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Low Back Pain: Considerations for Rotary-Wing Aircrew (Reprint)

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14. ABSTRACT
Low back pain remains a significant issue among helicopter aircrew. There is a considerable body of scientific literature devoted to the problem, including epidemiologic and experimental studies addressing prevalence, characteristics, primary etiology, and contributing factors. It is endemic and multinational, with a prevalence ranging from 50-92%. Archetypal pain begins with flight or within hours of flight, is mostly targeted in the low back/lumbar region and/or buttocks, is transient, and is commonly described as dull and achy. A minority develop chronic, persistent pain that is variously described with dissimilar characteristics. The pernicious effects of back pain or discomfort while piloting may affect flight performance and safety, including reduced operational effectiveness and lost duty time, occupational attrition, curtailed or cancelled missions, compromised emergency egress, and performance deficits during critical phases of flight. The majority of etiologic studies have focused on the pathophysical posture adopted by pilots for aircraft control and exposure to whole body vibration. (Continued on next page.)

15. SUBJECT TERMS
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With more evidence for the former, it remains likely that both, as well as other factors, may have a contributory and perhaps integrative or concerted role. Corrective and mitigation strategies have addressed lumbar support, seat and cockpit ergonomic redesign, and improved aircrew health. Flight surgeons should be familiar with this prevalent issue and future research must address longitudinal cohort studies with clear definitions, relevant and valid exposure data, dose-response detail, and control for contributing factors and confounders.

REVIEW ARTICLE

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Steven John Gaydos

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Low back pain remains a significant issue among helicopter aircrew. There is a considerable body of scientific literature devoted to the problem, including epidemiologic and experimental studies addressing prevalence, characteristics, primary etiology, and contributing factors. It is endemic and multinational, with a prevalence ranging from 50–92%. Archetypal pain begins with flight or within hours of flight, is mostly targeted in the low back/lumbar region and/or buttocks, is transient, and is commonly described as dull and achy. A minority develop chronic, persistent pain that is variously described with dissimilar characteristics. The pernicious effects of back pain or discomfort while piloting may affect flight performance and safety, including reduced operational effectiveness and lost duty time, occupational attrition, curtailed or cancelled missions, compromised emergency egress, and performance deficits during critical phases of flight. The majority of etiologic studies have focused on the pathophysical posture adopted by pilots for aircraft control and exposure to whole body vibration. With more evidence for the former, it remains likely that both, as well as other factors, may have a contributory and perhaps integrative or concerted role. Corrective and mitigation strategies have addressed lumbar support, seat and cockpit ergonomic redesign, and improved aircrew health. Flight surgeons should be familiar with this prevalent issue and future research must address longitudinal cohort studies with clear definitions, relevant and valid exposure data, dose-response detail, and control for contributing factors and confounders.

Keywords: backache, low back pain, aircrew disability, helicopter, rotary wing.

I now wish to turn to … workers in whom certain morbid affections gradually arise from … some particular posture of the limbs or unnatural movements of the body called for while they work.—Bernardio Ramazzini, *De Morbis Artificum Diatriba* (Diseases of Workers), 1713 (71)

LOW BACK PAIN IN the general adult population is exceedingly pervasive. The overwhelming majority of the population (70–90%) will experience an episode of low back pain at some time with most people having their first episode by age 35 (39,56,73). In a recent Department of Health and Human Services survey (65), almost one-third of adults reported an episode of low back pain within the previous 3 mo, whereby pain lasted at least a whole day or more. Recurrences are generally thought to be common (up to 85%) (92), though not universally so (85). The World Health Organization notes that comparable proportions of back pain are common to all cultures and it remains a leading cause of disability worldwide (25). Specifics in the literature may vary depending on definitions and populations under study, but back pain consistently ranks very high (often first) as a reason to seek medical care, a cause for disability and inability to work, and a major factor in poor quality of life (14,25,41). Healthcare expenditures for back pain are substantial, almost 100 billion dollars per year in the United States, for example (55).

Low back pain is not a specific disease. It's often used as an imprecise "catch-all" term for pain or discomfort that may represent a whole host of pathologies ranging from the (usually) minor and self-limiting through the emergent and life-threatening. The etiology may not even arise from the "back" per se, in the traditional musculoskeletal sense. There are many ways to classify back pain; a practical categorization includes localized, radicular, and referred (75). Localized pain is confined in the anatomical region, usually defined as below the shoulder blades or ribs down to the gluteal folds (92), presumably coinciding with the location of the causative pathology. Radicular pain radiates into the thigh or lower leg, though the pathological source remains in the back (e.g., herniated nucleus pulposus, stenotic compression). Referred pain may include a host of diverse systemic or nonmusculoskeletal pathology such as aortic aneurysm, pancreatitis, nephrolithiasis, malignancy, and many others (39,73). The pathophysiology and etiology of the pain can be very diverse: muscles, fascia, periosteum, tendons, ligaments, joints, vasculature, and spinal nerves may all be a source of pain through irritation, inflammation, mechanical compression, ischemia, and pressure (23,73). Back pain is also commonly delineated by time: acute (less than 6 wk), subacute (6 wk to 3 mo), and chronic (greater than 3 mo) (22,92). Further complicating precise definitions, 85–90% of cases are classified as idiopathic or "non-specific," without definitive pathological diagnosis identified (23,92).

Given that back pain is common and often self-limiting, most clinical guidelines recommend that physicians rule-out a serious or definable etiology first, and then

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approach the patient with conservative, expectant management (41,73). More extensive or urgent evaluation is usually limited to those with "red flags" including (but not limited to) history of trauma, advanced age, immunosuppression, cancer, uncharacteristic pain, or associated constitutional symptoms. Concerning findings elicited on physical exam may include abnormal vital signs, neurologic deficits, or signs suspicious for serious etiology (39,73,84). Once these patients have been identified and treated (or dispositioned to appropriate specialists), one can expect about 90% of acute episodes of uncomplicated back pain to resolve within weeks with close to 10% going on to develop chronic pain (3,23,73).

Occupational and Military Aspects of Back Pain

More than one-third (37%) of back pain worldwide is attributed to occupational exposures with an estimated 818,000 disability-adjusted life years lost annually (70). It is foremost in causes of work-related disability and most expensive in terms of compensation and medical expenses (23). Excellent reviews and evidence-based guidelines are available in the literature (13,90). The National Institute for Occupational Safety and Health (56) conducted an epidemiological review of five work-related physical factors affecting low back disorders: 1) heavy physical work; 2) lifting and forceful movements; 3) awkward postures (nonneutral trunk posture); 4) whole body vibration (WBV); and 5) static work postures. Reviewing more than 40 epidemiologic studies, it was determined that evidence exists for a positive relationship between back disorder and heavy physical work and awkward posture, and strong evidence for WBV and work-related lifting. These limited physical criteria place a host of occupations at risk (e.g., professional drivers, dentists, farmers, heavy equipment operators, miners, officer workers, and many others), including helicopter aircrew. Lis and colleagues (53) specifically assessed the association between sitting and low back pain, finding that overall, among all occupations, sitting alone as an independent risk factor was controversial. However, the odds ratio (OR) did increase when analyzed with co-exposures of WBV and awkward posture. Note that these criteria do not represent other nonwork-related physical or psychosocial factors that may also be associated with back pain.

The military is affected by high rates of back pain, as well. It ranks among the most frequent causes of lost duty time and medical visits among the U.S. Armed Forces (3), and a recent report (4) noted, "…back injuries/back pain accounted for extraordinarily large numbers of ambulatory visits and lost duty time; resources should be focused on preventing, treating, and rehabilitating back pain/injuries among active component members." The physically demanding tasks of soldiering, often with heavy loads and over difficult terrain, are associated with many known risk factors. In fact, the required equipment and load carriage, as well as the individual body mass index (BMI) of troops have increased over the years (47,48). For example, in Airborne Operations in Afghanistan and Iraq, average personal loads ranged from 327-380 lb (including bodyweight, combat equipment, 28-lb parachute, and 14-lb reserve) (49). In a 10-yr surveillance study, about 1 in 10 (860,524 incident encounters) of all service members reported for medical evaluation of low back pain, half with more than one episode (3).

METHODS

A systematic literature review was conducted to establish the current understanding of the extent and potential causative factors of low back pain among rotary-wing (RW) aircrew. Searches were conducted in conjunction with a reference librarian. Five primary databases were searched, including the Defense Technical Information Center (1945-2011), National Technical Information Service (1964-2011), Medline (1950-2011), Embase/Excerpta Medica (1974-2011), and PsychInfo (1887-2011). The search string included "backache or back pain" and "helicopter or helicopters or rotary wing" for English full text articles, foreign text with English abstracts, technical reports, and book chapters. The initial search yielded 65 unique sources. Further articles were selected based on references listed in works delineated by the original search criteria.

Rotary-Wing Low Back Pain

Extent of the Problem

Back pain among helicopter pilots has been reported for almost 50 yr (10,82). Lis et al. (53) noted that among all occupations under review in 25 studies, the strongest association with back pain was found among helicopter pilots (OR = 9.0). It is common and multinational, with prevalence ranging from 50–92% (37,61,86). Such endemicity should not surprise flight surgeons who care for this population, especially given the occupational risks associated with such pain—namely, a static seated environment with pathophysical posture and vibration. However, a degree of caution should be exercised with direct comparison of such studies with differences in methodology, period prevalence, airframes, mission/roles, and aircrew-borne equipment (**Table I**).

Sheard and colleagues (80) found a high 12-mo prevalence of back pain among British Royal Navy RW aircrew (82%) vs. nonflying controls. Bridger and colleagues (11) also found a very high prevalence of back pain (80%) over a 1-yr period among British helicopter pilots with appreciable pain-related disability: interference with flying (66%), sleep (51%), and duties outside of aircraft (32% of those rating back pain higher). Among pilots operating to oil rigs in the North Sea, back pain was 12 times more common during trips than at home (second only to headache as a reported medical symptom) (31). Cunningham and colleagues (15) reported comparable prevalence among military and civilian helicopter pilots: 83% and 81%, respectively. This is noteworthy in that additional safety and survival equipment requirements in military aircraft (e.g., aircrew body armor) not present in civilian airframes may be contributory (57).

TABLE I. SURVEY STUDIES OF PREVALENCE.

Author(s)	Year	Rotary-Wing Subjects (*N*)	Prevalence (%)
Bongers, et al.	1990	Dutch military/civilian pilots (133) v. nonflying controls (228)	68/17
Bridger, et al.	2002	British Royal Navy pilots (185)	80
Cunningham, et al.	2010	Royal Air Force pilots (78) v. civilian pilots (52)	83/81
Froom, et al.	1987	Israeli AH-1 Cobra pilots (18)	72
Hansen, et al.	2001	Royal Norwegian Air Force (105) v. fixed-wing controls (99)	51/18
Shanahan	1984	U.S. Army pilots (802)	73
Sheard, et al.	1996	British Royal Navy aircrew (138) v. nonflying controls (228)	82/52
Thomae, et al.	1998	Royal Australian Navy and Regular Army pilots (131)	92

Among Norwegian helicopter aircrew, Hansen and Wagstaff (37) reported a 2-yr prevalence of 50.5%, greater than fixed-wing controls. In the Canadian Forces, it remains the second most common cause of operational grounding (88), whereas a survey of Australian military helicopter pilots revealed that only a startling minority (8%) were back pain free (86). A study from the Israeli Air Force noted that more than half (57.6%) of the 264 helicopter pilots under study reported low back pain or discomfort during and immediately after flight (vs. 23.1% and 17.6% for fighter and transport pilots, respectively) (29). Interestingly, in this study, helicopter pilots had similar prevalence of back pain unassociated with flight to their counterparts, with the authors suggesting a transient flight-related effect. Israeli investigators (51) likewise noted a high prevalence of lumbar degenerative findings by magnetic resonance imaging in helicopter pilots (though sample size was small and uncommonly affected the upper instead of lower lumbar spine). Although pathology evidenced by imaging does not necessarily correspond with pain or functional deficits, the authors suggest that the high prevalence of symptoms in helicopter populations may correspond with lumbar degenerative changes. Other investigators have noted increased (four times higher) prevalence of lytic spondylolisthesis in helicopter pilots compared to cadets and transport pilots (30). However, a Turkish study (5) of spinal changes in four-view radiographs of pilots and controls failed to demonstrate significance in helicopter pilots for the prevalence of lumbar changes when compared to other pilot groups or controls (but did demonstrate significantly higher cervical osteoarthritic changes).

The problem is not limited to pilots. "The plight of pilots should not allow that of other members of the crew to be forgotten," cautions Delahaye (20), specifically citing the flight engineer in certain airframes. Grant (35), for example, conducted an ergonomic evaluation of the crew station and flight-related activities of flight engineers and gunners in the HH-60 helicopter, noting that they adopt a number of awkward postures plausibly associated with back pain. A case-control study of 5095 U.S. Navy pilots and aircrew showed aircrew, not pilots, to have a higher risk of diagnosed back problems by physical exam for both helicopters and fixed-wing aircraft (81).

In fact, the literature may very well understate the full extent of the problem. Many studies employ survey methodology or rely on aircrew self-reporting, and aviators are often reluctant to report deficits for fear of flying restriction or potential effect on employment (29,81,86). Furthermore, this type of data is subject to a survivor bias or healthy worker effect with selectivity for those remaining on active flying status (33,86).

Type of Pain

The 'prototypical' RW back pain begins during flight or within hours of flight, is mostly targeted in the low back/lumbar region and/or buttocks, is transient, and is commonly described as dull and achy (10,20,77). It often resolves postflight or within hours after flight (though this period is described variably in the literature) and the aviator remains relatively asymptomatic until re-exposure to flight conditions. Shanahan (79) makes the case that this is different than the 'routine' episodes of low back pain experienced by the general adult population, whereby incident episodes are rarer, marked by extended asymptomatic periods, and are more unpredictable in recurrence. However, Bowden (10) cautions comparisons of the malady of the general adult population versus that of helicopter aircrew with data of the former often coming from epidemiologic review of medical records or patient encounters—very different than that of self-reported surveys whereby one may be symptomatic but not necessarily seek care or intervention. He cites literature that does, indeed, support a population of transient pain occurring in other occupational settings (drivers, tankers, and heavy machine operators) temporarily associated with their occupational tasks.

As in the general adult population, there is evidence of two disparate populations in helicopter aircrew reporting back pain—a larger population with prototypical pain features as described and a minority with chronic pain unrelieved by cessation of flying (8,10,87). This pain is frequently described as lasting for days or longer (54,77,87), but also may include characteristics as pain not temporally associated with flight (10,29), exhibiting sciatica or radicular features (8,54,63), or leading to major disability or incapacity to fly (63,75,79). It has been suggested that the prototypical transient pain is primarily posture-related, while the latter may be influenced by posture and vibration (8,86). In studying 163 helicopter pilots versus 297 nonflying officer controls, Bongers et al. (8) determined that transient pain was associated with hours of flight per day, while chronic pain was associated with total hours of flight time (significantly higher prevalence of chronic pain for >2000 h). The authors attributed this to accumulative vibration dose and posture (subjectively reported), concomitantly. Shanahan (79) also noted an association between chronicity of symptoms and flight hours; a small but noteworthy subset (14.5%) reported pain lasting greater than 48 h after flying. This group had more flight hours and more time on flight status. It may very well be that aircrew developing chronic pain may not be representative of the classic "idiopathic" back pain with specific pathology causing the chronic symptoms (e.g., degenerative osteoarthritis, discogenic disease).

Posture

The helicopter pilot must simultaneously control three distinct, aerodynamically related controls: collective, cyclic, and antitorque pedals (21). The collective lever, operated with the left hand, collectively changes the angle of incidence on all rotor blades contributing to total force vector and lift. The cyclic, operated between the legs with the right hand, differentially changes the angle of incidence on the blades around the rotor system (changing the attitude of and effectively 'tilting' the rotor disk). This controls the direction and magnitude of the thrust vector. Antitorque pedals vary pitch (resultant thrust) of the tail rotor, counteracting main rotor torque and controlling heading and yaw. Some helicopters are designed with two tandem main rotors (no tail rotor), but aircrew of these platforms likewise experience prototypical helicopter low back pain features (7). An inherently unstable platform, helicopters require simultaneous control with all four limbs (discounting effects of autopilots, automated flight control systems, and related equipment). Generally, small muscle forces are desired for fine control. A common technique, for example, is for the pilot to rest his or her right forearm on the right thigh to stabilize the arm and allow for more precise cyclic inputs. Hand control with a supported arm optimizes conditions for accurate tracking (59). Similarly, the pilot's left shoulder and elbow remain in a flexed position with the hand gripping the collective lever isometrically (**Table II**).

Colloquially known as "helo hunch," the pathophysical posture associated with helicopter piloting is well-known to aircrew; it was described almost 50 yr ago (82). Pelham and colleagues (61) provide a succinct, kinesiology-based breakdown of the required maladaptive posture that RW aviators must endure: kyphotic flexion of thoracic and lumbar segments, restricted pelvic rotation, extension of the cervical spine, and forward-shifted center of mass. Multiple mechanisms have been proposed, and the evolving cascade with repeated exposure over time may include posture-supporting muscular fatigue, inappropriate loading and insult to joints and supporting tissues, compromised architecture (including the intervertebral disk), inflammation, and osteoarthritis with pain and loss of flexibility. Many posture-related effects may be exacerbated by issues of anthropometry. For example, a pilot with shorter arms may have to select a lower seat position to allow full downward collective control, aggravating cervical extension, to see out through the windshield.

The high prevalence of pain in Sheard and colleagues' survey of RW aircrew (80) was thought to be attributed to ergonomic factors, and more than two-thirds of Cunningham et al.'s (15) pilot-respondents (66% military and 68% civilian) reported that they did not find their seat comfortable. Bridger and colleagues (11) likewise

TABLE II. MALADAPTIVE POSTURE REQUIRED OF HELICOPTER PILOTS.

Etiology	Pathophysical Posture	Resultant
Forward flexion of trunk and shoulders; cyclic control with RUE resting forearm on thigh	Kyphotic posture of thoracic and lumbar spine with middle to low thoracic spine fulcrum[1] and loss of normal lumbar lordosis	Isometric activity and resultant fatigue of spinal extensors (erector spinae, multifidus)
Neck extension; view instrument panel and environs through windshield	Compromised cervical spine segment posture	Degree of extension (with or without rotary component) and assoc. fatigue dependent upon pilot height, seat height, and other factors[2]
Unsupported sitting; feet required to operate antitorque pedals	No support base of feet; unable to place "flat on the floor" with LE support[3]	Hips and knees flexed (psoas and iliacus fatigue) with feet dorsiflexed. Posterior pelvic tilt rocking on ischial tuberosities[4]
Asymmetric collective control with LUE	Leftward rotational twist of trunk and lateral bend	RUE resting forearm on thigh contributes to leftward rotation; lateral bend to LUE use of collective lever[5]

RUE – right upper extremity; LUE – left upper extremity; LE – lower extremities.
[1] Compressive loads, particularly in the lower spine (L3-L5), higher in kyphotic than erect seated posture.
[2] Results exacerbated with addition of head-supported mass (e.g., night vision goggles).
[3] Some aircraft with stability augmentation or automatic flight control systems allow for "feet on the floor" flying rather than continuous antitorque pedal adjustment in cruise and other specified flight conditions.
[4] Trunk flexion exacerbated when seated with <70° knee flexion.
[5] Bend exacerbated in low-power settings with more horizontal collective lever position.

attributed their high prevalence to poor posture as the principal etiology, as it was most associated with instrument flight (worst forward-flexed trunk position) and least for the nonflying pilot (better trunk posture). This is suggestive of another posture-related factor in low back pain contribution: flying task. The nonflying pilot often can maintain a more symmetrical posture and is afforded the opportunity to adjust and shift position (and posture-related pressures) as frequently as necessary for comfort. Furthermore, cruise flight with an automatic flight control system affords similar benefits to the flying pilot versus less ideal postural circumstances (e.g., precision hovering or instrument flight). Delahaye and colleagues (20) mention the association of pain with multiple takeoffs and landings (e.g., commando insertions) or prolonged precision hovering flight (e.g., shipboard winching exercises).

In an effort to isolate and control posture from vibration, Shanahan and Reading (78) constructed a UH-1 helicopter cockpit mock-up mounted on a multiaxis vibration platform. There was no difference in onset or intensity of back pain in 11 subjects 'flying' 2-h blocks with and without vibration, suggesting the major etiologic factor to be posture. Likewise, Pope and colleagues (68) studied muscle response in sustained posture versus vibration in a simulated cockpit mock-up with (marginally) significant fatigue occurring only as a result of static posture, but tests with and without vibration produced subjective discomfort. Another study noted that pilots reported back pain six times more often than nonpilot aircrew (who are also subjected to the airframe's vibration, but provided opportunity to move, adjust, stretch, etc.), also suggesting piloting posture as a significant etiology (37).

Froom and colleagues (28) strengthen the pathophysical posture argument in comparing notably different crew stations and controls among the same helicopter. In a cross-over design comparing the rear seat cockpit with the front seat copilot gunner (CPG) station of the AH-1 Cobra, rear-pilots (with traditional controls and associated forward posture) reported increased prevalence (nonsignificant), quicker onset, and greater pain intensity than the CPG. The front CPG seat allows for a more upright, neutral posture with sidearm cyclic and collective. Worth mention, however, is that more than half (55.6%) of CPG pilots also reported pain, suggesting a multifactorial etiology.

Muscle fatigue, whether by asymmetric posture or vibration, has been suggested as a causative role in helicopter-related back pain (8,10,61). Electromyograms (EMG) have produced provocative if not somewhat conflicting results. Asymmetrical lumbar muscle activity has been demonstrated by EMG in flight and cockpit mock-ups (54,87), suggesting the etiologic contribution of posture. Vibration-related EMG studies have demonstrated that low-frequency vertical sinusoidal oscillations recruit a synchronized response in erector spinae muscles (76) and that vibration-related EMG modulation is more prominent with higher baseline muscle activity before exposure (93). EMG study has also demonstrated development of fatigue in erector spinae muscles with seated exposure to WBV of 5 Hz compared to static conditions (67). De Oliveira and colleagues (18,19), however, found no evidence of localized muscular fatigue in support of vibration or posture when assessing erector spinae EMG in-flight evidence (including both short and long flights and submaximal and maximal normalization). The authors discount fatigue based on the in-flight results and suggest cyclic spinal mechanical load as a resultant etiology. Nonetheless, given the resonance behavior of the seated human body, the forward-bent posture commonly described of helicopter pilots gives rise to the greatest risk of back problems (46).

Whole-Body Vibration

The body of work analyzing the association of whole-body vibration (WBV) with back pain and back disorders dates back more than 50 yr (19,40). The definition provided by the European Union Directive (2002/44/EC) on health and safety requirements (26) is "mechanical vibration that, when transmitted to the whole body, entails risks to the health and safety of workers, in particular lower-back morbidity and trauma of the spine." The international standard for human exposure guidelines is the International Organization for Standardization's Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body Vibration (ISO 2631-1) (43). The American National Standards Institute guide is identical to ISO 2631-1 (83). The American Conference of Governmental Industrial Hygienists provides guidelines based on the ISO 2631 guide with emphasis on equipment and ground vehicles (12,58,83). An excellent textbook review of WBV in aerospace environments, as well as vibration effects on humans, has been written by Smith and colleagues (83).

Among occupations exposed to prolonged WBV, the most common chronic health issue is back pain and back disorders (44,83). Studies have demonstrated exposure to WBV to be positively associated with back pain (9,52,67) and likely injurious to the spine (42,43). The postulated mechanisms are not well understood and may include compensatory muscular fatigue, microtrauma and tissue failure, metabolic or nutritional compromise, microvascular damage, degenerative changes, pain neuropeptide alteration, or a combination of these. Z-axis sinusoidal vibration in the seated position, for example, has been noted in vivo to produce vibration in the lumbar vertebrae in horizontal and vertical directions, as well as a flexion-extension rotational component (60). Upper body first resonance (seated posture) occurs between 4.5-5.5 Hz, with other resonances identified at higher frequencies (17,46,67). This is noteworthy, as helicopters may expose aircrew to a vibration frequency range that coincides with the spinal resonant frequency or a harmonic thereof (though accelerations are usually relatively small) (17,32,79). Vibration is transmitted (and may be amplified) to aircrew via contact surfaces, including seating, floor, and controls (44,87), and in-flight helicopter vibration transmissibility measurements have suggested the presence of resonance in pilot spines (17).

Vibration levels may vary by aircraft and mode of flight (8,20,44) with both mechanical and aerodynamic contributions. The z-axis, along with profiles of maximum speed and 45° turn, correspond with the highest vibration levels (44).

Bongers and colleagues (8) studied 163 helicopter pilots vs. 297 nonflying military officer controls, quantifying the vibration levels of different helicopters and calculating a cumulative exposure dose. Data suggested that more serious, chronic back pain develops with increasing vibration dose or total flight time, complicating individual assessment since the two are highly correlated. In a recent study, Kasin and colleagues (44) developed a protocol for measuring WBV and performed a risk assessment processing vibration root mean square values with time spent per various operational flight maneuvers for six different military and civilian helicopters. The A(8) calculated daily exposure values were noted to be low (0.32-0.51 $m \cdot s^{-2}$), and all were below the European Union A(8) exposure limit value of 1.15 $m \cdot s^{-2}$ (26). Only one aircraft (S-92) studied minimally exceeded the European Union exposure action value (0.5 $m \cdot s^{-2}$) and daily occupational exposures would likely be much lower given that most pilots do not fly 8 hours per day. The study was also important in demonstrating that vibration emissions are repeatable and the results are likely representative of twin-turbine single rotor aircraft in general given the relatively small distribution of variation. The authors note that although the results suggest pilots should not be at risk for vibration-related back pain, there is no universally agreed lower threshold at which WBV is considered without risk. Hansen and Wagstaff (37) reported a 2-yr prevalence of low back pain in RW aircrew to be much higher than fixed-wing controls (vibration levels are much lower in fixed-wing aircraft compared to helicopters (44)). However; a case-control study looking at diagnosed back-related disorders on physicals of U.S. Navy aircrew failed to demonstrate an association between types of aircraft (81).

It remains unclear if the increased risk of helicopter low back pain from WBV exists independently as a causal factor or only in combination with other factors (e.g., poor posture and prolonged sitting). It has been noted that vibration-associated mechanical stress may interfere with tissue metabolic demand, contribute to degenerative processes, or worsen endogenous pathology (43). Critical review of the epidemiologic literature does favor a positive association between WBV and back pain, but a clear causative and dose-response or quantitative relationship is weak (9,43,52). Hill and colleagues (40) cite that studies lack detailed multifactorial exploration of the vibrational parameter space (frequency, amplitude, and duration), as well as health of the surrounding tissue as the primary cause for inconclusive and/or contradictory study results. There is ample evidence to suggest that vibration is not the sole driving factor in RW back pain (see above). Reader (72) noted that the aircraft most associated with back pain are those with poor seating arrangements, not necessarily those that vibrate the most. While it may not, in and of itself, cause the whole of the problem, it is likely contributory (and not restricted to helicopters). One occupational study noted a fourfold increase in pain with co-exposure to both awkward posture and WBV (53). While there exists a predominant presentation, the "back experience" of helicopter pilots and aircrew is not uniform, and it has been posited that vibration may have a principal in role chronic pain, while posture is responsible for the predominant transient type (8). In addressing improved design for future WBV studies, Lings et al. (52) note that well-defined, nonbiased occupational/control groups, complete exposure data with dose-response, and information regarding other contributory factors should all be included. Despite lack of definitive evidence, however, they do acknowledge existence of sufficient cause for reduction of occupational vibration to the lowest possible levels.

It may very well be that we cannot consider posture and WBV as separate entities when evaluating back pain associated with RW aircraft. Principal resonance frequencies (and the associated tissue axial and shear deformations) change with posture and biodynamic models must incorporate this complexity to be properly predictive (46). Given the application of such complexity to the diverse and confounding (and common) problem of low back pain, the lack of clarity and causality in the scientific literature is not surprising. Still, there exist epidemiological associations such that the problem cannot be wholly dismissed. Disregarding isolated large or traumatic accelerations, contributions to low back disorder in helicopter aircrew from vibration are most likely to be a function of posture.

Contributing and Confounding Factors

It can be difficult to clearly attribute a pilot's back pain to a helicopter-related causation versus that of the 'routine' back pain found with such high prevalence in the general adult population. The definition of back pain itself can be problematic and caution should be exercised in incorporating disparate pathophysiology under one idiopathic or 'nonspecific' umbrella. Furthermore, although occupation is important, many physical and psychosocial factors may be related to back pain: previous back injury, family history, age, smoking, physical fitness, BMI/obesity, anxiety and depression, stress, workload, work dissatisfaction and boredom, compensation systems, nonoccupational activities, and others (16,56,66). The mechanisms are poorly understood. A clear causative (vs. simple associational) relationship can be difficult to establish and focus on a single factor risks exclusion of potentially important and complicated multifactorial relationships and concerted roles at play.

It is perhaps expected that incident presentations or prevalence of back pain among aircrew would increase with flight hours (i.e., more exposure). Shanahan (79) noted a logarithmic-type growth association between percentage of pilots with back pain symptoms and total flight hours. Delahaye and colleagues (20) also described higher incidence among aircrew with higher hours, though he notes that the thresholds for pain (both typical and chronic) vary widely in the literature. Recently, Nevin and Means (57) demonstrated a significant increase in self-reported aircrew pain with increased RW flight hours in a deployed setting, but the magnitude of risk was modest for low back pain (highest for arms and groin). Bongers et al. (8) associated high flight hours per day and total hours of flight time with increased back pain (transient and chronic pain, respectively). Other studies, however, have not demonstrated this association between hours and pain. Hansen and Wagstaff (37) reported no significant difference in total flying time between helicopter aircrew with and without low back pain (though higher flight time was associated with higher incidence of sick leave and treatment). Bridger and colleagues (11) identified a high prevalence of back pain (80%) in RW pilots, but did not identify significant associations between height/weight, smoking, family history, sports participation, or flying hours. Furthermore, there were no associations demonstrated among psychosocial scales, with the authors suggesting a predominantly physical component. Likewise, Thomae and colleagues (86) also performed analysis for predictive factors, finding only previous history of back injury significant (with height/weight, BMI, age, education, posture, and total flying hours also considered).

The absence of nonflying or psychosocial effects on the prevalence of back pain in helicopter pilots has not been universal. Bongers et al. (8) identified mental stress and tension to be contributory (in addition to posture). Bowden (10) also noted that workload may be an important component via mechanisms of tension and muscle fatigue, and he cites literature to this effect in other occupations. It is an interesting consideration. Pain associated with certain modes of flight, for example, may not be solely influenced by a maladaptive posture required of the pilot for the maneuver, but perhaps associated with concomitant workload, stress, and psychophysical fatigue. Aircrew-borne equipment must be a consideration, as well. One study looking at military aircrews in a deployed setting postulated body armor as a contributing factor to aircrew pain in some anatomic locations (57). Delahaye and colleagues (20) note that survival equipment can exacerbate poor posture and spinal loads, especially when seat and cockpit design was never intended to accommodate the pilot carrying such equipment. In many cases, direct comparison between studies is confounded by different methodology, different aircraft with different cockpit ergonomics and vibration, pilots of various anthropometric ranges flying different types of missions, psychosocial considerations, and other factors. There are, indeed, many potential factors at play, and isolation of these (and exploration of their relative importance) can be moderately difficult. Amid such confusion, the medicolegal aspects of etiology are noteworthy. Among civilian helicopter occupations or in nations in which the armed forces no longer have immunity from prosecution, proper attribution of causality is becoming increasingly important.

The Cost of Low Back Pain in the Rotary-Wing Community

The "cost" of helicopter aircrew flying with back pain or discomfort extends well beyond dollars spent for clinical care and associated medical disability. Pain is an inconvenience at best and may affect flight performance and safety, including reduced operational effectiveness and lost duty time, occupational attrition, curtailed or cancelled missions, compromised emergency egress, and distraction and performance deficits during critical tasks or phases of flight. In a study of 802 Army aviators, for example, almost half reported discomfort on more than a quarter of flights, while a quarter reported symptoms on more than half of their flights (79). In this group, 28.4% admitted to rushing missions and some (7.5%) had even refused missions secondary to back pain. A survey of 648 U.S. Navy aviators was worse: 88.1% of respondents reported pain on at least half of their flights, while a third admitted pain was affecting situational awareness (63). Van Leusden and colleagues (88) reported it as the second most common cause of operational flying restriction among the Canadian Forces. Almost half (48.6%) of Norwegian pilots with back pain reported an adverse effect on their performance (37). More than half (54%) of Thomae and colleagues' (86) Australian respondents reported that back pain had interfered with concentration and a significant number (16%) had hurried a mission, while some had refused to fly. Bridger and colleagues (11) also found a very high prevalence of back pain (80%) with appreciable pain-related disability: interference with flying (66%) and sleep (51%). Civilian pilots did not fare any better, with Cunningham et al. (15) reporting that 87% of civilian respondents reported pain affecting everyday activities (68% for military pilots).

Flight surgeons, commanders, and those responsible for aircrew health should be intimately familiar with helicopter associated back pain—not only the clinical problem, but the potential operational effects on a mission. Furthermore, the nature of many aircrew to minimize or under-report a medical issue or performance deficit should highlight the importance of a good flight surgeon-aircrew relationship. For most studies reporting access to care, approved clinical encounters were engaged by aircrew. Interestingly, however, more than 1 in 10 of one study sought unapproved care (86). Self-medication should also be a concern. A recent brief by the American College of Preventive Medicine (1) cited that more than one-third (35%) of adults use over-the-counter medications on a regular basis and a third also admit to have taken more than the recommended dose. One may certainly question that if the aerospace medicine community is not adequately addressing this issue and caring for aircrew, then who is? Interestingly, a Centers for Disease Control and Prevention report (6) highlighted that more than a third of adults within the previous year had used some form of complementary or alternative medicine, most often for musculoskeletal problems, chiefly among them back pain.

The Way Forward

Among the affected population, it has been posited that RW back pain is perceived as so common that it is simply accepted and endured as an occupational nuisance (27). The author has personally cared for pilots who simply dismiss that it "comes with the territory." It does not have to (nor should it) be a fait accompli. The RW community—both military and civilian—invests heavily in the selection, training, and readiness of aircrew. Likewise, our "customers" are conspicuously vested in the RW community's ability to safely and professionally execute missions. To this end, what should be done to address such a pervasive, but complicated condition?

There is ample evidence of the importance of posture and attention has been focused on providing better lumbar support to restore normal lordotic curvature (10,15,91). Graham-Cumming (34), for example, reported that almost two-thirds (62.3%) of the helicopter groups under study had relief of symptoms by questionnaire with individually molded lumbar support. Sheard et al. (80) likewise reported that back pain was considerably reduced among those using lumbar support (though numbers using such support were small). A large number of the Thomae et al. (86) population used such back supports with beneficial results and some aircrew in Hansen and Wagstaff's study (37) reported relief with simply a rolled-up blanket for the lower back. Symptom relief with lumbar support has not been universal, however. Bridger and colleagues (11) noted that lumbar support users as a group did not report lower levels of pain than nonusers. In one trial, fixed-wing, not helicopter pilots, received the most benefit from lumbar supports (fatigue relief, less pain, improved comfort), with authors suggesting they were able to more consistently sit upright and capitalize on the benefits as opposed to the helicopter pilots (69). There have also been many advocating for better seat design (20,34,63), improved flight control geometry (11,20,79), and larger related issues of overall cockpit ergonomic redress (10,80,86). Regarding seats, crash dynamics should not be the sole driving consideration (36). Authors have advocated that future changes should incorporate better vibration attenuation/isolation features and posture/kinesiology-based principles (described extensively in the literature). Likewise, adjustments must allow for full anthropometric ranges. Design teams should incorporate not only engineers, but pilot and aircrew users, ergonomic and human factors experts, and vibration specialists. Requirements should also incorporate consideration for aircrew-borne safety and survival equipment and reflect that missions often require pilots to remain seated in the cockpit for extended periods—far longer than simply the endurance of a single tank of fuel (e.g., surge operations with "hot" re-arm/refueling). Robust, adaptive, and predictive biodynamic modeling capability is also an area that deserves further research attention for design, evaluation, and countermeasures. Such work may be economized by capitalizing on existing efforts in other transportation-related industries or types of chronic spinal injury modeling.

Regarding flight control design, a common reference for improvement is the front cockpit of the AH-1 Cobra (although comfort was not the motivating design). This pilot station has sidearm collective and cyclic controls with forearm supports, allowing for a more upright and anatomically correct posture (28,79). It is worth noting, however, that some Cobra pilots found this design difficult to fly with precision (personal communication, AH-1 pilot with significant airframe experience; 2011). In most cases however, complete cockpit workstation redesign may not be practical. But there have certainly been numerous modifications and upgrades to existing airframes, whether to improve navigation, communication, power, crashworthiness, or armament. When such force modernization upgrades are entertained, they should include seat and cockpit ergonomic considerations for aircrew. Such investment will likely not only pay dividends in reduced pain, occupational retention, and quality of life, but also in increased safety, better flying performance, less pain-related absenteeism, and reduced healthcare expenditure. Furthermore, it is exciting to think that the issue may one day be addressed by simply removing the controls altogether, with scientists recently demonstrating virtual helicopter control via noninvasive brain-computer interface by electroencephalography (24).

Another (comparatively inexpensive) approach directs investiture in the aircrew themselves versus the airframe. Many have advocated for back strengthening (20,75), exercise (7,50,81), and stretching or other related physio-regimens to address the problem (61,63,79). There is literature addressing efficacy for subacute and chronic back pain in the general population (38,62,89), and it has been demonstrated to be successful for other types of spinal pain in helicopter pilots (2,74). Pelham and colleagues (61), for example, advocate for the aviator-athlete concept, noting that that a sport-specific type approach may be of value. They provide a protocol of proprioceptive neuromuscular facilitation by stretching, focusing on major muscle groups of the hips, legs, and chest that is currently in use by the Canadian Forces.

Finally, a comment regarding future research is warranted. The natural sequence of studies in human populations begins with clinical observations and reviews of available data through case-control or cohort studies to planned interventions or randomized trials (33), with each having its strengths and limitations. Cross-sectional survey data, for example, is subject to survivor and response bias and many authors have rightly noted such. But caution must be exercised to distinguish epidemiologic associations vs. causation. Following establishment that exposure is associated with disease, the next step should entail investigation as to whether that association is causal. This is difficult under the best of circumstances, but particularly problematic with low back pain—an entity that has issues with even a precise definition, let alone the myriad physical, occupational, and psychosocial confounders. The aerospace medicine community should subscribe to Sir Austin Bradford Hill's criteria: association alone is not sufficient to prove causation, nor is uncertainty regarding causal relationship sufficient to necessarily warrant intervention (45,64). This is stated not to adduce inaction, but to call for well-designed longitudinal cohort studies with clear definitions, relevant and valid exposure data, dose-response detail, and control for contributing factors and confounders. In the current milieu of fiscal and resource constraint, the question is more than academic; costly interventions must be based on clear factors of causation.

In conclusion, low back pain among the general adult population is common, with one author denouncing it as the "albatross of industry and the nemesis of medicine." (67). Back pain among helicopter aircrew is prevalent across the spectrum of airframes and countries. The problem is complex with likely important factors including maladaptive posture, vibration, and other physical and psychosocial factors. These do not exist in isolation and the totality of the problem is likely attributable to a combination of agents. Solutions require broad engagement among a consortium of scientific disciplines to leverage actionable science. Regardless of etiology, it has clear pernicious effects on aircrew health and the potential to jeopardize flight performance, safety, and operational readiness. Future research and advancement should address improved seats, better flight control geometry, redress of cockpit ergonomics, comprehensive modeling, and aircrew health. Well-designed longitudinal studies with relevant exposure data and control of confounders are required to clarify factors of causation.

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