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REVIEW

Cardiovascular risk in high-hazard occupations: the role of occupational cardiology

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Work is beneficial for health, but many individuals develop cardiovascular disease (CVD) during their working lives. Occupational cardiology is an emerging field that combines traditional cardiology sub-specialisms with prevention and risk management unique to specific employment characteristics and conditions. In some occupational settings incapacitation through CVD has the potential to be catastrophic due to the nature of work and/or the working environment. These are often termed 'hazardous' or 'high-hazard' occupations. Consequently, many organizations that employ individuals in high-hazard roles undertake pre-employment medicals and periodic medical examinations to screen for CVD. The identification of CVD that exceeds predefined employer (or regulatory body) risk thresholds can result in occupational restriction, or disqualification, which may be temporary or permanent. This article will review the evidence related to occupational cardiology for several high-hazard occupations related to aviation and space, diving, high altitude, emergency workers, commercial transportation, and the military. The article will focus on environmental risk, screening, surveillance, and risk management for the prevention of events precipitated by CVD. Occupational cardiology is a challenging field that requires a broad understanding of general cardiology, environmental, and occupational medicine principles. There is a current lack of consensus and contemporary evidence which requires further research. Provision of evidence-based, but individualized, risk stratification and treatment plans is required from specialists that understand the complex interaction between work and the cardiovascular system. There is a current lack of consensus and contemporary evidence in occupational cardiology and further research is required.

Keywords Occupational cardiology • Hazardous occupations • Sudden Cardiac Death • Primary prevention • Risk stratification • Aviation medicine

Introduction

Occupational cardiology is an emerging field[1] that combines traditional cardiology sub-specialties with prevention and risk management unique to specific employment characteristics and conditions. While the best interests and optimum clinical care of the patient remain paramount, there is also a responsibility to advise the risk holder (the employer) who often has a duty of care to the employee, but also other employees and the public.[2] Consequently, many organizations that employ individuals in high-hazard roles undertake initial medicals and periodic medical examinations (PME) to screen for cardiovascular disease (CVD). In parallel, employers should inform employees on factors that may increase cardiovascular risk related to their high-hazard roles.

Many individuals develop CVD during their working lives. Work has been shown to be beneficial for health; a concept known as the 'healthy worker effect' which may bias epidemiological research when comparing workers to a general population.[3] This beneficial effect may be due to improved access to healthcare, routine disease screening, increased physical exercise, or psychosocial benefits.[4] However, in some occupational settings, incapacitation through CVD has the potential to be catastrophic due to the nature of work and/or the working environment. These are often termed 'hazardous' or 'high-hazard' occupations. By morbidity and mortality the most

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hazardous occupations are commercial fishing, construction, agriculture, mining, and work in the oil and gas industry.[5] The morbidity and mortality in these roles are largely related to the potential for falls, the use of heavy dangerous machinery, transportation of workers, noise and vibration, noxious chemicals, and exposure to adverse weather conditions. All of these may occur remote from developed healthcare facilities, which compounds the risk, but arguably may not directly induce or exacerbate CVD. For the purposes of this article high-hazard roles are defined as: 'where incapacitation may particularly endanger employees, co-workers and/or the general public'. This definition is aligned with the 'safety-sensitive' occupations label adopted by the American College of Occupational and Environmental Medicine.[6]

In high-hazard occupations, risk assessment (and prevention) often starts with pre-employment screening to identify occult CVD or to risk-assess known CVD. Employees may undergo further periodical examination and risk assessment, contextualized to the specific hazardous nature of their occupation. The identification of CVD that exceeds predefined employer (or regulatory body) risk thresholds can result in occupational restriction, or disqualification, which may be temporary or permanent. Occupational risk assessment incorporates the clinical condition and treatment, the likelihood of a distracting and/or incapacitating event, and the potential consequence in a given occupational role.[7] However, data on occupation-specific risks of cardiovascular incapacitation in otherwise asymptomatic individuals are limited, and there is a tension between sensitive identification of cardiac pathology and the risk of potentially 'career-ending' false-positive results. This article will review the evidence related to occupational cardiology for high-hazard occupations, focusing on environmental risk, screening, surveillance, and risk management for the prevention of events precipitated by CVD. Where applicable we highlight the mechanisms of increased cardiovascular risk to high-hazard employees and employers to provide the opportunity for worker education and prevention.

Methods

A search of electronic databases including PubMed and Web of Knowledge as well as directly from appropriate academic journals was conducted using terms: (hazard* OR 'safety sensitive') AND (work OR occupation*) AND ((cardiovascular OR cardiac OR heart) AND disease) to ascertain the evidence base for hazardous occupations. We identified potential evidence of an increased risk of CVD and death from heart disease in several hazardous occupations including fishing, construction, logging, and mining;[8–11] however, we opted to select hazardous occupations where CVD has the potential to impact the safety of the employee and/or others and the employer has a duty to manage these risks. This mapped broadly to high altitude, aviation and space, diving, emergency services, the military, and commercial transportation. Further searches for these specific occupational roles were undertaken. The selected occupations encompassed most safety-sensitive roles and published evidence.

High-hazard occupations and the cardiovascular system

Pilots and aircrew

Aircraft loss attributed to CVD in pilots is rare and pilot incapacitation in-flight is uncommon. However, events do occur where pilot incapacitation results in aircraft accidents and fatalities.[12] As a result of these rare events screening for CVD and its risk factors remain essential components of licensing requirements to ensure air safety.[12] When considering occupational limitations in aircrew the usual acceptable risk of incapacitation for dual-pilot commercial flying is based on the so-called '1% rule' where the maximum acceptable risk of pilot incapacitation is less than 1% per year.[13] The 1% rule has limitations however[14] and the concept of acceptable risk in commercial aviation continues to be debated with proposed risk limits ranging from 0.5 to 2% per year.[15] Additional requirements for older pilots have attracted added controversy.[12] While studies demonstrate an age-dependent risk of pilot incapacitation, this needs to be balanced against the value of experience as a significant factor in reducing accident risk.[16] The International Civil Aviation Organization (ICAO) sets the minimum standards for pilot licensure, but additionally, individual agencies guide commercial pilots, including the Federal Aviation Authority (FAA) in the USA, the European Union Aviation Safety Agency (EASA) in Europe, and the Civil Aviation Authority (CAA) in the UK.[17] Despite recent efforts to unify standards to improve consensus in cardiovascular risk assessment,[11] diverse approaches exist to evaluate a pilot's risk of CVD events. Requirements to report medical conditions to authorities are also variable across regulatory jurisdictions.

There appear to be no long-term detrimental effects on cardiovascular health in commercial pilots who carry passengers in a multi-crew, dry, contained environment, usually pressurized at the equivalent of 5000–8000 feet (1500–2400 m) terrestrial altitude, allowing a tolerable degree of hypoxia.[15] Pilots demonstrate age-standardized mean BMI and hypertension similar to the highest income quintile of the general population, while obesity and smoking prevalence are significantly lower.[18] This translates to a lower risk of cardiovascular mortality despite the prevalence of coronary artery disease (CAD) being the same as age-matched controls.[19]

Most commercial transport pilots fly in dual/multi-crew environments; however, rotary (helicopter) pilots, recreational pilots, and military fast jet pilots, often operate single-seat aircraft and the latter (plus those performing aerobatics) may need to perform under intense physiological challenge (both from sustained acceleration and a hypobaric/hypoxic environment). Sustained acceleration (or *G*), experienced in flight, is a centrifugal gravitational force that is most often applied to the vertical (*z*) axis of the body. It can be either positive (head to foot) or negative (foot to head).[15] Positive G_z (greater than the usual terrestrial $+1G_z$) places strain on the cardiovascular system (*Figure 1*) and reduces the hydrostatic pressure required to maintain vital cerebral and coronary perfusion. Altered G_z, and the rapid transition from positive to negative G_z (or negative to positive G_z), can exacerbate sympathetically mediated dysrhythmias and cause transient reflex hypotension with subsequent deleterious effect on the $+G_z$ tolerance. This can increase the likelihood of G-induced loss of consciousness. These physiological challenges mean that optimal coronary flow, ventricular pump function, and valve behaviour are even more important to competent performance than when operating under normal gravitational conditions and oxygen partial pressures.

Astronauts

Whilst astronauts sustain analogous physiological stressors as pilots, particularly on take-off, there is less requirement to control the vehicle in comparison to fixed-wing pilots. Contemporary data demonstrate similar rates of CVD in astronauts compared to the general population,[21] with no reported deaths during space flight secondary to CVD. However, there is evidence that space exploration increases the lifetime risk of CVD, with cosmic radiation being the highest risk to astronaut health on extended space exploration missions beyond the Earth's magnetosphere.[22]

Figure 1 (Right) Chest radiographs of a chimpanzee undergoing centrifuge testing at +1, +2, +4, and +6 Gz; mediastinal elongation with topographic changes (Fischer[20]). (left) Australian aerobatic pilot Paul Bennet flying his Wolf Pitts Pro biplane VH-PVB with exposure to significant G.

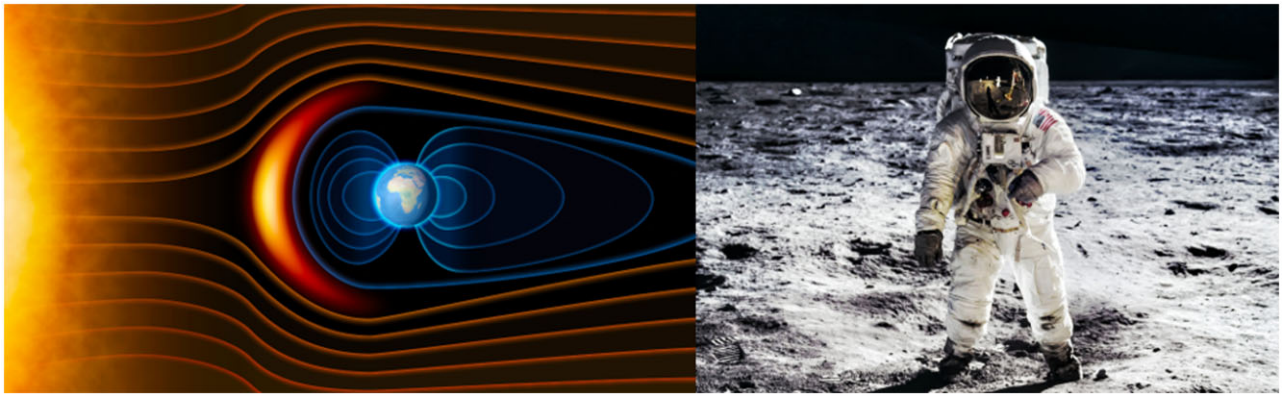

Figure 2 (Left) A graphic of the Van Allen Belts. A Van Allen radiation belt is a zone of magnetically trapped, highly energetic charged particles which originated from solar wind and galactic cosmic rays. They surround the Earth at an altitude of 500–58 000 km. Galactic cosmic radiation is composed of protons and high-energy heavy ions which are effective in inducing biological damage. The Van Allen Belts work as a magnetic shield for Earth and missions in low-Earth orbit. Currently only the Apollo astronauts (right) have left low-Earth orbit with exposure 100–300 times higher than the normal background exposure on Earth.[23]

Missions to low-Earth orbit, such as to the International Space Station, are largely shielded from cosmic radiation due to Earth's Van Allen belts (*Figure 2*); energetic charged particles that are held by the planet's magnetosphere. Missions beyond low earth orbit, such as a return to the Moon, or a manned mission to Mars would result in a much greater dose of radiation.[24] From a cardiovascular perspective, radiation-induced CVD may result in coronary artery disease (CAD) (secondary to vascular endothelial damage, accelerated inflammation, and age-dependent atherogenesis[25]) hypertension, valvular heart disease, cardiomyopathy, conduction abnormalities, and pericarditis.[26] The risk of radiation-induced CVD significantly increases at radiation doses beyond 0.5 Gray (the estimated dose range for a manned mission to Mars[27]); although adverse effects may occur at lower doses.[28]There has been a reported increased CVD mortality for the 24 Apollo astronauts who flew beyond low earth orbit, compared with astronauts who participated only in low-Earth orbit missions, who were recruited but never flew, and the age-matched US population.[22] Confidence in the significance of these findings is limited by the small sample size.

Other effects of space flight on the cardiovascular system include the sedentary nature of microgravity[29,30] although deleterious effects of this appear to be ameliorated by daily physical activity programmes.[31,32] Spaceflight also has several other physiological effects on the cardiovascular system included reduced demand on baroreflex response and reduced total blood volume.[32–34] This diminishes astronaut's orthostatic tolerance on return to 1 G due to reduced venous return and cardiac stroke volume from reduced plasma volume, insufficient peripheral vasoconstriction,[35] and impaired cerebral autoregulation,[36] which is often accompanied by vasovagal synope.[37] With the advent of commercial space travel and 'space tourism', it is likely that the occupational management of astronauts will increase over the next decades.

Divers

Diving places unique strains on the cardiovascular system including exercise, changes in pressure (hyperbaric), cold, and psychological stress of submersion, coupled with a safety-associated limited capability to rapidly withdraw from the environment. Immersion increases central venous pressure due to augmented venous return, with resultant diuresis. Cold exposure, combined with an increase in oxygen partial pressure, increases peripheral and coronary vasoconstriction and left ventricular afterload. Cold and breath-holding can result in bradyarrhythmias.[38] Acute changes in physiology have been identified immediately following a single dive exposure, with an increase in systolic pulmonary arterial pressure and a decrease in right ventricular ejection fraction.[39]

As a diver descends and breathes gas, the body tissues become saturated with dissolved nitrogen. As the diver ascends, the sum of the gas tensions in the tissue may exceed the ambient pressure and lead to free gas in the form of bubbles. Gas bubbles often present in the venous circulation due to low pressure and high gas tension. Where there is a communication between the right and left heart, such as a patent foramen ovale (PFO) or atrial septal defect, there is the potential for right to left shunts resulting in paradoxical air emboli and severe neurological decompression sickness (DCS). Right–left heart shunting of gas bubbles may be increased by straining and Valsalva manoeuvres (*Figure 3*). There is a strong association between PFO, and acute, severe DCS, with a relative risk (RR) of DCS of between 2.5 and 5.5.[40] Baseline screening for PFO is not usually conducted due to the low incidence of decompression sickness (less than 5 in 10 000 dives), despite high prevalence of PFOs (25% of the population[41]). Closure of a PFO, whether identified incidentally or following DCS, may enable some patients to return to diving but is associated with an increased likelihood of developing atrial arrhythmia.[42] Some have advocated that divers with asymptomatic PFOs should not be routinely considered for closure and the diver should instead be counselled to dive conservatively (avoiding decompression diving, and not diving to the limits of their computer's tables or decompression algorithms). Rarely, a diver with a known PFO and no history of DCS who plans to participate in expedition-level dives involving extensive decompression may request closure in advance of these dives.[43]

Sustained diving is associated with both hypertension and ischaemic heart disease, with an increased prevalence of self-reported hypertension in divers who omitted a dive-free day after 3 days of diving, compared with those who rarely violated these regulations (28% vs. 18%, RR 1.47).[44] The prevalence of ischaemic heart disease has been shown to increase in divers with >150 professional dives/year, compared with <50/year (11% vs. 4%, RR 2.91), whilst the prevalence of myocardial infarction (MI)/angina increases in divers with >2000 dives in total compared to divers with <2000 dives (16% vs. 3%, RR 5.05).[44] Divers should be made aware of the adverse long-term cardiovascular effects of diving to address classical cardiovascular risk factors. It has been advocated that hypertensive divers (blood pressure > 160/100 mmHg) require blood pressure (BP) management prior to diving and hypertensive divers should be assessed for cardiac ischaemia or dysfunction as well as dive with an increased margin of safety to lower the risk of DCS.[43] However, there is little evidence to support screening for cardiac disease in recreational, military, or commercial divers and screening recommendations vary among organizations.[40] Some (Divers Alert Network, Undersea and Hyperbaric Medical Society) recommend exercise stress testing for all potential divers older than 40 years, while others (e.g. South Pacific Underwater Medicine Society) reserve such testing for divers over 45 years, or anyone with significant risk factors for CAD. The British Subaqua club recommends exercise stress testing for divers with cardiac symptoms and in asymptomatic patients with cardiac risk factors.[40] In April 2016, the Association of Diving Contractors International (ADCI) consensus[45] guidelines began recommending annual cardiovascular risk stratification of commercial divers using the Framingham Risk Score (FRS). This has been found to reclassify intermediate-risk divers as low risk so prolonging the careers of divers while limiting the need for additional testing and adverse operational impact.[45]

UK Royal Naval divers require a physical examination, a BP <140/80 mmHg, an exercise tolerance test, and an ECG at the initial recruitment. The identification of any organic CVD renders the candidate permanently medically unfit to dive. History or evidence of myocardial ischaemia, even if treated by angioplasty or coronary artery bypass grafting, remains a bar to continued professional diving. Abnormalities found

Figure 3 (right) Complications due to diving include barotrauma and decompression sickness. Pulmonary barotrauma can lead to arterial gas embolism. Right-to-left shunt in divers increases the risk of paradoxical air emboli with resultant severe decompression sickness. Recompression in a hyperbaric oxygen chamber (left) is the gold standard for treatment of both decompression sickness and arterial gas embolism. The administration of pure oxygen displaces inert gases (primarily nitrogen) from the lungs and increases the oxygen and nitrogen gradients between the lungs and other tissues. This increased gradient enhances the removal of nitrogen from the tissues.

on cardiovascular examination, such as murmurs or ECG findings, must be investigated before a decision on fitness is made.[46] In the German Navy a diving examination consists of the individual medical history, a physical examination, and the assessment of the cardiovascular fitness by ECG and bicycle ergometry.[47] An argument for increased testing in professional divers is the occurrence of sudden death in cardiac patients caused by the 'autonomic conflict'. By submersion in cold water both the sympathetic nervous system is activated by the 'cold shock response' and the parasympathetic nervous system by the 'diving response'. This may lead to a high incidence of arrhythmias in healthy volunteers, and possibly lethal arrhythmias in cardiac patients.[48] Patients with significant ventricular arrhythmias or exercise-induced arrhythmias should undergo cardiac stress testing before being permitted to dive. Among patients with congenital long QT syndrome (particularly LQTS type 1), swimming or diving can induce potentially fatal ventricular arrhythmias.[49–51]

Mountaineers

Mountaineers face multiple physiological challenges to the cardiovascular and pulmonary systems due to the environment. These include reduced barometric pressure and subsequent hypobaric hypoxia, exercise, dehydration, change in diet and metabolism, thermal stress, hypothermia, exposure to increased UV radiation as well as the emotional stress which accompanies physical danger (falls, avalanche), or conflict. These factors may exacerbate known or occult CVD[52] with poor outcomes more likely due to remoteness from advanced medical care.

At high altitude, hypoxia is the main physiological stressor (*Figure 4*). During exercise at altitude, significant reductions in peripheral oxyhaemoglobin concentration (SpO2) are observed due to reduced partial pressure of oxygen and limitations in maximal pulmonary diffusing capacity. High pulmonary artery pressure occurs due to hypoxic pulmonary vasoconstriction, which increases right ventricular work. There is also increased cardiac contractility of the left ventricle (with increased left ventricle apical twist, tachycardia, and increased cardiac output, with consequent increased myocardial workload.[55–58] Resting and exertional arterial adrenaline levels are also higher than at sea-level.[59] This, in addition

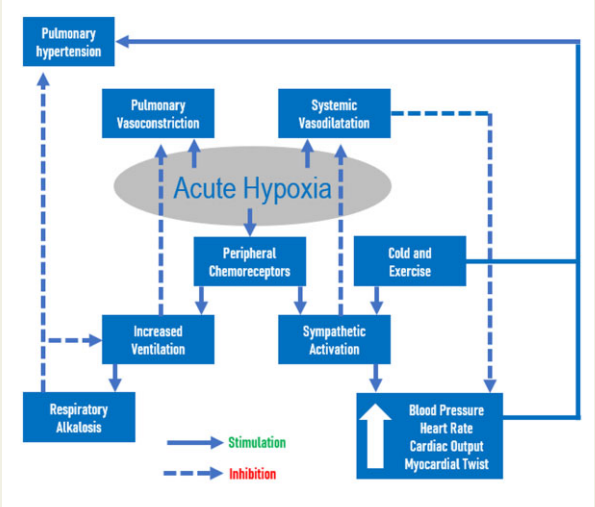

Figure 4 The effects of acute hypoxia on systemic and pulmonary circulation (adapted from Bartsch and Gibbs[53])

to the respiratory alkalosis that occurs, may further predispose to palpitations, arrhythmias, and ischaemia, especially in those with pre-existing cardiac disease.[52]

One study reported that 10% of fatalities while trekking in Nepal are due to CVD.[60] Mortality rates in mountaineers have been reported to be 0.6 per 100 participants with SCD incidences of 1–10 per million person-days activity.[61] In addition, syncope of unknown cause is a significant problem on arrival at altitude and is inversely related to arterial oxygen saturation.[52] Death rates increase with increasing altitude[61] although this is potentially confounded by reduced access to emergency care.[62]

In a study of 16 participants who underwent implantable loop recorder implantation prior to a Himalayan summit attempt (8167 m), significant rhythm abnormalities were observed in 9 of 16 subjects (56.3%) at high altitude. Arrhythmias included rapid atrial fibrillation and supraventricular tachycardia. Pauses >3 s were identified in 53% in subjects at >4800 m. The pauses increased with altitude and with the duration of altitude exposure and were thought to be related to increased nocturnal vagal tone and sleep-disordered breathing.[63] Acute altitude exposure has also been reported to induce a rise in arterial BP in normotensive and hypertensive mountaineers which was evident in ambulatory conditions but particularly at night and during exercise.[59,64,65]

No screening is currently mandated for healthy mountaineers although some have advocated for graded exercise testing in older adults.[52] Exercise testing in hypoxic conditions has been shown to be a more sensitive tool to identify asymptomatic CAD than exercise testing in normoxia.[56] Recently, evidenced recommendations for assessment of individuals with cardiovascular conditions who plan exposure to altitude have been suggested, with proposals on when and how to ascend to altitude.[66] It has been suggested that hypoxia training, intermittent interval hypoxic training, and altitude pre-exposure may improve adaptation to exercise and work under hypobaric hypoxia.[66]

Emergency workers

The occupational risk for emergency services employees is dependent on the employee role. Environmental factors include thermal stress (heavy clothing and personal protective equipment), noxious gases and chemicals (carbon monoxide and other toxic chemicals), exertion (heavy lifting, running), and the emotional demand of roles in the acute response environment. This is exacerbated by the impact of periods of sedentary work,[67] and the known deleterious effect of 24-h shift work on cardiovascular health.[68]

The risk of CV death in firefighters is similar to the general population.[69] However, one might expect a lower incidence of CV death in firefighters secondary to the healthy worker effect and increased cardiorespiratory fitness.[70] Cardiovascular disease remains the most common cause for firefighter death while on duty; a trend that has increased over the last two decades,[71] with MI and SCD accounting for 45% of deaths among firefighters on active duty.[72] Levels of SCD in firefighters are akin to sport-related SCD in the general population, although higher than those seen in athletes.[73] The incidence of SCD in firefighters is lower for those performing low-risk duties [information ratio (IR) 11.0/100 000 person-years, 95% confidence interval (CI) 8.9–13.7] compared with high-risk duties, (IR 38.3/100 000 person-years, 95% CI 31.5–46.6).[74] Sudden cardiac death, from CAD, occurs disproportionately during fire suppression activities (*Figure 5*), despite representing 1–5% of firefighter's occupational time, as compared to firefighters engaged in non-emergency activities [odds ratio (OR) 12.1–136].[72]

Figure 5 Sudden cardiac death from coronary artery disease, occurs disproportionately during fire suppression activities (right and left), despite representing 1–5% of firefighter's occupational time, as compared to firefighters engaged in non-emergency activities. Exposure to extreme heat and physical exertion during fire suppression activates platelets, increases thrombus formation, impairs vascular function, and promotes myocardial ischaemia and injury in healthy firefighters.[54]

Few studies have reported levels of CVD in emergency healthcare workers. While doctors[75] and nurses[76] may have lower levels of CVD than that of the general population, work-related exposures may exacerbate existing CVD particularly during the COVID-19 pandemic.[76] In a US study on emergency medical services, 18% of on-duty deaths of paramedics were as a result of cardiovascular incidents over 6-years of follow-up.[77] A further study has shown that 48% of paramedics were at high or very high risk of CVD with tobacco use, hypertension, and high cholesterol reported in 19%, 13%, and 31% of individuals, respectively.[78]

Among law enforcement personnel there appears to be an increased cardiovascular risk compared with the general population in many,[79–82] but not all[83] studies. As for firefighters, one might anticipate a lower incidence compared to the general population. Compared with the public, diabetes appears to be less prevalent in active-duty police officers[84] normalizing on retirement.[85] Police officers (both active and retired) have higher cholesterol[84–86] and are more obese[87,88] although have a comparative prevalence of hypertension.[82,84,85] Historically, high levels of smoking among law enforcement personnel have been reported, though levels now appear to be reducing.[89] There is potentially a role for education in cardiovascular risk in emergency workers; however, it is unclear if the risk is as pronounced outside of the US where many studies have been based.

Commercial drivers

Incapacitation while driving potentially endangers the driver, passengers, and other road users. Multiple studies have shown increased cardiovascular risk factors in professional drivers[90–93] which appears to be common to many countries. An increased incidence of hypertension[94–96] obesity[96–98] diabetes and dyslipidaemia[91,97,99,100] has been described in bus drivers, which in one study was related to the number of miles driven and hours spent behind the wheel.[101] Several studies have indicated that arrhythmia is a common cause of sudden driver incapacity[102,103] although others have suggested that drivers who suffered incapacitation related to CVD at the wheel did not cause serious harm to the general public.[104,105] Potential reasons for a relatively low incidence of crashes resulting from arrhythmia or SCD include there being sufficient time for the driver to recognize illness and slow or stop the vehicle prior to incapacitation and the high proportion of journeys in urban areas at relatively low speed.[106]

While the cardiovascular risk is possibly explained by shift work and long working hours[91,107,108] and associated sedentary behaviours, other studies have described the role of stress[99,100] and pollution.[109] Other factors include cabin ergonomics, violence from passengers, traffic congestion, inflexible running time schedules, intermittent heavy exertion (changing tires, loading/unloading cargo), and poor social support.[91,107,110,111] In a questionnaire study of 1650 drivers those with high over-commitment scores (measured using a psychological model of effort-reward imbalance) had an increased risk for CVD (not including hypertensive disease) [hazard ratio (HR) 1.27, 95% CI 1.05, 1.54] and ischaemic heart disease (HR 1.32, 95% CI 1.05–1.65).[112] The association between particulate urban air pollution and MI is well established.[113–115] A study has reported an exposure–response relation between the highest average exposure intensity during the work history and the risk of MI[116] with a reported incidence of coronary heart disease in bus and tram drivers up to 3 times higher than for other occupational groups.[99]

In the UK, all initial Group 2 licence (heavy goods vehicle and bus) applications require a medical assessment by a registered medical practitioner with a systematic approach that specifically asks about potential disqualifying medical conditions. There is an annual risk tolerance for cardiovascular events of 2%, compared with 20% for standard road users. The same assessment is required again at 45 years of age and on any subsequent reapplication, with recommendations for further testing based on the information supplied at the time of assessment. The driver has a legal requirement to declare medical conditions to the UK driver and vehicle licensing authority and the practitioner can break confidentiality in the interests of public safety if the driver has not declared the condition.[117]

Coronary artery disease risk screening of commercial drivers is recommended using validated risk scores to initiate aggressive risk factor management or additional cardiac testing. The United States Preventive Services Task Force (USPSTF) concluded that screening asymptomatic individuals in certain high-risk occupations, such as commercial drivers,

could be recommended based on the possible benefit to public safety. However, the USPSTF also cited insufficient evidence to recommend for, or against, routine cardiac stress testing of asymptomatic commercial drivers with CVD risk factors.[17] The American College of Cardiology and American Heart Association Guidelines for exercise testing similarly noted that there are insufficient data to justify routine treadmill stress testing although 'evaluations are done for statutory reasons' in some cases.[118] While the commercial driver's licence does not restrict work activity, drivers need to be able to display the ability to perform reasonable exertion to be certified. Completion of Stage II (>6 METS) of the standard Bruce treadmill protocol, equivalent to lifting heavy objects of 50 lbs or more, is considered sufficient for a commercial driver to perform job-related tasks.[119]

Military

The military encompasses many high-hazard occupations already covered. There are military divers and pilots as well as service personnel who will be regularly or intermittently be exposed to extremes of physical exertion, high altitude, and/or the cardiovascular complications of heat illness.[120] However, military populations are heavily skewed toward younger males.[121] Accordingly, CVD prevalence in the military is significantly lower than that of the general population.[17,121,122] As in the general population, age is the predominant determinant of CVD risk.[121] While in younger service personnel SCD is more commonly attributed to genetic, electrophysiological, or congenital structural cardiac abnormalities, in those over the age of 35 years, atherosclerotic CAD predominates.[123] The reported SCD rate in US military recruits is approximately 13 per 100 000 recruit years[124] which is perhaps high for a young fit cohort.[121] The leading autopsy findings were anomalous coronary artery origins (31.0%), structurally normal hearts [also known as the sudden arrhythmic death syndrome (SADS)] (34.9%), myocarditis (10.3%), and hypertrophic cardiomyopathy (HCM) (6.3%). Deaths throughout the US Armed Forces (not exclusively in recruits), demonstrated an overall mortality rate of 5.9 per 100 000 service years and a higher rate in males compared with females.[125] The most frequent autopsy findings in the <35-year cohort were SADS (41.3%), CAD (23.2%), HCM (12.8%), myocarditis (5.7%), and anomalous coronary arteries (4.0%). The incidence of death in the US military secondary to CAD for those <35 years of age is 0.65 per 100 000 service years, 13.69 in those >35 years of age, and 83.5 in those >50 years.[126] In the UK Armed Forces, CAD remains the most common cause of SCD and is the most frequent cause of cardiovascular medical discharge from service.[122]

ECG screening has been adopted by the UK Armed Forces at entry following a study in which 2.6% of individuals screened were found to have one or more conditions associated with SCD. However, approximately half of these personnel had conditions which would not necessarily have been identified on ECG.[127] A retrospective review of 126 atraumatic deaths of 6.3 million military recruits aged 18–35 years of age demonstrated that coronary artery abnormalities, including anomalous coronary origins, were the predominant structural cardiac abnormality (61%).[124] A cardiovascular risk factor assessment is performed in the UK Armed Forces at the age of 40 and has been performed in the US Army[128] with a subsequent opportunity for risk factor modification and management.

Initial screening, surveillance, and risk management in high-hazard occupations

Different employers use a variety of clinical assessments both prior to employment and then at PME. The level of scrutiny and periodicity of assessment is variable and depends on role, risk threshold, and (often statutory) regulatory frameworks. Screening, surveillance, and risk management of CVD in high-hazard occupations is commonly performed using a history and physical examination, a validated measurement of cardiovascular risk factors, a resting ECG, and an objective measure of cardiorespiratory fitness.[129]

The history remains central to the occupational cardiology consultation, however, the focus from an occupational perspective is not only on a diagnosis *per se* but also on how the diagnosis, symptoms, and (any) treatment might impact the patient's ability to perform their work within an acceptable risk envelope. Furthermore, consideration must be made of what impact their work could have on disease progression. In many occupations, history taking by a clinician is substituted by a health questionnaire, although evidence suggests these have a low predictive value in detecting adverse future health and occupational outcomes.[130] Physical examination may be required but examination alone cannot be relied upon, especially to elicit mild disease in asymptomatic participants, given the low detection rate for occupationally relevant disease in this setting.[130] Risk prediction models include the Framingham risk score, the Reynolds risk score, and QRISK scores[131] which are used to identify whether individuals in the general population are at high risk (≥20%) of developing (10 years) CVD and consequently could benefit from primary prevention. They have been used in bus drivers,[91] pilots,[18] astronauts,[132] divers, astronauts,[132] divers,[45] and firefighters[133] although their utility in occupational assessment has been questioned.[134]

ECGs are often used in high-hazard occupational assessments, even in the absence of symptoms, particularly in aviation and the military, although this practice is not common place for commercial drivers or divers.[135] The utility of ECG screening in the detection of occult cardiac disease is debatable. Screening at entry is intended to identify undiagnosed inherited cardiac conditions. This appears to be relatively effective in the screening of athletes, with the ECG being shown to be 5 times more sensitive than the history alone, and 10 times more sensitive than the physical exam[136] with a false positive rate of 6%, (lower than for either history or exam). ECG screening is not without secondary risk but has demonstrated a survival benefit in at least one setting, though this finding has not yet been replicated in other studies.[137] As workers age, the predominant focus of CVD detection shifts to occult coronary atheroma. This bimodal age distribution is often reflected in ECG schedules for high-hazard professions with an ECG performed on entry followed by a long period with no ECG and then progressively more frequent testing with increasing age.[135] Asymptomatic personnel with resting ECG abnormalities have a 2- to 10-fold increased risk of coronary heart disease compared with those with a normal ECG.[138–140] While the presence of ECG abnormalities increases the adjusted relative risk for cardiovascular mortality and morbidity by 1.5- to 2.5-fold,[140] the utility of these findings for screening is limited, with studies reporting that a resting ECG adds little to standard CVD risk scores.[141]

Several occupations, such as the military and fire service, use an objective measure of cardiovascular fitness. The Physical Assessment Test (PAT) attempts to simulate the physical requirements essential for firefighting duties. The PAT, which is endorsed by major Fire Service organizations, has been reported to elicit approximately 73% of maximal oxygen uptake and 90% of maximal heart rate.[142] Like the pre-placement examination, PAT components and requirements are usually predetermined by a regulatory body or recommended by private groups that have convened expert panels.[143] The PAT is not used instead of, but rather in addition to, a medical examination to determine medical clearance.[129] Many PME (fire services and aviation) involve an annual measure of lipids, blood pressure, and anthropometric data.[14]

Given the limitation of the resting ECG to detect occult CAD, many organizations that employ high-hazard workers use sub-maximal or maximal exercise testing (with or without ECG), at various age intervals, for

the assessment of their workers.[135] Most occupational exercise testing is performed without an ECG with a view to assessing the minimal required exercise tolerance. The Chester step test (CST), is an adaptable and inexpensive sub-maximal, multistage test, where heart rate and exertion levels are monitored continuously.[144] The test is halted when the subject reaches 80% of their maximum estimated heart rate and/or an Rating of Perceived Exertion (RPE) of 14 on Borg's 6–20 scale and can be used with varied step heights. It can be used to predict maximal aerobic power (VO_2max) and has been utilized widely in Britain, Europe, USA, and Asia, for divers, fire crew, ambulance workers, police, prison officers, and in offshore and wind farm industries.[144,145] For the UK fire service an aerobic capacity of 42.3 mLO_2/kg/min predicted from CST is required for operational duties.[144] Other sub-maximal tests include the Astrand-Rhyming nomogram cycle ergometer protocol, the American College of Sports Medicine protocols for cycle ergometry and treadmill, and the Canadian standardized step test of fitness.[145]

Screening exercise ECGs are often used to predict increased risk of coronary events and cardiac deaths. Contrary to the evidence in diagnosing obstructive CAD, the evidence for risk prediction is equivocal in men, with a predictive value only evident at 7- to 10-years follow-up[146,147] but not at 20 years follow-up.[148] In contrast, women with impaired median exercise capacity and heart rate recovery, have been shown to have a 3.5-fold increased risk of cardiovascular death (95% CI 1.57–7.86) compared with those above the median for both variables.[148] The presence of a high exercise capacity regardless of symptoms and ECG changes confers an excellent prognosis, even in the presence of significant CAD,[70,138–140] outperforming risk assessment based on smoking, hypertension, history of diabetes, left ventricular hypertrophy, history of heart failure, history of myocardial infarction, ST-segment depression, body mass index, and cholesterol. Each additional MET (1 MET metabolic activity at rest) is associated with a 12% increase in survival.[70] The exercise ECG also has a useful role in the diagnosis of rate-related left bundle branch block, and other conduction abnormalities; demonstrating suppression (or exacerbation) of ventricular ectopy, exercise-induced tachyarrhythmias, shortening of QTc on exertion (or examining the QTc post-exercise), risk stratification and in 'enhanced cardiovascular assessment' of older workers (particularly men) in whom the pre-test probability of CAD is higher.[135] The role of exercise ECG testing or graded exercise testing is heavily dependent on the employee age, risk factors, symptoms, and their occupational role.

Further assessment and the role of cardiovascular imaging

Abnormalities found at the PME, even if mild, often lead to the occupational restriction, particularly in pilots, while further investigations take place. Cardiac imaging is often utilized when ECG and/or exercise testing are equivocal, or further risk stratification reassurance is required. Cardiac imaging plays a central role in the diagnosis and monitoring of cardiac disease and enables more evidence-based risk stratification of high-hazard employees. Where concerns are raised at pre-employment assessment, advanced imaging techniques can be used to ensure optimal diagnostic specificity so as not to unnecessarily exclude applicants from employment based on a false-positive result. Cardiovascular imaging techniques include echocardiography [standard transthoracic (TTE), exercise stress, or transoesophageal], cardiac CT [coronary artery calcium scoring (CACS) and CT coronary angiography (CTCA)], cardiovascular magnetic resonance (CMR) imaging, and perfusion imaging (perfusion CMR or nuclear myocardial perfusion scintigraphy).

Transthoracic echocardiography is often used as a first-line investigation (with exercise ECG and 24 h Holter) in those with abnormal resting ECGs, or incidental murmurs (which are relatively common in young, working-age adults). Transthoracic echocardiography is the gold standard test for the initial assessment of valve disease, however, for the exclusion of cardiomyopathy, CMR is also increasingly used due to its ability to accurately measure cardiac function, visualize both ventricles and characterize tissue, even at an early stage. In a study of military aircrew comparing standard care (history, examination, exercise ECG, 24 h Holter, and TTE) with those undergoing a CMR in addition, a normal TTE did not reliably exclude abnormalities subsequently detected by CMR. The addition of CMR resulted in an upgraded occupational status in 62% of those investigated, with 37% returning to unrestricted duties, so supporting the role of CMR in providing accurate diagnoses and risk assessment in high-hazard occupations.[149]

In some high-hazard occupations, such as aircrew, the detection of a high burden of atheromatous plaque (even if non-obstructive) will lead to the occupational restriction, as it is often the rupture or erosion of these (non-flow-limiting) lesions that cause acute symptoms in this younger cohort. For this reason, an anatomical test is often preferred. CACS is a proven independent CAD risk marker, providing improved patient-specific diagnostic and prognostic accuracy over traditional CAD risk factors alone[70] with increasing scores strongly associated with a higher incidence of major adverse cardiovascular events.[70,150] In the US, while the National Fire Protection Association (NFPA) has suggested 12 METS as the minimum capacity required for safe firefighting, the Los Angeles County Fire Department, refers asymptomatic firefighters with abnormal maximal treadmill tests for CACS with a follow-on CT coronary angiogram (CTCA) depending on the Agatston score. Current National Aeronautics and Space Administration (NASA) guidelines, established with the assistance of a committee of national experts, include a CACS to determine the suitability of astronaut applicants.[136,137] However, a zero CACS is not necessarily reassuring in a younger cohort, despite being associated with very low CHD event rates (0.1%/year) at a whole population level.[150] CACS does not identify non-calcified plaques, which predominate in younger individuals. Even these younger individuals, when risk stratified, may have an event risk that exceeds regulatory limits. CTCA can provide a comprehensive non-invasive assessment of the coronary arteries, accurately detecting—or excluding—both calcified and non-calcified plaque disease,[151] as well as high-risk features such as positive remodelling.[152] A normal CTCA (no plaque and zero CACS) confers a CV event rate of <1% over 7 years of follow-up even among symptomatic patients.[150] In a study of aircrew, 5% of patients referred for a CTCA and CACS had an Agatston score less than 10 but had at least 50% stenosis on CTCA.[153] The choice of test to assess for CAD depends on exactly what question is being asked and in what occupational context. Additional investigation is often considered in individuals over the age of 40, with abnormal exercise ECG, or other findings that suggest an increased risk of occupationally relevant CAD.

Managing uncertainty and access to occupationally informed sub-specialist opinions

It is the nature of occupational screening in asymptomatic working-age adults that ECG abnormalities and subsequent investigations may reveal findings that are difficult to quantify in terms of risk of role-specific distraction and incapacitation. This raises uncertainty, especially considering the current lack of a robust evidence base with which to inform decision-making. The occupational cardiologist therefore needs to develop relationships with sub-specialist colleagues (electrophysiologists, inherited cardiac conditions, cardiomyopathy experts, structural interventionists, and cardiac surgeons) who are willing to work together to contextualize and distinguish clinical findings within the occupational context. Occupational cardiologists also need to have a clear understanding as to

the consequence of intervention (whether pharmacological, percutaneous, or surgical). Several medications and treatments have effects that are inconsistent with certain roles/assessments.[15] It is imperative that occupational cardiologists can appropriately consent individuals, regarding treatments and/or intervention, considering the potential impact on their role. Whilst existing guidelines should be adhered to as far as possible, where there is an equal or acceptable alternative, that may allow individuals to continue in their occupational role (either wholly, or partially), these should also be considered.

The challenge of occupational cardiology

Occupational cardiology is a challenging field that requires a broad understanding of general cardiology, environmental, and occupational medicine principles. The lack of research and evidence base has led some institutions, who have a duty of care to employees undertaking high-hazard occupations, to develop consensus guidelines. However, widespread variation remains in an occupational health evaluation, and limited consensus has been achieved to date regarding occupation and patient-specific criteria that may warrant additional enhanced screening for CVD. Even where standards do exist, occupational guidelines are often outdated when compared to the rapid changes in clinical evidence borne out of contemporaneous clinical research. Ethical and legal considerations also vary across occupations and between international regulatory agencies. Accurate reporting of medical conditions to licensing authorities can also be challenging, as occupation candidates are often required to self-report their medical history. While most candidates will provide full disclosures, the potential for recall bias and unreported or undetected illness remains. For pilots, the International Civil Aviation Organization (ICAO) regulations require an independent aeromedical examiner to certify fitness, with full access to medical records. However, some countries (such as Germany) have laws that permit only a partial transfer of information, balancing patient privacy against public safety.[17] Significant debate remains in this area and ongoing legal challenges continue to weigh up the interest of public safety vs. individual's right to privacy.

The lack of consensus or contemporary evidence typically results in decisions being made based on expert opinion. This can result in a lack of consistency in clinical decision-making which is increasingly being challenged, both by employees and employers.[154] The psychological and financial effect of cardiovascular diagnoses, through occupational restriction, is considerable. A standardized response to the same clinical condition in a person with a given occupation should be the aspiration of occupational cardiologists. However, the complexity of employment roles and disease processes coupled with the variation in individual presentations mean that deviations from a consensus document, however comprehensive, will never be eliminated. To occupationally manage individuals who undertake high-hazard employment one requires a detailed and nuanced understanding of the acceptable risk of an individual's employer, a specific understanding of the environment that work is performed in, and the specific roles individuals undertake. Arguably many cardiologists do not currently have specific training in this.

The precise role for occupational health screening remains an ongoing debate, and collaboration is needed among stakeholders to provide transparent criteria for occupational screening that balance individual health, patient rights, and public safety. This is further challenged by the 'prevention paradox' where the most adverse cardiovascular events often occur in patients considered to be low- or intermediate-risk by current clinical risk scores. Furthermore, hazardous occupation workers, which we have covered in this review, are presently predominantly male.[155] Although CVD is a leading cause of mortality and morbidity in both women and men, there are substantial sex/gender differences in the prevalence and burden of different CVDs.[155] This needs to be considered, from an occupational perspective, both in terms of risk management, as well as the requirement for more research as women move into more hazardous roles.[156]

We recognize several limitations to this review and the available evidence. While we have endeavoured to provide a comprehensive review of the literature, the potential exists for missing data and publication bias. We attempted to minimize this by reviewing multiple databases and a recursive search of references. This does not include all occupations but includes those that warrant evaluation for CVD and its risk factors. However, we acknowledge that this review represents a minority of the millions of working adults. We have not addressed several hazardous occupations such as construction, mining, fishing, or logging which may carry an increased risk of CVD[8–11] and this merits further research along with the impact of CVD on other blue-collar workers. We recognize that different risk applies to different occupational roles, and we have attempted to be as comprehensive as possible. We do not advocate enhanced screening of the general population, at variance to current national or international guidelines, but rather we address the need for enhanced screening in those with high-hazard occupations and/or with increased cardiovascular risk due to the presence of risk factors.

Conclusion

This review focuses on screening and preventive cardiology in the occupational environment. Occupational cardiology serves millions of working adults who fuel the economy. Provision of evidence-based, but individualized, risk stratification and treatment plans, is required from specialists that understand the complex interaction between work and the cardiovascular system.

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