. In each case, full body harnesses were worn, one suspended from the rear dorsal ring, the other by a lower frontal attachment. Symptoms were found as shock — cold and clammy skin and shortness of breath. This occurred after approximately ten to 15 minutes. In one case, when the casualty was brought to the ground, nausea was also experienced.

1.8 DISCUSSION

The literature reviews show that symptoms of pre-syncope occur in the vast majority of test subjects in all the research into suspension trauma. This is generally shown to be due to the effects of venous pooling. The potential serious consequences of being suspended and motionless in a harness are made clear. In some instances, syncope actually occurred during the research, despite the best efforts of the monitoring doctors to avoid it. Once syncope occurs, the result — death — is inevitable, unless the correct action is taken quickly.

In every instance, the research reviewed highlights a problem that could contribute to the onset of pre-syncope: pain caused by the body holding devices, i.e. the harnesses and belts used. For example, in Nelson's work [13] (1979), 21 of the 65 test subjects reported intense pain (34%) and 25 of the subjects reported lower body numbness (39%). In another example, [27, appendix 5 p103] (1991) "both the threatened circulatory collapse and strong pains caused by the safety harnesses[60] were observed; both symptoms led, respectively, to breaking off the hanging trials." This work also refers to earlier work by Thomas, A. et al (1982), the comments on which are worth repeating, in part, here:

"These authors emphasize that in the literature,[61] pain-induced, so called vagovasal[62] (vasodepressor) syncopes are described, which are triggered by a reflex reduction of the peripheral flow resistance in the skeleton muscle and in the splanchnic area (stomach area). They also observed that even subjects with relatively strong pain reached a hanging duration of 30 minutes without collapse, and concluded that there were highly variable tolerances of pain and tendency to collapse among individuals. Ultimately, however, they say, it is merely a question of time until vagovasal[63] syncope occurs, even in an individual tolerant of pain."

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[59] *Personal communication with Peter Ferguson, HiRise Access, Australia. Information supplied by Gary Grant, Fallright, Western Australia.*
[60] *Full body harnesses*
[61] *Of Thomas et al*
[62] *This is quoted directly from the German to English translation, but is probably a mistake and probably should say vasovagal.*
[63] *See above*

"The authors came to the conclusion that[64] a webbing strap path should be aimed at, which is as comfortable and pain-free as possible, and that following a fall into a harness, regular movement of the free-hanging legs, at best in conjunction with stepping slings,[65] can ensure an increase in venous return flow…."

The pain and its effects referred to in the examples above relate only to persons in suspension. It does not take account of the (earlier) effects of a fall, either physical or psychological. These could also have a bearing on the onset of pre-syncope and syncope, because the body is likely to be in some state of shock immediately after the fall, as the suspension period commences. Pain caused by the harness during the suspension phase of the incident would very likely exacerbate the situation and encourage the onset of syncope.

There seems to be some conflict of advice with regard to the best position for a casualty who has been suspended and is suffering from pre-syncope or syncope. It can be seen that researchers themselves strongly advise that the casualty is initially placed in a huddled position, for example sat up against a wall, possibly with the knees raised, for a period of around 20 to 40 minutes and only moved to a horizontal position gradually after this. This is to prevent a massive return of venous pooled blood to the heart, which cannot cope, and which can result in cardiac arrest due to a failure of the right ventricle. It is readers of the research (rather than the researchers themselves) who seem to have missed this point and advised or implied, rather confusingly, that the casualty should be placed in a horizontal position as soon as possible. It is possible that the researchers may have only been considering protecting against suspension trauma, while the other commentators could have been taking other aspects of rescue into account, such as protection of the airway and breathing, and the possibility of the casualty suffering from dehydration or hypothermia. A sensible approach might be that anyone in a situation where they could be liable to the onset of suspension trauma should be kept as horizontal as possible. However, someone suspected of already suffering from the condition should not be allowed to become horizontal and should be placed in the sat-up position described earlier.

There appears to be little or no evidence of occurrences of suspension trauma in a normal working environment, where workers are suspended in harnesses while working, e.g. in rope access. The questionnaire referred to in 1.7 and given in detail in appendix B resulted in not one report of experience of the symptoms, despite two reminders of the request for information. It would seem to be fair to assume from this that suspension trauma is not a problem in a normal working environment for workers in suspension. There could be two main reasons for this:

a) that workers who have to work suspended in a harness try to ensure that the harness and/or system of suspension that they use is comfortable;

b) that these workers are usually carrying out physical work, which encourages muscle pumping in the limbs and, therefore, normal return of venous blood to the heart.

Bariod and Théry (1997) [17] say: "The pathology caused by safety harnesses only occurs in the special context of a person hanging suspended and motionless."

Harnesses used for suspension are used as a tool and can be thought of as active, while harnesses used as part of a normal fall arrest system are not usually used for suspension and can be thought of as passive. Because passive harnesses are normally only used for suspension in an emergency, e.g. after a fall, the need for them to be comfortable is less obvious and quite often

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[64] *In harness design*
[65] *i.e. footloops*

overlooked or even ignored. Mattern and Reibold (1991) [27] make another valid point: "Quite often, the most comfortable position for suspension conforms little to the position following deceleration in such a harness." The pain that results from being suspended in some harnesses could be enough to encourage the onset of pre-syncopal symptoms. A suspension test before first use as advocated in BS 7985 [35 8.3.6.2] and similar to the one specified in International Standard ISO 10333-1 [38] might create a few surprises but could resolve this problem.

The use of a workseat is advocated by European legislation [37] and by the British Standard for the use of rope access methods for industrial purposes [35], where the worker is suspended for extended periods. There are different types of workseat, ranging from a simple webbing strap, a flat board with side straps to suspend it (like a child's swing) through to the more luxurious boatswain's chair type seats. Different types of seat will suit different types of work situation. While the use of a workseat is likely to increase the comfort of the user, which, indeed, is its main intention, its effect compared with being suspended in a harness in delaying the onset of suspension trauma in someone who is motionless is unclear.

It is essential that a plan and resources are in place to enable the immediate rescue of any person who becomes vulnerable to the onset of suspension trauma. If a suspended worker is injured and movement of the lower limbs is limited or if the casualty is unconscious, the evidence shows that suspension trauma is highly likely to ensue, unless immediate steps are taken to remedy the situation.

2 HARNESSES AND THEIR ATTACHMENT POINTS

2.1 INTRODUCTION

Section 2 looks at the various harness types used in fall protection systems, their attachment points for connection into the fall protection system, and the advantages and disadvantages of the position of those attachment points. Information on personal fall protection systems is given first as background information to help readers understand more fully the thinking behind the use of the various harness types. Appendix C provides additional information on fall protection philosophy.

2.2 BACKGROUND TO SOME ASPECTS OF FALL PROTECTION

On October 12, 1983, Dr M Amphoux made a presentation to the International Fall Protection Seminar in Toronto, Ontario, Canada. Entitled *Exposure of human body in falling accidents* [39], Dr Amphoux set out very clearly the reasons for the fundamental principles of some aspects of fall protection, which are to a large extent still in place nearly two decades later. He explained that the human body is not designed to tolerate unexpected falls. "The greater the drop, the greater the risk of injury. If the drop is more than two or three metres, injuries are frequently severe or fatal. Nobody may accept such a risk for workers." So, ideally, he said, collective protection equipment such as scaffolding, platforms with guard-rails, etc.,[66] where everyone may walk without fear of falling, should be used, wherever possible. But in some circumstances it was impossible to set up such systems, and everyone admitted that it was then necessary to equip workers with a body support and lanyard connected to an anchor point, "to resist shock in the event of falling."

Amphoux went on to say that, from a practical point of view, the lanyard needed to be around two metres long, so that the worker could reach to the highest point for his anchor connection. The anchor should always be above the worker, but thinking of the worst case, with the anchor at foot level, and not recommended, a fall of four metres would be possible. Falls were not always such that the worker's body would be vertical with the feet down. All positions were possible. Falling and swinging, head first, was not uncommon. As falling occurred accidentally and unexpectedly, a person could not be expected to make any effective reaction during a fall.

Finally, the evacuation of a casualty hanging by his lanyard in space could be difficult if the user lost consciousness or was in shock, either due to the accident itself, for example, by a blow to the head, or by simply being in suspension.

"So, personal equipment for protection against falls should allow the worker to fall four metres, whatever the position may be, and to wait for assistance, without increasing the consequences. The solutions we suggest are based on that maximum hypothesis."

The equipment should not cause pain, either during working or during a fall, arresting a fall or waiting for assistance. The kinetic energy developed during the fall should be dissipated without the human body absorbing a dangerous amount and "the speed acquired during the free fall

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[66] *i.e. fall prevention equipment*

must be cancelled without causing injuries through negative or positive accelerations of the body or some parts of it."

In experiments on the position of the attachment point on the harnesses, Amphoux found that a high attachment point was preferable because "it gave a better disposed suspension" and that it was "specially effective when the attachment is on the back. When the falling stops, the neck flexes forward. If the attachment point is in the front of the sternum, the neck flexes backwards and the lanyard may strike the face".

Amphoux raised the question of energy dissipation and described how the current figure of a maximum impact force of 6 kN was decided:

"The second question concerns the dissipation of kinetic energy, consequence of the 'quantity of motion' acquired during the free fall. For a fall of four metres and a clothed worker of 80 kg, that makes more than 3,000 Joules to be absorbed.

The human body's possibilities of absorption are limited, both for the complete human body and for some of the parts. Those limits are difficult to define. Data in the literature speaks more frequently of limits of tolerance to forces or pressures than to energy.

So, in practice, we measured the draw-back strength with a dynamometer between lanyard and the supporting equipment. Then we were able to compare this directly with the values measured in the same conditions at the moment of the opening of a parachute. In that moment, the strengths measured are frequently near 12 kN, without bad consequences. But parachutists are young, athletic, and have been given special training. They bale out voluntarily and have time to take the best position they learned before the opening. Rare accidents reported frequently occurred when the parachute opened with the body in an incorrect position.

The workers who fall are neither especially young nor specially trained. Moreover, they can't foresee their falling and will be stopped in any position, without essential protection of general muscular contraction learned by parachutists.

So we thought it reasonable to propose an upper limit for the acceptable maximum arrest force at 6 kN. Some experts prefer 8 kN, for technical more than physiological reasons. The probability of injuries is in direct ratio to the fixed limit, but it can't be calculated, for lack of possible tests."

Amphoux pointed out that these values were only pertinent for a worker provided with a harness, by which he meant a full body harness. The harness absorbed a large part of the energy and distributed it on important surfaces of the body. Therefore, the data were not pertinent for belts or chest harnesses. Nor would they be pertinent for harnesses that could not distribute stress sufficiently in any position of the body when the fall was arrested. For example, in a head-down fall the shoulders and shoulder straps were the most stressed, although the body would swing quickly and take up the normal position with feet down.

All the components of the harness must have both sufficient surface and sufficient strength, but at the same time localized stress on each part of the body must not exceed the injury threshold. The pelvis was the most favoured place for the part where the stress of the harness straps would be applied. However, the shoulders and thorax could endure forces of the same level, depending on the position of the body at the time of arrest of the fall, if the attachment point was high on the back. That was one of the reasons why the limit was set at 6 kN: the pelvis could endure more, probably, but the shoulders probably not. One of the reasons why attachment to a belt was rejected was because there could be unacceptable stresses on the abdomen or lumbar column.

(The maximum impact force of 6 kN is achieved by the use of energy absorbers. These are discussed in Amphoux's paper, but are considered to be outside the scope of this document and are, therefore, not mentioned further.)

Amphoux considered the point of attachment to the (full body) harness. He explained that whatever the place of attachment, the cervical column (i.e. the spine at the neck) would always be compressed. Tests carried out notably by the Japanese and the Americans on dead bodies had indicated that the resistance of the vertebrae to compression was less than to tension and that this was especially true in the most fragile part of the column, i.e. the neck. The study of parachuting and traffic accidents had shown that the neck was especially vulnerable in sudden extension, i.e. whiplash, with tragic consequences.

Amphoux continued that it would be better for the compression to be localised on the body of vertebrae and not on the posterior joints, which were too fragile. Therefore, he said, the attachment point would be better on the back than pre-sternal and should be high enough to reduce the potential neck injury. In addition, the forward flexion would be stopped by the thrust of the chin on the chest. That was why Amphoux and his colleagues strictly recommended attachment high on the back. It also protected the face from the lanyard when falling. In the case of falling head first, regaining a feet-first position would involve flexion of the head, whereas if the attachment were pre-sternal, the head would more often be projected backwards.[67] However, it was accepted that a front attachment might be preferred in a few working situations. This was only acceptable when the height of the potential fall was very short. Whatever the choice of body support, it should not be forgotten that it was only a compromise and not a guarantee of absolute security.

Although not directly connected with harness suspension, the subject of this report, but nevertheless partly relevant, it is interesting to note that in the standard *ANSI Z359.1-1992, Safety Requirements for Personal Fall Arrest Systems*, the Americans have chosen 8 kN as their maximum arrest force, rather than 6 kN as adopted in European Standards. The explanation why 8 kN was chosen by the Americans is provided in E3.1.2 in the standard and is given here:

"The 1,800 pound (8 kN) maximum arrest force criteria included in this standard is based on the following considerations. In the mid-1970s, medical information developed in France confirmed earlier United States research which observed that approximately 2,700 pounds (12 kN) is the threshold of significant injury incidence for physically fit individuals subjected to drop impacts when wearing harnesses. The French arbitrarily halved the above force and established 1,350 pounds (6 kN) as their national standard for the maximum arrest force in personal fall arrest systems. Canada's Ontario Ministry of Labor reviewed this information and elected to establish 1,800 pounds (8 kN) for the maximum arrest force. This maximum arrest force has been in effect since 1979 in the Ontario Provincial standard. Since that time, there have been no reported deaths or serious injuries associated with the arresting of accidental falls of individuals….[68] On the basis of this information, 1,800 pounds (8 kN) is considered the appropriate maximum arrest force for inclusion in this standard, where harnesses are to be used in arresting falls."

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[67] *Reviewer's note: For a harness with a pre-sternal attachment, in a headfirst fall, the direction of rotation of the body will depend on the exact position of the torso and the legs at the time of impact.*
[68] *When the standard was published in 1992*

2.3 FALL PROTECTION SYSTEMS

Sulowski, in *Fall protection systems — Classification* (1984) [40] classifies fall protection equipment into collective and personal systems. Collective systems would include, for example, work platforms and fall arrest nets, which in general terms would be described as fall prevention systems and fall arrest systems, respectively. Personal fall protection systems would include work restraint (also known as travel restriction), for example using a belt, lanyard of fixed length and an anchor (personal fall prevention system), and a full body harness, lanyard, energy absorber and anchor (personal fall arrest system). He considers that work positioning systems and rescue systems are not fall protection systems. He says:

"Due to the employment of equipment with similar generic names in all four systems (fall arrest systems, travel restriction systems, work positioning systems and height rescue systems), the work positioning system and height rescue system are sometimes mistakenly treated as fall protection systems. In fact, in neither of these two is full fall protection the purpose of the system… The work positioning system is used while the work is being done, the travel restriction system provides protection against the risk of falling, the fall arrest system stops the fall and the height rescue system is used to rescue the victim after the fall."

The European Standardization Committee (CEN) has taken a different approach to work positioning and rescue systems. While the primary function of work positioning and rescue equipment might not be to protect against a fall, it has become normal practice to incorporate a fall prevention or fall arrest function in both systems. This is recognized by the European Standards covering work positioning equipment and rescue equipment, which require static strength tests equal to those of the fall arrest equipment standards. Work positioning equipment and rescue equipment are also subjected to dynamic tests in the standards. Although the dynamic tests are less onerous than those for fall arrest equipment, the tests are nevertheless considered to be appropriate for the intended work and potential fall protection situations likely to be encountered.

Harnesses for protection against falls from a height are used in personal fall protection systems. CEN has agreed definitions for such fall protection systems [41]. At the time of writing, the definitions have not been formally adopted by CEN but are at an advanced draft stage. The definitions are unlikely to change but if they do, the changes are likely to be minimal. The definitions start with a general definition for a personal fall protection system, then go on to define more specific systems:

Personal fall protection system: assembly of components for protection against falls from a height at work when the risk of a fall exists, including at least a body-holding device connected to a reliable anchor.

NOTE. Excludes systems for professional and private sports activities.

Fall arrest system: personal fall protection system by which a fall is arrested to prevent the collision of the user with the ground or structure.

Restraint system: personal fall protection system by which a person is prevented from reaching zones where the risk of a fall exists.

NOTE. Also known as a work restraint system and a travel restriction system.

Work positioning system: personal fall protection system which enables a user to work supported in tension or suspension in such a way that a fall is prevented or restricted.

Rope access system: personal fall protection system, which uses two separately secured sub-systems, one as the means of support and the other as a safety back-up for getting to and from the place of work, and which can be used for work positioning systems.

Rescue system: personal fall protection system by which a person can carry out a rescue, rescue himself/herself or be rescued from a height or a depth by pulling, lifting or lowering.

More information on fall protection systems is given in appendix C.

2.4 HARNESS TYPES

2.4.1 General

Harnesses are body-holding devices with various functions. Harnesses for the protection of falls from a height can be divided into two basic types of use:

- fall arrest, which means to stop a fall in progress;

- fall prevention, which means to avoid the start of a fall.

Harnesses for fall prevention are further divided into two types of use:

- work positioning (including suspension and non-suspension use, i.e. in tension but not in suspension);

- work restraint (travel restriction).

Fall protection systems utilising work positioning harnesses should be designed so that a fall cannot occur, i.e. the fall is prevented. However, sometimes there are circumstances where, given an unlikely sequence of events, a fall of limited length and force could be envisaged. The standards for work positioning equipment recognize this and fix their strength requirements accordingly.

Harnesses used in rope access systems are typically work positioning harnesses. However, they can be fall arrest harnesses with an additional work-positioning function, depending on the exact nature of the system employed.

Work restraint systems simply do not allow the worker to reach zones where the risk of a fall exists, i.e. they restrict the travel of the worker, so a work restraint "harness" could be a simple belt.

Rescue harnesses are in a category of their own but have a fall prevention function.

So, the range of harnesses for protection against falls from a height can be described as follows:

- fall arrest harnesses;

- work positioning harnesses and work positioning belts;

- work restraint (travel restriction) belts;

- rescue harnesses.

Some harnesses are multi-functional, i.e. they may have been designed for a primary purpose, e.g. fall arrest, but are also designed to be suitable for additional purposes, e.g. work positioning.

2.4.2 Fall arrest harnesses

2.4.2.1 *Attachment points and angles of suspension*

Fall arrest harnesses are used primarily in personal fall arrest systems. They usually have a passive use, i.e. they are only used "in anger" when a fall occurs. They are not generally used actively as a working tool, e.g. for support, as a work positioning harness would be, except perhaps to attach the occasional piece of equipment, such as a spanner, unless they are specifically designed to be multi-functional. Fall arrest harnesses typically comprise sub-pelvic straps of webbing arranged to provide sub-pelvic support, which are linked to upper torso straps in such a way that the body will be contained and will provide an attachment point or points for connection into the fall arrest system; i.e. they are full body harnesses. Sometimes a waist belt is also incorporated. Standards for fall arrest harnesses invariably require that the attachment point is effectively above the centre of gravity of the wearer. Minimum angles of suspension are specified. This is checked during the testing of the harness on a rigid torso dummy. The test torso illustrated in figure 7 is used in the European and Australian standards, which is also used for the static strength and dynamic performance tests. The test torso used in the American and Canadian standards is different from, but similar to, the test torso in the illustration, and is used for the same tests as the CEN test torso. The ISO standard specifies both test torsos: the first for the static tests and the second for the dynamic tests. The angle of suspension test is carried out on the test torso used for the dynamic tests. The test torso in figure 7 has a mass of 100 kg. The mass of the test torso used in the American standard is 136 kg. The mass of the same test torso in the Canadian standard is 100 kg.

European Standard EN 361 [42] specifies in clause 4.2 that the fall arrest attachment point "may be placed so as to lie during use of the full body harness, above the centre of gravity, in front of the chest and/or at the back and/or at both shoulders of the wearer."

International Standard ISO 10333-1 including Amendment 1 (2002) [38] specifies in clause 4.2.2: "A fall arrest attachment element shall be positioned so that it lies either at the back of the wearer and centrally between the upper shoulder blades, or centrally at the front of the chest at approximately the height of the sternum."

American Standard ANSI Z359.1-1992 [43] specifies in clause 3.2.2.4: "The fall arrest attachment shall be located at the back (dorsal) position."

Canadian Standard CAN/CSA-Z259.10-M90 [44] specifies in clause 4.1.4: "Group A[69] harnesses shall have one D-ring for fall arrest attachment affixed to both shoulder straps at the back."

Australian/New Zealand Standard AS/NZ 1891.1:1995 [45] specifies in clause 2.2.1: "The harness shall incorporate attachment hardware for attachment to the lanyard assembly, located

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[69] *Fall arrest harnesses*
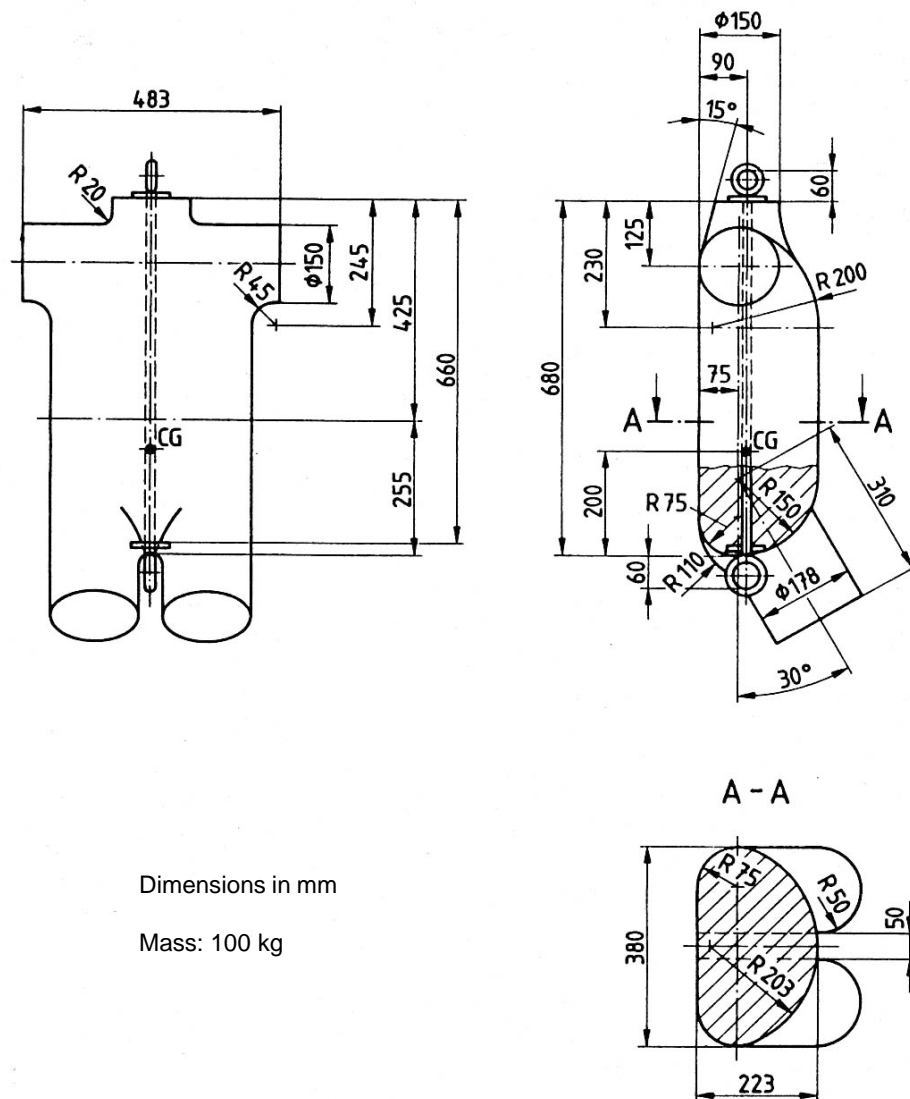
Figure 7 Example of a rigid torso dummy used in testing harnesses

in such a position that the wearer, whether conscious or unconscious, is retained in the head-up position in the event of a fall."

This last example gives a clue to the thinking behind the requirement for the high position of the attachment points. This is that it is considered to be important after a fall that the wearer of the harness is held in an upright position. Some of the standards specify the maximum angle for the torso dummy used in the static and dynamic tests. The maximum angle allowed from vertical varies depending on the standard (see figure 8 and table 6).

European Standard EN 361 [42] specifies in clause 4.4: "After each drop test the torso dummy shall be arrested in a head-up position and the angle between the longitudinal axis of the dorsal plane of the torso dummy and the vertical shall be a maximum of 50°."

International Standard ISO 10333-1+Amd 1 (2002) [38] specifies in clause 4.7.2: "At the conclusion of the test,[70] the angle formed between the back of the torso test mass and the test lanyard shall not exceed 45°."

American Standard ANSI Z359.1-1992 [43] specifies in clause 3.2.2.7: "...The angle at rest measured between the torso vertical center line and the vertical shall not exceed 30 degrees after the test torso comes to rest."

Canadian Standard CAN/CSA-Z259.10-M90 [44] specifies in clause 5.2 states: "...The angle at rest of the test weight after the feet first drop test... shall be not more than 30° when measured in accordance with Clause 6.1.2.3."

Australian/New Zealand Standard AS/NZ 1891.1:1995 [45] does not specify an angle but states in clause 4.7.2 (c): "The dummy shall remain securely suspended in the assembly, head up in the case of the fall arrest harness (i.e. head higher than torso)."

The American and Canadian standards only allow a back attachment, with a maximum angle of 30°. The ISO and European standards allow both back and front attachments, with maximum angles of 45° and 50° respectively. The Australian standard allows both front and back attachments but does not specify a maximum angle, only that the dummy must be head up. The European standard additionally allows attachment at the shoulders. With this type of attachment, the user would be suspended almost vertically, but it is rarely practicable for a fall arrest harness to use an attachment point at this position, except perhaps for confined space work. With a back attachment, the head of an unconscious person will hang forwards and with a front attachment, it will hang backwards. For more on the angle of suspension, see 3.3.9.

There are advantages and disadvantages for both front and back attachments and for both steep and shallower angles of suspension. It is not clear in any of the standards why the maximum angle requirements are what they are. It is important that standards developers assess very carefully the advantages and disadvantages before setting the requirements for the maximum angle of suspension. It is a topic that would perhaps be worthwhile being revisited by them.

2.4.2.2 *Fall phases*

There are four phases to a fall. The first is the initiation of the fall, the second is the fall itself, the third is the arrest of the fall and the fourth is the suspension phase after the fall. The attachment point on the harness plays a part in the last three of these phases. The permitted angle of suspension plays a vital role in the last two.

The orientation of the body at the initiation of the fall and during the fall itself (first and second phases) will determine which part of the body will take the first, most important, impact during the arrest (third) phase. The rotation of the body (amount and violence of swing, hyperextension and/or flexion of the neck, degree of compression on the spine, etc.) at the moment of arrest will be determined by where the attachment point is on the harness. The trajectory for the front or the back of the head towards the structure and the possible impact with it is also determined at this stage. The angle of suspension of the body, determined during testing with the test torso, will influence all the factors in this third phase.

After the fall is arrested, the fourth phase is entered: suspension. The position of the attachment point on the harness and the permitted angle of suspension influence greatly the position of the body during this phase. After the fall and its arrest, the person is likely to be suffering to some

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[70] *Dynamic test*

extent from shock, if not injury. Shock is known to contribute to the onset of suspension trauma, given the right circumstances. The person should be held in relative comfort, and ideally should be held in a position such as not to encourage suspension trauma. If only the onset of suspension trauma is considered, this position would appear to be as horizontal as possible. However, the casualty should be able to breathe easily, whether conscious or unconscious, and this could affect the desired orientation of the casualty's body. There is no point in saving a person's life by arresting the fall, only for him or her to die due to a blocked airway or from the effects of suspension trauma, either then or later.

There is another important stage to all falls: rescue. It is essential that, with any fall protection system, there is a rescue plan, resources and trained personnel in place before the work commences, and that these are assessed regularly, e.g. daily or at a change of shift. Harnesses should be chosen that would facilitate any rescue, e.g. by ensuring that there is an attachment point or points on the harness appropriate to the rescue method chosen. Examples are:

- that the attachment point is in the correct place for the rescue procedure chosen;

- that the rescuee would be in an appropriate orientation during rescue;

- that the attachment point planned to be used in any rescue is large enough for the connection of any rescue equipment planned or likely to be used, and that it is free, i.e. not being fully used for some other purpose.

2.4.2.3 *Advantages and disadvantages of attachment points on full body harnesses*

Amphoux, in his presentation given in 1983, *Exposure of human body in falling accidents* [39], stresses that the best position for the attachment point on a full body harness is at the back, above the centre of gravity. The reasons given for this are that:

- "it gives a better disposed suspension";

- the resistance of the vertebrae to compression is less than to tension and that this is especially true in the most fragile part of the column, i.e. the neck. The study of parachuting and traffic accidents has shown that the neck is especially vulnerable in sudden extension, i.e. whiplash, with tragic consequences. It would be better, therefore, for the compression to be localised on the body of vertebrae and not on the posterior joints, which are too fragile. Therefore, the attachment point is better on the back than pre-sternal and should be high enough to reduce the potential neck injury. In addition, the forward flexion would be stopped by the thrust of the chin on the chest;

- it protects the face from the lanyard when falling. In the case of falling head first, regaining a feet-first position would involve flexion of the head, whereas if the attachment were pre-sternal, the head would more often be projected backwards;[71]

- if the attachment point is in the front of the sternum, the neck flexes backwards and the lanyard may strike the face.

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[71] *Reviewer's note: For a harness with a pre-sternal attachment, in a headfirst fall, the direction of rotation of the body will depend on the exact position of the torso and the legs at the time of impact.*

The argument for using only a full body harness for fall arrest, and only with a back attachment, is given in greater detail in *Physiopathological aspects of personal equipment for protection against falls* (1982) [46].

Amphoux concedes that sometimes a front attachment might be preferred in a few working situations. This is, he says, only acceptable when the height of the potential fall is very short. He also says that the evacuation of a casualty hanging by his lanyard in space could be difficult if the user lost consciousness or was in shock, either due to the accident itself, for example, by a blow to the head, or by simply being in suspension. By this, he means the risk of suspension trauma.
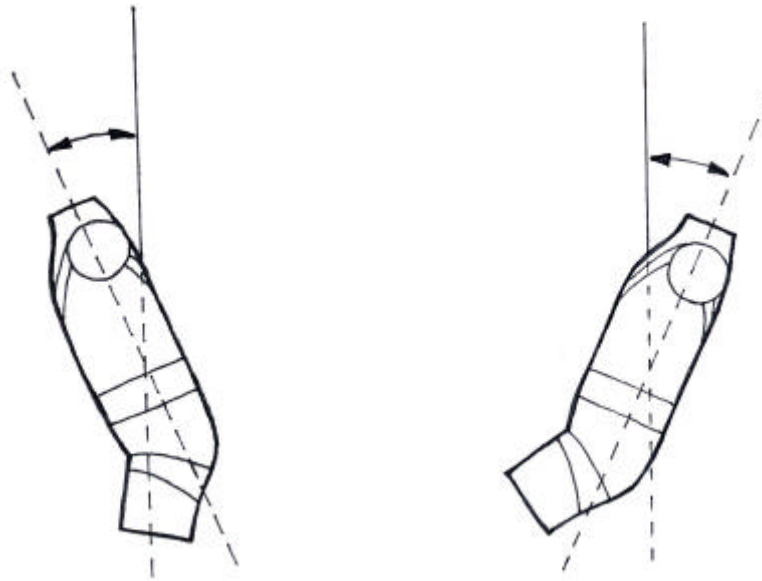
Figure 8 Measuring the angles of the test dummy in suspension

Table 6 Maximum angles and attachment point positions in full body harnesses

Standard	Max. angle °	Front	Back	Comment
AS/NZ 1891.1	---	Yes	Yes	Angle not specified: must be head up
ANSI Z359.1	30	No	Yes	
CAN/CSA-Z259.10-M90	30	No	Yes	
EN 361	50	Yes	Yes	
ISO 10333-1	45	Yes	Yes	

Amphoux also says, "it should not be forgotten that the choice of body support is only a compromise and not a guarantee of absolute security."

It is not clear whether the general insistence of a back attachment is due to a study of the effects on parachutists as the parachute opens, on people falling or on anthropomorphic dummies being dropped. An important point to consider is that an anthropomorphic dummy equates more to an unconscious person than to a conscious one. During a fall, a conscious person is likely to have the muscles tensed, and consequently there is likely to some control over movements of the body during the fall and at impact.

The insistence of a high back attachment as opposed to a pre-sternal attachment is made mainly because of the effects of whiplash (hyperextension of the neck) under the worst conditions. While it is accepted that the reduction of hyperextension is an extremely important criterion in the choice of position of the attachment point, it should be remembered that there are other criteria that should also be taken into consideration, when identifying the hazards and assessing the risks associated with the use of a full body harness. It could be more than just the height of the potential fall being very short that determines whether or not a front or back attachment would be appropriate. In some fall arrest systems, it is important that the user can connect to and disconnect from the system easily, and/or make adjustments to it, and for ergonomic reasons needs the connecting lanyard at the front. For example, the Australian Supreme Court case of Lanza v Codemo (2001) [47] highlights the importance of being able to inspect connections to attachment points. The judge in this case said "The finding I therefore make in relation to the first issue in that the harness failed to arrest the plaintiff's fall because the hook was not properly connected to the D ring, even though the plaintiff understood that to have been the case." He awarded 6.2 million Australian dollars (£2.3 million in March 2002).

In a fall with a front attachment, the worker has a visual clue as to when the impact will occur and can possibly prepare for it. This is not the case when a back attachment is used. There is always a chance, if a front attachment is used, that the worker could grab the lanyard with his or her hands at the initiation of the fall or during it (which happens frequently in falls by climbers). This reduces rotation of the body and whiplash. Grabbing the lanyard is not an option when a back attachment is used.

There is also the post-fall period to consider, in terms of comfort, susceptibility to suspension trauma, and ease of rescue. This could be either self-rescue or rescue by another person.

The perceived advantages and disadvantages of back and front attachment points for fall arrest on full body harnesses specified in the various standards are shown in tables 7 and 8.

2.4.3 Work positioning harnesses and belts

While there is a European Standard for work positioning belts, EN 358 [48], the use of a belt alone is not advised if there is any possibility of a fall (other than perhaps the tensioning of the lanyard, which in a good system of work would be no more than just a few centimetres), or if the person could be freely suspended from it, i.e. without any support from the feet. The standard allows the addition of sub-pelvic straps for support (strongly recommended by this reviewer) and of shoulder straps, which would assist in keeping the belt in place around the waist. The belt can also be incorporated into a full body harness. EN 358 does not, however, specify the sub-pelvic straps or the shoulder straps in any detail.

As a minimum for work positioning, a sit harness to EN 813 [50] would be more appropriate, particularly if combined with the extra waist support specified in EN 358. These harnesses are

not intended for fall arrest, although they are tested in a similar manner to fall arrest harnesses, with the same static strength requirements but with less onerous dynamic test requirements. The main reasons why many standards experts will not accept such harnesses for fall arrest are because of:

- the possibility of whiplash due to the front low attachment;

- the possibility in a non-feet first fall of an impact across the waist, with potentially serious injury to the spleen, liver and spine;

- the likelihood in a head-first fall of all the force being taken at the waist by the hips: the load would not be distributed through other parts of the body, e.g. the strong sub-pelvic region;

- a resulting position for a badly injured or unconscious casualty being either upside down or with the back arched and the head back, so that both head and feet are below the waist.

However, these concerns are not likely to be applicable in good work positioning systems, where the potential for a fall should at best be eliminated and at worst be restricted to very short falls of low impact force.

The attachment on a work positioning harness is typically either a single central point at about waist level (usually slightly lower than waist level), or double points (always to be used as a pair) located one at either side of the waist (at waist level) to accommodate a pole strap. In the latter, the pole strap is passed around the pole and clipped to each of the two side attachment points. It provides support as the user, feet placed on the structure, leans back against the harness.

Side attachment points should never be used singly: in the event of a slip, the body would be loaded at the side of the waist, which is an area extremely vulnerable to the injury of vital organs, and none of the load would be taken by the sub-pelvic straps. An injured person would therefore be suspended from the side of the waist; a position not recommended for comfort or survival.

Work positioning harnesses (and belts, if belts must be used) should be used in conjunction with other components, e.g. an additional lanyard connected to the structure, to add back-up security to protect against a fall. It could be appropriate to include an energy absorber, just in case there is a fall, but the method of work should ideally be designed to exclude such a possibility.

Harnesses used in work positioning are used actively, i.e. they are used as tools as well as providing protection against falls (when combined with other components). For rope access and work positioning other than perhaps pole work, the low, central, single attachment point of a sit harness is ideal, from a working point of view. The user is easily able to reach the attachment point, which is in fact the point of support, and to connect and disconnect components as required. This would be very difficult with a high (or low) back attachment. The low, front attachment point ensures that the load is distributed evenly over the sub-pelvic straps and provides a basic seat, hence the name sit harness. In the event of a slip or short fall, the load is taken on the most appropriate part of the body: the strong thighs and buttocks. Unless the casualty is in deep shock, seriously injured or unconscious, he or she will have no difficulty in maintaining an upright position. The central, front attachment point is well placed for the user to commence a swing to get back on to the structure if suspended away from it after a fall. It is also ideally placed for a single-person (snatch) rescue, more so than a higher front attachment on a full body harness and much more so than a high back attachment. The rescuer is able to be

more or less on the same level as the casualty, and close to him or her, and is thus in an ideal position to provide care and reassurance: this is vitally important in any rescue situation.

It is highly unlikely that rope access workers or any work positioning system users will ever be in a position where they are in a worst case fall situation as described by Dr Amphoux, i.e. with a potential for a four-metre fall on a two-metre lanyard. The impact forces endured by these users (bearing in mind that the system should generally be designed to prevent a fall) will be lower than such a worst case situation, and consequently, so should be the amount of whiplash. Rope access workers, in particular, already undergo substantial training and assessment in working safely. The impending new UK Work at Height Regulations, based on the European Temporary Work at Height Directive [37] should ensure that other users are trained and assessed, too. The need for a high back attachment, therefore, is perhaps not as great as it is expounded to be by Dr Amphoux and his colleagues for harnesses used in fall protection systems for rope access and work positioning.

It is interesting to note that in the rope access industry and in work positioning in general, manufacturers and users alike are turning towards using a hybrid design of harness. This is essentially a work positioning harness with its convenient, low, central attachment point, but which also has a higher front attachment point. The harness can be converted into a full body harness, i.e. a fall arrest harness, "on the fly" if the situation dictates it, or the back-up security system (e.g. the lanyard) can be permanently connected to the high attachment point.

2.4.4 Work restraint (travel restriction) belts

Belts for work retraint (sometimes referred to as travel restriction) are intended to be used to ensure that users cannot reach zones where the risk of a fall exists [41]. They should not be used for support (i.e. in tension) or in any area where there could be a fall, e.g. on a flat roof where the user could access any fragile roof assembly, including skylights. The travel restriction is accomplished by the attachment of a lanyard of appropriate length, which is connected to the belt and to a suitable anchor, so that the user is unable to enter areas of risk. Attachment to the belt is typically via a D-ring, which is connected permanently to the belt, and a connector, such as a locking karabiner, which is used to link the D-ring and the lanyard. Work positioning belts and harnesses, and full body harnesses could also be used for travel restriction.

2.4.5 Rescue harnesses

Apart from work restraint belts and, arguably, work positioning belts without sub-pelvic straps, all types of harness should be capable of being used in a rescue. Should there be need to have a harness on site dedicated to rescue, a rescue harness conforming to European Standard EN 1497 [50] could be appropriate. The attachment point for harnesses conforming to EN 1497 is specified only in terms of its opening (25 mm). The position of the attachment point on the harness and the angle in suspension on the test torso are not specified: it is recognized that both these will vary depending upon the nature and type of rescue.

Table 7 Advantages and disadvantages of a back attachment point on a full body harness

Function	Advantage	Disadvantage
For falling	Minimum (backward) whiplash effect at impact in a feet-first fall. In a feet-first fall, the head is pushed forward at impact and stopped by the chin hitting the chest: better than being pushed back into hyperextension. Minimum swing in a feet-first fall. In a properly adjusted harness, the lanyard and connector are unlikely to catch the head (either front or back) in a feet-first fall.	Large swing in a head-first fall. Possibility of hitting the front of the head against the structure in both a feet-first and a head-first fall. In an imperfectly adjusted harness, the connecting D-ring and connector may pull up during the arrest phase and make a forceful impact with the back of the head. Lanyard and connectors may catch the back of the head in a head-first fall.
For angle of suspension	Head is held forward. If unconscious, the casualty will not swallow the tongue.	Head is held forward. If casualty is unconscious, the airway may be blocked. Casualty is held at a steep angle (usually almost vertical). Usually, the geometry of the harness is such that this causes the leg-loops or thigh straps to concentrate pressure at the inside thigh and/or the groin area, which can result in considerable discomfort. This, together with possible restriction of blood vessels in the legs, steep angle, and lack of ability to move encourages venous pooling and onset of suspension trauma. A more horizontal position could be better from this point of view. Difficult to attach a footloop to the attachment point to aid comfort.
For rescue	Casualty is held at a steep angle (almost vertical). Good for vertical rescue from confined spaces. Easy for a vertical rescue using a winch.	Very difficult to self-rescue if hanging free (i.e. away from the structure) because it is difficult to begin a swing in order to reach the structure; it is difficult, if not impossible to reach the lanyard in order to attach self-rescue devices, and it is more difficult to carry out a snatch (single person) rescue, up or down.
For working	The lanyard is out of the way at the back and so will have minimum interference with the work being carried out.	It is not possible to see the attachment point and it is difficult to get to the connector to check that it is connected safely to harness and lanyard. More difficult than with a front attachment to adjust a lanyard to the optimum length, i.e. with no or little slack.

Table 8 Advantages and disadvantages of a front attachment point on a full body harness

Function	Advantage	Disadvantage
For falling	In a head-first fall at impact, the initial movement of the head is often forward (chin hits chest). The next "bounce" in the fall is backwards but is less serious, i.e. with less force than the first. Possibility of grabbing the lanyard at the initiation of a fall or during it, thus reducing rotation of the body and whiplash.	Always a head-back swing in a feet-first fall, with the possibility of hitting the back of the head against the structure. Some hyperextension of the head in a feet-first fall. Strong reversing effect after head-back swing: risk of frontal impact against the structure. Lanyard and connector could make a forceful contact with the front of the head during the arrest phase, particularly if the harness has not been adjusted correctly.
For angle of suspension	Usually more comfortable than a back attachment. Usually, the geometry of the harness allows less pressure at the inside thigh and/or groin area than with a back attachment. Easy to attach a footloop to aid comfort.	Head may be held back in an unconscious casualty. This could cause the tongue to fall back into the throat and block the airway. Although the angle of suspension is usually greater than that with a back attachment, i.e. less vertical, there is still a great risk of suspension trauma for an injured or unconscious person. An even greater angle, i.e. more horizontal, could be of benefit in this respect.
For rescue	Good for self-rescue because: easy to start a swing towards the structure; easy to attach self-rescue components to the lanyard, e.g. a footloop or an ascender. Easier and better for a rescuer/first aider to connect the rescuee to the rescuer and to administer care and attention. Easier to carry out a snatch (single person) rescue.	Not as good as a back attachment for vertical rescue from confined spaces, because person hangs less vertically.
For working	Easy to adjust a lanyard to the optimum length, i.e. with no or little slack. Easy to check that connections to the harness are correct.	Lanyard can sometimes get in the way of working.

2.5 HARNESS DESIGN FOR WOMEN

The gender of persons working at a height, where there is a requirement for fall protection equipment, is predominantly male. Consequently, harnesses are generally designed around the needs of men. However, the design, i.e. the strap configuration and range of adjustment, of many harnesses is such that they will fit females just as well as they fit males. There are exceptions. For example, where the harness design incorporates waist belt and leg loops that fasten around the thighs, the designer has to allow for the generally slimmer waists of women and for other dimensional differences. Otherwise, the waist belt will not fit in proper alignment with the waist. Some manufacturers have addressed this issue in the design of harnesses used in rope access and sport (e.g. climbing and caving) and produced harnesses especially for women. It is not clear at the time of writing whether this is so for harnesses used in other fall protection applications.

There are difficulties in designing full body (fall arrest) harnesses for women because the requirement for a high attachment point means that there has to be straps passing over the shoulders and sometimes around the chest. Pressure from these straps can be quite painful for women.

Women should consider the above issues before using a harness for the first time.

2.6 WEIGHT AND SIZE ISSUES RELATING TO FALL ARREST HARNESSES

Harnesses are usually made in sizes, e.g. small, medium, large, but are adjustable within these sizes. Typically, the harness is the right size for the user if the straps adjust sufficiently to allow the donning of the harness with sufficient overlap of the straps (i.e. the loose end of strap), after they have been correctly fastened in the buckles, and in accordance with the manufacturer's instructions. If there is insufficient overlap of strap after the buckles are correctly fastening, a larger size of harness must be chosen.

Usually, if the person is outside the size range of a manufacturer's model of harness, they are likely also to be over the 100 kg mass with which harnesses conforming to European Standards currently are tested. If either of these two situations apply, users should contact the harness manufacturer for advice.

Harnesses conforming to European Standard (EN 361) are tested dynamically with a mass of 100 kg and statically to 15 kN. Harnesses to the American Standard (ANSI Z359.1-1992) are tested dynamically with a mass of 136 kg, and statically to 22 kN (actually, 22.2 kN), and so harnesses approved to the American Standard might be appropriate for persons over 100 kg.[72] There is nothing to stop manufacturers producing harnesses to any size range they wish. However, there are a few issues for the manufacturer and test house to consider if they decide to carry out tests to European Standards with a mass greater than 100 kg:

- Will the harness fit properly on the rigid test torso, i.e. is the test torso big enough for the extra large harness?

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[72] *It is difficult to compare the two dynamic tests, as the lanyard material and drop height in the European Standard are different from the American Standard. The European Standard specifies a lanyard of 2 m length made from mountaineering rope (which is designed to absorb energy) and a 4 m drop. The American Standard specifies a lanyard made of wire rope, which has little energy absorption, and a drop height of 1.83 m (6 feet).*

- Will the additional weighting of the rigid test torso used in EN 361 (to 136 kg, for example) affect the requirement to measure the angle of suspension after the dynamic test?

- Is the static strength requirement of 15 kN high enough or should it be raised to 22 kN like the American Standard?

With regard to the 15 kN static strength requirement, there is an argument that the actual force applied to a harness depends on the energy absorber incorporated in the fall protection system. Therefore, the argument goes, if the energy absorber in any fall protection system will keep the force below the maximum allowed, a requirement for additional strength of the harness over and above 15 kN is not necessary. In the European Standard EN 355, the maximum impact force allowed for an energy absorber when tested dynamically with a 100 kg mass is 6 kN.[73] The argument concludes that if an energy absorber existed or were developed that achieved no more than this impact force when tested with a mass greater than 100 kg, a harness with a static strength of 15 kN would be sufficient. At the time of writing, the opinion of the author is that the subject needs more discussion. The difference between 6 kN and 15 kN is a safety factor to cover, for example, degradation of the materials. However, it is interesting to note that there are no *specific* requirements in the product standards that make allowance for degradation in use.

There is another important issue with regard to the heavier person, and that is comfort when suspended in the harness, e.g. after a fall. The mass of the user will influence the comfort provided by the supporting straps. The heavier the user, the greater will be the force impacted on the straps at the arrest of the fall and the greater will be the force exerted on them over a given surface area during suspension, thus affecting comfort, i.e. pain levels. Pain levels can have a bearing on the onset of suspension trauma. Therefore, harnesses suitable for the heavier person might need strap and padding dimensions to be increased to take account of this.

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[73] *The American Standard ANSI Z359.1 allows a maximum impact force of 8 kN (see 2.2).*

3 SUSPENSION REQUIREMENTS AND ADVICE IN A SELECTION OF HARNESS STANDARDS

3.1 INTRODUCTION

This section looks at the requirements dealing with harness suspension in a selection of harness standards and at any advice that these standards offer on the subject. To simplify the task, only standards written in English were chosen. The objective was to see whether the chosen standards addressed adequately the important issues of suspension in general and, in particular, the suspension phase of a fall. Eleven standards were chosen, from Australia/New Zealand, Canada, the European Union, the United States of America and the standards of the International Standards Organization (ISO). It was thought that this range of standards would be sufficient to demonstrate the approach of standards developers in general to the subject of harness suspension. A list of the standards is given in appendix D.

3.2 EXAMINATION CRITERIA

It was decided to restrict the choice of standards to those published since 1990, so that they would reflect fairly up to date thinking. The dates of publication of the standards were, in fact, from 1990 to 2002.

Of the eleven standards chosen, three were for full body harnesses only, three were for belts and full body harnesses, one was for sit harnesses and full body harnesses, one was for sit harnesses only, two were for belts only and one was for belts, sit harnesses and full body harnesses (see appendix D, table D1).

The standards were examined to see if and how they addressed the following:

- suspension test requirements. Do the standards recognize the need for the harness to be comfortable and/or appropriate for rescue?

- advice on carrying out a suspension test. Is the user encouraged to check that he/she has a harness that is adjustable, that it fits, and that it is comfortable when suspended in it?

- any advice or warnings on suspension trauma. Is the user going to be warned of the dangers of suspension trauma?

- anything in the definitions that addressed suspension issues. Do the standards recognize the issues?

- anything under design or ergonomics clauses dealing with suspension issues. Do the standards recognize the issues?

- what the minimum requirements were for support straps. The width and bulk of the support straps can make a great deal of difference to the comfort of the harness. Do the standards take account of this?

- any minimum angles from vertical given for a person when in suspension. Do the standards take into account *all* the factors regarding safety in suspension?

- the requirements for the position of the harness suspension points. How appropriate is the position of the attachment point from an ergonomic and a safety point of view?

3.3 FINDINGS AND OBSERVATIONS

Eleven standards were examined. The following is a summary of the results. More detail is given in appendix D.

3.3.1 Suspension test requirement

Only one standard required a suspension test to be carried out: ISO 10333-1.

Observation. The fact that only one standard includes a suspension test requirement would seem to indicate that the potentially serious problems associated with suspension are not generally appreciated, or that they have been overlooked or even ignored.

3.3.2 Suspension test advice

Only two standards gave advice to carry out a suspension test before first use: EN 12277 and EN 813.

Observation. This would seem to indicate that importance of a comfortable harness and the potentially serious problems associated with suspension are not generally appreciated, or that they have been overlooked or even ignored.

3.3.3 Suspension trauma advice

Two standards gave advice on suspension trauma: AS/NZS 1891:4 and CAN/CSA Z259.10-M90.

Observation. This would seem to indicate that the potentially serious problems associated with suspension are not generally known, understood or appreciated.

3.3.4 Minimum width of thigh support

Three standards specified 40 mm as the minimum width for support at the thighs: AS/NZS 1891.1, EN 361 and ISO 10333-1.

Two standards specified 41 mm: ANSI Z359.1 and CAN/CSA Z259.10-M90.

Two standards specified 43 mm: EN 12277 and EN 813.

Three standards did not specify the minimum width for support at the thighs: ANSI A10.14, ASME A39.1 and EN 358, and for one of the standards this was not applicable (NA): AS/NZS 1891.4.

Observation. The issue of comfort is more generally recognized in active harnesses than passive harnesses because active harnesses are used as a tool, i.e. for support as part of the normal

working activity. Passive harnesses, e.g. those used purely for fall arrest, are not usually used for suspension and the question of comfort, if ever they are required to support the user, is rarely considered. The mass of the user will influence the comfort provided by the supporting straps when in suspension: a heavy user is likely to experience less comfort, i.e. suffer more pain, than a lighter user (see 2.6). In the light of information provided in sections 1 and 2 of this report, harness manufacturers might now be encouraged to address these issues.

3.3.5 Minimum width of waist support

Three standards specified 40 mm as the minimum width for support at the waist: AS/NZS 1891.1, EN 361 and ISO 10333-1.

Three standards specified 41 mm: ANSI A10.14, ANSI Z359.1 and CAN/CSA Z259.10-M90.

Three standards specified 43 mm: EN 12277, EN 358 (for restraint belts) and EN 813.

One standard specified 75 mm: ASME A39.1.

One standard specified 80 mm: EN 358 (100 mm if a pad is fitted), and for one of the standards this was not applicable (NA): AS/NZS 1891.4.

Observation. The same comment as in 3.3.4 applies to this clause.

3.3.6 Minimum width of upper body support

Three standards specified 40 mm as the minimum width for support of load-bearing straps, which would include chest and shoulder straps: AS/NZS 1891.1, EN 361 and ISO 10333-1, and two standards specified 41 mm: ANSI Z359.1 and CAN/CSA Z259.10-M90.

One standard specified 43 mm for support at the chest, but only 28 mm for shoulder straps: EN 12277.

Four standards did not specify such information: ANSI A10.14, ASME A39.1, EN 358, and EN 813, and for one of the standards this was not applicable (NA): AS/NZS 1891.4.

Observation. Shoulder straps should be of a width and density to enable potential forces and support to be taken on the shoulders without causing injury to them.

3.3.7 Definitions

Seven of the eleven standards referred to suspension within the definitions. These were ANSI Z359.1, AS/NZS 1891.1, CAN/CSA Z259.10-M90, EN 12277, EN 361, EN 813 and ISO 10333-1.

Observation. The possibility of a person being suspended in a harness is addressed in those standards cited.

3.3.8 Ergonomics and design

Four standards referred to suspension in either clauses on ergonomics or in the requirements. These were ANSI A10.14, AS/NZS 1891.1, AS/NZS 1891.4 and ISO 10333-1.

Observation. The possibility of a person being suspended in a harness is addressed in those standards cited.

3.3.9 Angle of suspension

The maximum angle of the test torso is measured when the harness and test rope suspends it. The angle is usually measured between the vertical rope and an imaginary line down the centre of the back of the dummy (see figures 7 and 8). The way in which the angle is measured in the Canadian standard CAN/CSA Z259.10 is slightly different, but the result is the same. Only the standards for full body harness require the angle to be specified. One of the full body harness standards, AS/NZS 1891.1, does not specify an angle; just that the dummy must be head up.

The required maximum angle of suspension varies from standard to standard. For ANSI Z359.1 and CAN/CSA Z259.10 this is 30° when suspended from a back attachment. For EN 361, the maximum angle is 50° when suspended from either a front or back attachment. For ISO 10333-1, the maximum angle is 45° when suspended from either a front or back attachment, and 10° for the class of harnesses for confined space use.

Observation. There is more to consider when determining the angle of suspension than just being upright. A substantially horizontal position could be more appropriate to prevent the onset of suspension trauma. Greater angles either from front or back attachment (but better from the front) usually means a more comfortable suspension: steep angles typically concentrate the load around the inside thighs, usually accompanied by great discomfort. Blockage of the airway by the tongue of an unconscious person when the head is tipped backwards, or blockage caused by the head being tipped forward must also be considered.

3.3.10 Position of harness attachment points

All the belts and work positioning harnesses (sit harnesses) use front or twin side attachment points. In the case of belts, they can often be moved around the waist to provide a back attachment, if needed. Full body harnesses are different. The attachment points are either high up at the back or high up at the front. Some harness standards only allow back attachments, some allow both, and in one case, EN 12277, where only a front attachment point would be of any use, a back attachment is not even considered.

ANSI Z359.1 and CAN/CSA Z259.10 only allow a back attachment. This is influenced by the thinking of the standards committees in North America. The international standard, ISO 10333-1, allows both front and back attachment, as does the European standard, EN 361 and the Australian/New Zealand standard, AS/NZS 1891.1.

Observation. When deciding on a fall protection system, the potential for whiplash must be considered, which, in addition to the position of the harness attachment point, will also depend on factors such as length and type of fall and associated forces. However, when choosing an attachment point on a harness, the ability to effect a self-rescue or improve comfort while in suspension should also be taken into account.

4 RECOMMENDATIONS FOR FURTHER WORK

If it is true that pain can lead to or encourage the onset of pre-syncope and, therefore, syncope, there could be a good case for a study into how body-holding devices could be made more comfortable. For example, subjective and objective tests could be carried out with different types, thicknesses, widths, densities and locations of padding in the appropriate sections of harnesses. As the majority of the body weight is usually taken by the sub-pelvic and pelvic parts of the body, both during the arrest of a fall and in suspension, research could be undertaken to examine the most ergonomic designs for leg loops/thigh/waist support straps. In addition, similar work could be undertaken for the chest and shoulder sections of full body harnesses, as these also play a part in taking some of the load in a fall and in providing support after the fall. To be meaningful, the research should be carried out using human beings and <u>not</u> other animals. In any case, *the author opposes the use of animals in any of the further work proposed.*

The use of a workseat is advocated by European legislation [37] and by the British Standard for rope access [35], where the worker is suspended for extended periods. There are different types of workseat, ranging from a simple webbing seat strap, a flat board with side straps to suspend it (like a child's swing) through to the more luxurious boatswain's chair type seats. Different types of seat will suit different types of work situation. While the use of a workseat is likely to increase the comfort of the user, which, indeed, is its main intention, its effect compared with being suspended in a harness in delaying the onset of suspension trauma in someone who is motionless is unclear. Comparative suspension duration tests between various types of workseat and active and passive harnesses could assist in determining what is most appropriate for given work situations, when all aspects have been taken into consideration.

During the establishment of fall protection principles, a worse case scenario was set, using a two-metre lanyard and a fall factor of two, i.e. a fall of four metres. This resulted in severe whiplash effects, particularly, it was said, for those harnesses with a pre-sternal attachment point. Consequently, dorsal attachments became a panacea in some fall protection experts' eyes, with dorsal attachments being recommended for all fall arrest harnesses. In the case of two harness standards, dorsal attachments are mandatory for fall arrest, although this is not the case for other harness standards reviewed. While dorsal attachments may be appropriate in some circumstances, there are many work situations where they are just not appropriate for the safe and efficient functioning of the intended work. There are many work situations where the lanyard never needs to be two metres or anchored in such a way that there would be a high fall factor or long fall. In such instances, the general violence of the fall is likely to be lower and thus, presumably, so is the degree of whiplash. In these cases, a front attachment point could be justified. There could be a real benefit in establishing just how serious the impact forces and whiplash effect would be with a front attachment utilising various shorter lanyards, lower fall factors and maybe specially designed energy absorbers, and making that information visible. There could be a case for having a new category between fall arrest and fall prevention, perhaps called *limited fall arrest*, which would have well-defined limits of permitted force and distance, lower than those currently the norm for fall arrest. If a more general acceptance of front attachments were agreed, albeit with restrictions on length of fall and force, it could lead to a more comfortable suspended position, which could delay the onset of suspension trauma.

It could be of benefit if standards developers revisited the subject of the maximum angle of suspension required by the harness standards. It is important that standards developers assess very carefully the advantages and disadvantages before setting the requirements for this angle. There are more than the fall and arrest phases to consider when setting the angle. For example,

in the suspension phase, it could be more appropriate to be substantially horizontal, to delay venous pooling and the onset of suspension trauma. A more horizontal position could also be more comfortable than an upright one. The prevention of blocking the airways due to extension or flexion of the head should also be included in this proposed study.

In many cases, standards developers seem not to have addressed properly the suspension phase of a fall and its implications. There is enough evidence in this document to show that the problems exist. The requirement for a suspension test, such as that in ISO 10333-1, the requirement for manufacturers firstly to advise potential users to test the harness in suspension before first use, such as that in EN 813, and secondly to provide information on suspension trauma should be included in new standards and revisions. Standards developers should be actively encouraged to address these issues.

The correct positioning of a casualty who is suspended or who has been suspended and may be suffering from suspension trauma needs to be clarified, for the benefit of both rescuer and rescuee. The standard practice of prioritization, i.e. airway, breathing, circulation (A B C), might be correct, and so might be the avoidance of placing a casualty suffering from hypothermia in a upright position. Without doubt, there is danger in placing a casualty who has been upright and motionless in a horizontal position, e.g. the recovery position. Rescuers and first aid workers should evaluate these points and, if not already in place, a strategy should be determined and publicized.

Attention is drawn to the work of Weber and Michels-Brendel [26], in which the authors say that, using the data obtained in their work, they found it possible to predict with amazing accuracy the suspension duration for front and back attachments in harnesses. Of particular importance to the prediction was body weight, body height, shoulder width and stomach girth (see 1.3, p18). This information could be studied, perhaps developed if necessary, and then put into practice by manufacturers and standards developers. Information such as this could also be useful when carrying out any risk assessment in the work place, with regard to the selection of equipment and establishment of the rescue plan and resources.

The recommendations can be summarized as follows:

- Subjective and objective tests to be carried out to improve the comfort of all harnesses, but in particular fall arrest harnesses.

- Comparative suspension duration tests between various types of workseat and active and passive harnesses to establish the most appropriate way of being suspended in a given work situation, when all aspects have been taken into account.

- The possibility examined of introducing a new category of fall protection for short falls with a low impact force, with well-defined limits of permitted force and distance, perhaps called *limited fall arrest.*

- Standards writers to revisit the maximum angle of suspension requirement in fall arrest harness standards. If it is necessary to set such an angle, careful consideration of all the criteria to be made before doing so.

- The suspension phase of a fall to be addressed much more thoroughly in standards than at present.

- If not already in place, rescue and first aid organizations to agree and publicize a strategy for the correct positioning of suspected suspension trauma casualties, particularly those who may be suffering from hypothermia and/or dehydration.

- The work of Weber and Michels-Brendel [26] to be examined with respect to the prediction of suspension duration for front and back attachments in harnesses and, if appropriate, a guide to be produced for manufacturers and users.

APPENDICES

APPENDIX A THE CIRCULATORY SYSTEM

Section 1, Suspension trauma, refers extensively to the body's circulatory system. This annex is provided to help readers understand how and why blood is carried around the body. The information is taken from The Franklin Institute Online [51] and tpgi.com [52] websites.

On average, the body has about 5 litres of blood, which continually travels through it by way of the circulatory system. The heart, the lungs, and the blood vessels work together to form this system. The pumping of the heart forces the blood on its journey.

The body's circulatory system has three distinct parts: pulmonary circulation (the lungs), coronary circulation (the heart) and systemic circulation (the rest of the system). Each part must be working independently in order for them all to work together.

There are three varieties of blood vessels: arteries, veins and capillaries. During blood circulation, the arteries carry blood away from the heart. The capillaries connect the arteries to veins. Finally, the veins carry the blood back to the heart.

Pulmonary circulation is the movement of blood, via the blood vessels, from the heart, to the lungs, and back to the heart again.

Coronary circulation refers to the movement of blood through the tissues of the heart. The circulation of blood through the heart is just one part of the overall circulatory system. The heart is about the size of a clenched fist. It has thick muscular walls and is divided into two pumps. Each pump has two chambers. The upper, smaller, thin-walled chamber, the atrium, receives blood coming from the veins, which flows into the larger, lower chamber called the ventricle. It has thick, strong walls that contract to squeeze blood through another valve, out into the arteries. Blood from the right-side pump is dark red (bluish) and low in oxygen. It travels along pulmonary arteries to the lungs, where it receives fresh supplies of oxygen and becomes bright red. The blood then flows along the pulmonary veins back to the heart's left-side pump.

The heart then pumps the oxygenated blood out through one main artery called the dorsal aorta. The main artery then divides and branches out into many smaller arteries so that each region of the body has its own system of arteries supplying it with fresh, oxygen-rich blood.

Systemic circulation is a major part of the overall circulatory system. It supplies nourishment to all of the tissue located throughout the body, with the exception of the heart and lungs because they have their own systems.

The oxygen-rich blood of the arteries enters the capillaries where the oxygen and nutrients are released. The waste products are collected and the waste-rich blood flows into the veins in order to circulate back to the heart where pulmonary circulation will allow the exchange of gases in the lungs.

The waste-rich blood enters the heart, via the right atrium through two large veins called the venae cavae. The right atrium fills with the waste-rich blood and then contracts, pushing the blood through a one-way valve into the right ventricle. The right ventricle fills and then contracts, pushing the blood into the pulmonary artery, which leads to the lungs. In the lung capillaries, the exchange of carbon dioxide and oxygen takes place. The fresh, oxygen-rich blood enters the pulmonary veins and then returns to the heart, re-entering through the left

atrium. The oxygen-rich blood then passes through a one-way valve into the left ventricle where it exits the heart through the main artery, the aorta. The left ventricle's contraction forces the blood into the aorta and the blood begins its journey throughout the body.

The one-way valves are important for preventing any backward flow of blood. The circulatory system is like a network of one-way streets. If blood started flowing the wrong way, the blood gases (oxygen and carbon dioxide) might mix, causing a serious threat to the body.

Arteries and veins run parallel throughout the body with a web-like network of capillaries, embedded in tissue, connecting them.

Arteries are tough on the outside and smooth on the inside. An artery actually has three layers: an outer layer of tissue, a muscular middle, and an inner layer of epithelial cells. The muscle in the middle is elastic and very strong. The inner layer is very smooth so that the blood can flow easily with no obstacles in its path.

The muscular wall of the artery helps the heart pump the blood. When the heart beats, the artery expands as it fills with blood. When the heart relaxes, the artery contracts, exerting a force that it strong enough to push the blood along. This rhythm between the heart and the artery results in an efficient circulation system.

The arteries deliver the oxygen-rich blood to the capillaries, where the actual exchange of oxygen and carbon dioxide occurs. The capillaries then deliver the waste-rich blood to the veins for transport back to the lungs and heart.

Veins are similar to arteries but, because they transport blood at a lower pressure, they are not as strong as arteries. Like arteries, veins have three layers: an outer layer of tissue, muscle in the middle, and a smooth inner layer of epithelial cells. However, the layers are thinner, containing less tissue.

Veins receive blood from the capillaries after the exchange of oxygen and carbon dioxide has taken place. It is important that the waste-rich blood keeps moving in the proper direction and not be allowed to flow backward. This is accomplished by one-way valves that are located inside the veins. The vein valves are necessary to keep blood flowing toward the heart, but they are also necessary to allow blood to flow against the force of gravity. For example, blood that is returning to the heart from the foot has to be able to flow up the leg. Generally, the force of gravity would discourage that from happening. The vein valves, however, provide footholds for the blood as it climbs its way up.

Blood that flows up to the brain faces the same problem. If the blood is having a difficulty in climbing up, there could be a feeling of light-headedness and possibly even a faint. Fainting is the brain's natural request for more oxygen-rich blood. When a faint occurs, under normal circumstances the head comes down to the same level as the heart, making it easy for the blood to reach the brain quickly.

Unlike the arteries and veins, capillaries are very thin and fragile. The capillaries are actually only one epithelial cell thick. They are so thin that blood cells can only pass through them in single file. The exchange of oxygen and carbon dioxide takes place through the thin capillary wall. The red blood cells inside the capillary release their oxygen, which passes through the wall and into the surrounding tissue. The tissue releases its waste products, like carbon dioxide, which passes through the wall and into the red blood cells.

Capillaries are also involved in the body's release of excess heat. During exercise, for example, the body and blood temperature rises. To help release this excess heat, the blood delivers the heat to the capillaries, which then rapidly release it to the tissue. The result is that the skin takes on a flushed, red appearance.

During systemic circulation, blood passes through the kidneys. This phase of systemic circulation is known as renal circulation. During this phase, the kidneys filter much of the waste from the blood. Blood also passes through the small intestine during systemic circulation. This phase is known as portal circulation. During this phase, the blood from the small intestine collects in the portal vein, which passes through the liver. The liver filters sugars from the blood, storing them for later.

Besides circulating blood, the blood vessels provide two important means of measuring vital health statistics: pulse and blood pressure. The heart rate, or pulse, is measured by touching an artery. The rhythmic contraction of the artery keeps pace with the beat of the heart. Since an artery is near the surface of the skin, while the heart is deeply protected, it is easy to touch the artery and get an accurate measure of the heart's pulse.

The arteries are used to measure blood pressure because it has a higher pressure than the blood in the veins. During the test for blood pressure, a column of mercury in the measuring instrument rises and falls with the beat of the heart. The height of the column is measured in millimetres. Blood pressure is measured using two numbers. The first number, which is higher, is taken when the heart beats during the systole phase. The second number is taken when the heart relaxes during the diastole phase. Normal blood pressure ranges from 110 to 150 millimetres (as the heart beats) over 60 to 80 millimetres (as the heart relaxes). It is normal for blood pressure to increase when a person is exercising and to decrease when sleeping. If the blood pressure stays too high or too low, however, there may be a risk of heart disease.

APPENDIX B SUSPENSION TRAUMA SURVEY DETAILS

The following is the request for information and the questionnaire that was placed on the News Page of the website of the Industrial Rope Access Trade Association on or around 09 August 2001. It stayed in place until 31 January 2002:

Request for information regarding suspension trauma (also known as harness induced pathology)

Paul Seddon, an IRATA individual member, is doing some work for the HSE concerning suspension trauma.

Suspension trauma is a condition in which a person suspended in a harness can experience nausea, dizziness and associated feelings, e.g. light-headedness and hot flushes, loss of consciousness and eventually death. The condition appears mainly to affect persons who are suspended in a harness without moving.

Although the condition certainly exists in situations where the subject is told not to move or cannot move, e.g. in clinical trials or in rescue or rescue training scenarios, it is less certain that it exists in a normal working environment. If suspension trauma is a problem in a normal working environment, IRATA technicians are likely to know, as literally millions of hours have been spent by them on ropes.

If any IRATA technician or member has suffered from, or knows of any occurrence of symptoms that could be attributed to suspension trauma, it would be very helpful, and directly related to the health and safety interests of technicians, if they could let Paul have the details.

Please <u>CLICK HERE</u> for a pdf document listing the type of information that would be useful. More information on suspension trauma is given on a useful website: <u>www.cancaver.ca/int/mexico/zotz/harness-death.htm</u>

Information can be made anonymously if recalling the experience could cause embarrassment or problems in any other way. Names will not be mentioned, unless you want them to be of course.

The final report is almost sure to be made public on the HSE website, hopefully to the benefit of all.

Please email, post or fax your reply direct IRATA, for the attention of Paul Seddon.

The questionnaire (annex A) is given below:

Annex A

Experience of symptoms that could be attributed to suspension trauma

The following information could be useful to the project:

- Did the experience happen to you or to a colleague?

- If the experience happened to a colleague, what was the relationship between you? (e.g. I was his/her supervisor/workmate.)

- If the experience happened to a colleague, were you there when it happened?

- Approximate date of the incident.

- Situation. (Brief description, e.g. inspecting block of flats at about 50 m from the ground.)

- Weather (e.g. cold/hot [give approximate temperature in Celsius]; fine/raining/snowing; windy).

- Type of harness being used (sit harness, sit harness coupled with chest harness or full body harness).

- Width of harness supporting straps or make and model of harness.

- Attachment point being used (e.g. low front, as in a sit harness, high front, high back).

- Was a workseat being used?

  If so, please give a brief description, e.g. wooden seat 50 cm by 30 cm; webbing strap 80 mm wide.

- Approximately how long had you/your colleague been suspended in the same position before any of the symptoms appeared?

- What were the symptoms? (Ideally, please give them in order of occurrence, but at least please give the first symptom.)

Rescue/recovery

- What caused the symptoms to disappear? (e.g. moved position, first aid, rescue)

- How long before the symptoms disappeared?

- Did the casualty go to hospital? Was he/she admitted? For how many days/nights?

Thank you again for your help.

Please email, post or fax your reply to IRATA at:

IRATA
Association House
235 Ash Road
ALDERSHOT
GU12 4DD
ENGLAND

Fax: 01252 333 901

Email: info@irata.org

Please mark for the attention of Paul Seddon.

Reminder (1)

A reminder was sent out by email from the IRATA secretariat to all IRATA members on 18 October 2001 as follows:

"Please could I remind members about Paul Seddon's request for information on any member experiencing suspension trauma (harness induced pathology), with reference to the item on the IRATA website. Further information is attached.

Symptoms of suspension trauma include nausea, dizziness, hot flushes, unusual sweating, breathlessness, increased pulse rate and blood pressure, decreased blood pressure, faintness or fainting while suspended, usually motionless, on the rope.

Please send any information to the IRATA office for forwarding onto Paul. If you wish to provide a contact number or address, Paul could contact you for any further details, if necessary.

The research project has to be concluded by the end of November 2001, so if it is to be included, any information is now needed urgently. Any Information would be gratefully received and would help to increase the knowledge of this potentially fatal hazard."

Reminder (2)

An extension of time to complete the project was given and the reminder was again emailed to IRATA members on 03 December 2001 as follows, together with an email attachment of the original questionnaire:

"Please could I remind members about Paul Seddon's request for information on any member experiencing suspension trauma (harness induced pathology), with reference to the item on the IRATA website. Further information is attached.

Symptoms of suspension trauma include nausea, dizziness, hot flushes, unusual sweating, breathlessness, increased pulse rate and blood pressure, decreased blood pressure, faintness or fainting while suspended, usually motionless, on the rope.

Please send any information to the IRATA office for forwarding onto Paul. If you wish to provide a contact number or address, Paul could contact you for any further details, if necessary."

APPENDIX C SOME ASPECTS OF FALL PROTECTION PHILOSOPHY

This appendix explains part of the philosophy behind the definitions of fall protection systems given in 2.2.

There are two essential elements in the protection of persons working at a height. The first element is the primary support the person has and the second element is the fall protection system employed. The fall protection system chosen depends on the result of the hazard identification and risk assessment process. The following points and their footnotes will serve to explain this further.

- A typist working on the tenth floor of an office block is an example of a person working at a height. The primary support is the floor. The fall protection system is the wall around the floor, which protects the typist from reaching zones where the risk of a fall[74] exists, i.e. the edge of the building.

- When the typist moves from one floor to a lower one by the stairs, the primary support is each step of the stairs. As long as the typist maintains controlled physical contact with the steps (i.e. balance is maintained), there will not be a fall. The balustrade running down the side of the stairs provides fall protection, i.e. the second element, by preventing a fall off the side of the stairwell and by the support of the handrail.[75]

- A person working on a flat roof has the roof for primary support. The fall protection system could be the barrier around the edge of the building. Alternatively, where there is no barrier in place, a restraint or travel restriction system could be used (subject to training). Both the barrier and the restraint system do not allow the worker to reach zones where the risk of a fall exists, i.e. the edge of the roof.

- If the angle of the roof and its state of slipperiness dictates that the worker requires support from a line to prevent slipping down it, this line is the primary support. The system is no longer a restraint or travel restriction system, but is now a work positioning system. An independent safety back-up is therefore required, to provide the fall protection system, i.e. the second element.[76]

- A suspended platform is also a work positioning system. The primary support is the platform.[77] The fall protection system could be barriers around the platform, a fall arrest

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[74] *This document does not consider "falls on the level".*

[75] *The hazard of the stairs will have been identified, the risk of a fall assessed, and the risk minimized by the design of the stairs, e.g. the angle, the rise and depth of the steps, the distance between landings, height of handrail, type of balustrade etc. ("designing out at source").*

[76] *The primary support for a person in a work positioning system utilising a support line in tension is the line in tension itself, e.g. a rope access working line or a polestrap. The second element of the system, i.e. the fall protection system, is the safety back-up, which is additional to the line in tension. This could be, for example, a short lanyard with no slack (i.e. for preventing a fall) a safety line as used in a rope access system (where there may be a limited fall), or a fall arrest system (where the consequences of a fall are mitigated). In the majority of cases, the fall protection system will only come into play if the support line or the connections to it fail. An example of an exception is where a pole worker loses control of his balance against the pole and he and his pole strap slip down it.*

[77] *Depending on the risk (severity and consequences) and the number of people involved, it may be necessary to provide protection in case of total failure of the primary support system (so-called redundancy within the system).*

safety line connecting the worker to the platform or, if practicable, a safety line to each of the workers connected independently of the platform.[78]

- If the work positioning system is properly erected and secured scaffolding, the primary support is the scaffold platform, e.g. the scaffold boards (working platform). The fall protection system is the guard-rail around the scaffolding, but could be extended to include a fall restraint system connected to the structure and the person, or a fall arrest system.

- The primary support for someone, e.g. a steel rigger or fixer, working in a situation where, if they lose controlled physical contact with the structure, they will fall, is the structure itself. The second element of the system (the fall protection system) is the fall arrest system. This will only come into play if the user loses controlled physical contact with the structure.

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[78] *The use of a safety line would also require the use of a body holding device (a harness), an energy absorber and a reliable anchor. It would also require due consideration of the required clearance distance beneath the user, so that in the case of a fall there would be no collision with the ground or other obstacle in the fall path.*

APPENDIX D HARNESS SUSPENSION IN STANDARDS

Appendix D provides details of the standards chosen for examination in section 3 of this report. Section 3 looks at how standards deal with the issues surrounding suspension in harnesses, particularly the post-arrest phase of a fall, or after an injury. Table D1 gives the numbers and titles of the chosen standards. Table D2 gives details of the findings of the examination.

Table D1 Numbers and titles of standards used in section 3

Standard number	Nationality of standard	Title
EN 12277:1998	European	Mountaineering equipment — harnesses — Safety requirements and test methods
ASME A39.1:1991+ A39.1a-1993	American	Safety requirements for window cleaning
ANSI Z359.1-1992	American	Safety Requirements for Personal Fall Arrest Systems, Subsystems and Components
ANSI A10.14-1991	American	American National Standard for Construction and Demolition Operations — Requirements for safety belts, harnesses etc for construction and demolition use
CAN/CSA Z259.10-M90	Canadian	Full Body Harnesses
AS/NZS 1891.1:1995	Australian/ New Zealand	Industrial fall-arrest systems and devices Part 1: Safety belts and harnesses
AS/NZS 1891.4:2000	Australian/ New Zealand	Industrial fall-arrest systems and devices Part 4: Selection , use and maintenance
EN 813:1997	European	Sit harnesses
EN 358:2000	European	Personal protective equipment for work positioning and prevention of falls from a height — Belts for work positioning and restraint and work positioning lanyards
ISO 10333-1: 2000/AMD 1: 2002	International	Personal fall arrest systems — Part 1: Full body harnesses
EN 361:2002	European	Personal protective equipment against falls from a height — Full body harnesses

Table D2 Suspension requirements and advice in selected harness standards

Number	Suspension test requirement	Advice to carry out a suspension test	Advice or warnings on suspension trauma	Minimum width of support at thighs (mm)	Minimum width of support at waist (mm)	Minimum width of support at chest (mm)	Definitions	Ergonomics/ design	Maximum angle of suspension(°) and Front (F) and/or back (B) attachment
ANSI A10.14-1991	No	No	No	No	41	No	No	5.1.4 Classification for use. Positioning and suspension belts are used for suspension or support.	No B
ANSI Z359.1-1992	No	No	No	41	41	41	2.9 body support. …straps suitably arranged to support the human body during and after fall arrest. (No mention of term body support in definition for full body harness and no mention of post-fall support.)	No	30 B
AS/NZS 1891.1: 1995	No	No	No, but see AS/NZS 1891.4 Part 4: 2000, Selection , use and maintenance	40	40	40	1.3.20 Sit harness: a work positioning harness designed to suspend the wearer in a sitting position.	2.2.1 The fall arrest harness shall incorporate attachment hardware…located in such a position that a wearer, whether conscious or unconscious, is retained in the head-up position in the event of a fall. 2.2.2 The work positioning harness shall incorporate attachment hardware…located in such a position that a conscious person is retained in the head-up after a restrained fall or a limited free fall.	No Head-up F B

Number	Suspension test requirement	Advice to carry out a suspension test	Advice or warnings on suspension trauma	Minimum width of support at thighs (mm)	Minimum width of support at waist (mm)	Minimum width of support at chest (mm)	Definitions	Ergonomics/ design	Maximum angle of suspension(°) and Front (F) and/or back (B) attachment
AS/NZS 1891.4: 2000	No	No	Yes. Appendix A, Suspension trauma. Four paragraphs warn of the dangers and possible preventative action.	NA	NA	NA	No	2.1.6 Rescue provisions: …Provision for rescue should reflect an awareness that a person can only be suspended in a harness for a short period after sustaining a fall. 4.1.2 (iv) Fall arrest harness… Ability to spread the load of a fall arrest on the wearer's body and provide a measure of comfort whilst the wearer is suspended after a fall.	See AS/NZS 1891.1: 1995
ASME A39.1: 1991 + A39.1a-1993	No	No	No	No	75	No	No	No	No
CAN/ CSA Z259.10-M90	No	No	Yes. Appendix A:A5.2 (a) Prolonged static suspension can cause some circulatory problems leading to a possible loss of consciousness.	41	41	41	2.1 … designed to support the user during and after the arrest of an accidental fall and/or during a rescue operation.	No	30 B

Number	Suspension test requirement	Advice to carry out a suspension test	Advice or warnings on suspension trauma	Minimum width of support at thighs (mm)	Minimum width of support at waist (mm)	Minimum width of support at chest (mm)	Definitions	Ergonomics/ design	Maximum angle of suspension(°) and Front (F) and/or back (B) attachment
EN 12277: 1998	No	Yes	No	43	43	43	3.1 harness. …Textile elements…which fit around the body to support it in a hanging position. 3.1.1 full body harness. …This type of harness will support an unconscious person in a head-up position. 3.1.3 sit harness. … Waist belt and …sub-pelvic support… to support a conscious person in a sitting position.	No	No
EN 358: 2000	No	No	No	No	[79]	No	No	No	No
EN 361: 2002	No	No	No	40	40	40	3.1 body support primarily for fall arrest purposes…straps…suitably arranged…to support the whole body of a person and to retrain the wearer during a fall and after the arrest of a fall.	No	50 F B

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[79] WP = work positioning (80 mm if no pad. If a pad is fitted: 100 mm). R = restraint (43 mm)

Number	Suspension test requirement	Advice to carry out a suspension test	Advice or warnings on suspension trauma	Minimum width of support at thighs (mm)	Minimum width of support at waist (mm)	Minimum width of support at chest (mm)	Definitions	Ergonomics/ design	Maximum angle of suspension(°) and Front (F) and/or back (B) attachment
EN 813: 1997	No	Yes	No	43	43	No	3.5 An arrangement of straps…waist belt with…connecting support encircling each leg suitably arranged to support the body of a conscious person in a sitting position.	No	No F
ISO 10333-1: 2000/ AMD 1: 2002	Yes	No	No	40	40	40	3.2.1 personal fall-arrest system: system designed…and to maintain the fallen person in a suitable post-fall attitude.	4.2.2 Class A full body harnesses are designed to support the body during and after the arrest of a fall. 4.3.1 The purpose of a full body harness is to contain the body and to suitably distribute the dynamic fall-arrest forces and post fall-arrest suspension forces over the body. The full body harness shall not create any supplementary risk and shall offer an acceptable degree of comfort.	45 F B 10 for Class AE (confined space)

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GLOSSARY OF MEDICAL TERMS AND DEFINITIONS

The terms and definitions in this glossary are taken or adapted from the Concise Oxford Dictionary (1), the Concise Oxford Medical Dictionary (2) or another source, e.g. a website (3), as indicated by the number in parentheses.

acidosis (metabolic)	condition in which the acidity of body fluids is abnormally high (2)
agglutinates	adhered cells or bacteria (1)
alveolar hypoventilation	See hypoventilation. Alveolar hypoventilation: may be primary, which is very rare, or secondary, which can be due to destructive lesions of the brain or due to an acquired blunting of respiratory drive arising from failure of the respiratory pump (2)
alveoli	blind-ended air sacs in the lungs of microscopic size (2)
anoxia	condition in which the tissues of the body receive inadequate amounts of oxygen (2)
arrhythmia	any deviation from the normal rhythm (sinus rhythm) of the heart (2) (alternative name: dysrhythmia)
arteriole	small branch of an artery leading into many smaller blood vessels, i.e. the capillaries (2)
atrium	cavity in the body, especially one of the two upper cavities of the heart receiving blood from the veins (adj: atrial) (1)
autonomic nervous system	part of the nervous system responsible for the control of bodily functions that are not consciously directed, including regular beating of the heart, intestinal movements, sweating, salivation, etc, which is subdivided into sympathetic and parasympathetic nervous systems (2)
axilla	armpit (1)
baroreceptor (baroceptor)	collection of sensory nerve endings specialized to monitor changes in blood pressure (2)
brachial	of or relating to the arm (1)
bradycardia	abnormally slow heart action (1)
cardiogram	a record of muscle activity within the heart, made by a cardiograph (1)
cardiograph	an instrument for recording heart muscle activity (1)
cardiovascular	of or relating to the heart and blood vessels (1)

catecholamines	group of physiologically important substances including adrenaline, noradrenaline and dopamine, having various different roles (mainly as neurotransmitters) in the functioning of the sympathetic and central nervous systems (2) (which prepare the body to meet emergencies such as fatigue, cold or shock)
cerebral ischaemia	inadequate flow of blood to the brain (2)
coma	state of unrousable unconsciousness (2)
cyanosis	bluish discoloration of the skin and mucous membranes resulting from an inadequate amount of oxygen in the blood (2)
cytoplasm	jelly-like substance that surrounds the nucleus of a cell (2)
diaphoresis	process of sweating, especially excessive sweating (2)
diastole	period between two contractions of the heart when the heart muscle relaxes and allows the chambers to fill with blood (2) (see systole)
diastolic blood pressure	pressure of blood against the walls of the main arteries when the ventricles are relaxing and refilling (2) (which is the time of lowest pressure in the cardiac cycle) (see systolic blood pressure)
digitalisation	administration of the drug digitalis or one of its purified derivatives to a patient with heart failure until the optimum level has been reached in the heart tissues, which may take several days (2)
disseminated intravascular coagulation	condition resulting from overstimulation of the blood-clotting mechanisms in response to disease or injury, which results in generalized blood coagulation and excessive consumption of coagulation factors (2) (scattered clotting within the blood vessels)
diuretic	causing increased output of urine (1)
dorsalis pedis artery	artery of the foot, which passes forward from the ankle-joint to the first intermetatarsal space (i.e. in the foot) where it divides into two branches (3)
dysrhythmia	See arrhythmia
electrocardiogram	recording of the electrical activity of the heart on a moving paper strip by means of an apparatus called an electrocardiograph (2)
electroencephalogram	recording of the electrical activity of the brain into a tracing (2)
encephalograph	instrument for recording the electrical activity of the brain (1)
endorphins	one of a group of chemical compounds that occur naturally in the brain and have pain relieving properties similar to those of opiates; also responsible for sensations of pleasure (2)

endothelium	single layer of cells lining the blood vessels, heart and lymphatic vessels (2)
extrathoracic	outside or beyond the body cavity between the neck and the diaphragm (3)
femoral	of or relating to the thigh or to the femur (2) e.g. femoral artery: artery running down the outside of the femur
fibrin	final product of the process of blood coagulation, produced by the action of the enzyme thrombin on a soluble precursor fibrinogen (2)
glomerulus	network of blood capillaries contained within the cup-like end of a nephron; the site of primary filtration of waste products from the blood into the kidney (renal) tubule (2)
histology	study of the structure of tissues by means of special staining techniques combined with light and electrical microscopy (2)
hyperextension	extension of a joint or limb beyond its normal limit (2)
hyperventilation	breathing at an abnormally rapid rate at rest, which causes a reduction of carbon dioxide concentration of arterial blood, leading to dizziness, tingling (paraesthesiae) in the lips and limbs, tetanic (spasmic) cramps in the hands and tightness across the chest, and if continued may cause loss of consciousness (2)
hypocapnia	condition in which there is an abnormally low concentration of carbon dioxide in the blood, which may be caused by breathing that is exceptionally deep in relation to the physical activity of the individual (2)
hypoglycaemic coma	coma caused by a deficiency of glucose in the bloodstream (1)
hypotension	condition in which the arterial blood pressure is abnormally low (2)
hypothermia	accidental reduction of body temperature below the normal range in the absence of protective reflex actions such as shivering (2)
hypotonia	state of reduced tension in muscle (2)
hypoventilation	breathing at an abnormally shallow and slow rate, which results in an increased concentration of carbon dioxide in the blood (2)
hypovolaemia	decrease in the volume of circulating blood (2)
hypoxia	deficiency of oxygen in the body tissues (2)
hypoxidosis	acute oxygen deficiency (3)
ischaemia	inadequate flow of blood to a part of the body (2)

MAST	Medical anti-shock trousers, which are wrapped around the legs and lower torso and then inflated to a pressure of 60 - 100 Hg in an attempt to squeeze fluid into the upper body and control blood loss in the lower body (3)
mechanoreceptor	sensory receptor that responds to mechanical stimuli such as touch or sound (1)
necrobiosis	gradual process by which cells lose their function and die (2)
necrosis	death of cells caused by disease, physical or chemical injury, or interference with the blood supply (2)
nephrology	branch of medicine concerned with the study, investigation and management of diseases of the kidney (2)
nephron	active unit of excretion in the kidneys (2)
neurogenic	1. caused by disease or dysfunction of the nervous system 2. arising in the nervous tissue 3. caused by nervous stimulation (2)
oedema	condition characterized by an excess of watery fluid collecting in the cavities or tissues of the body (1)
orthostasis	upright posture (3)
orthostatic	relating to the upright position of the body: used when describing this posture or a condition caused by it (2)
paraesthesiae	spontaneously occurring abnormal tingling sensations (2)
parasympathetic	relating to one of the two divisions of the autonomic nervous system, having fibres that leave the central nervous system from the brain and the lower portion of the spinal cord and are distributed to blood vessels, glands and the majority of internal organs (2) (see also: sympathetic)
pathogen	micro-organism, such as a bacterium, that parasitizes an animal (or plant) or man and produces a disease (2)
pathogenesis or pathogeny	manner of development of a disease (1)
pathogenetic	manner of development of a disease (1)
pathogenic	capable of causing disease; applied to a parasitic micro-organism (especially a bacterium) in relation to its host (2)
pathology	study of disease processes with the aim of understanding their nature and causes (2)
pre-syncope	symptoms warning of impending syncope (3)

renal tubule	fine tubular part of a nephron, through which water and certain dissolved substances are reabsorbed back into the blood (2)
Ringer's solution	clear, colourless solution of sodium chloride, potassium chloride and calcium chloride prepared with recently boiled water (2) (widely used, intravenously, in the initial resuscitation of an injured person)
shock	condition associated with circulatory collapse, when the arterial blood pressure is too low to maintain an adequate supply of blood to the tissues (2)
splanchnic	relating to the viscera (2)
stasis	inactivity; stagnation; a cessation of flow (e.g. blood) (2)
supine	lying on the back or face upwards (2)
sympathetic	relating to one of the two divisions of the autonomic nervous system, having fibres that leave the central nervous system, via a chain of ganglia close to the spinal cord, in the thoracic and lumbar regions (2) (see also: parasympathetic)
sympathoadrenal	relating to effects of the responses of the sympathetic nerves and associated catecholamines (3)
sympathomimetic	drug that has the effect of stimulating the sympathetic nervous system (2) (and which mimics at least part of adrenalin or catecholamine responses)
syncope	loss of consciousness induced by a temporarily insufficient flow of blood to the brain (2) (fainting)
syndrome	combination of signs and/or symptoms that forms a distinct clinical picture indicative of a particular disorder (2)
systole	period of the cardiac cycle when the heart contracts (2) (i.e. when blood is pumped into the arteries)
systolic blood pressure	pressure of blood against the walls of the main arteries when the ventricles are contracting (2) (which is the time of highest pressure in the cardiac cycle) (see diastolic blood pressure)
tachycardia	abnormally rapid heart rate (1)
vacuole	space within the cytoplasm of a cell, formed by infolding of the cell membrane, that contains material taken in by the cell (2)
vago	prefix denoting the vagus nerve (2)
vagus nerve	tenth cranial nerve, which supplies motor nerve fibres to the muscles of swallowing and parasympathetic fibres to the heart and organs of the chest cavity and abdomen (2)

vaso   prefix denoting vessels, especially blood vessels (2)

vasodilatation   increase in the diameter of blood vessels, especially arteries (2)

vasovagal   relating to the action of impulses in the vagus nerve on the heart and fall in blood pressure (2)

vasovagal attack   excessive activity of the vagus nerve, causing slowing of the heart and a fall in blood pressure, which leads to fainting (syncope) (2)

venous pooling   accumulation of blood in the veins (of the legs) due to gravity and lack of muscular pumping (3)

ventricular   relating to either of the two lower chambers of the heart or to one of the four fluid-filled cavities within the brain (2)

viscera   organs within the body cavities, especially the organs of the abdomen cavities, e.g. stomach, intestines, etc. (2)