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## LETTERS



## CASE REPORTS



## ORIGINAL ARTICLES



## REVIEW ARTICLES



## CROSSROADS: AEROSPACE MEDICINE

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## VOLUME 13 ISSUE 2 2011



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## ACKNOWLEDGMENTS

The executive committee of the McGill Journal of Medicine would like to thank all of the sponsors for the the *McGill Journal of Medicine 13.2*.

The executive committee further extends their gratitude to all those who worked hard to make this issue of the McGill Journal of Medicine a reality.

LETTER FROM THE EDITORS

# The Final Frontier

## A medical student's mission to boldly dream where no dream has gone before

Laura Drudi*

One simple idea can be the spark of a dream that begins to shape a lifelong journey of exploration, discovery, and transformation. I recall tilting my head towards the night sky at the age of nine years old. I was drawn to the vastness and beauty of space and I further envied those who could ride rickets to their destination. As I stared in complete admiration at the night sky, I hoped I would go to space, either as an astronaut or as a space tourist. My dreams were fostered as if it were more of a destiny than a mere fantasy. I knew I wasn't content with being bound to the Earth and my imagination, mind and heart began to soar to the limitless possibilities that the void of space encompassed. That void harbored a sense of awe, adventure and a belief that anything is possible.

This dream was harnessed into a passion that drove my motivation and led me to excel. I decided to pursue an unconventional career path pursuing space medicine. However, my passion was unquestionable allowing me to overcome challenges paving the way to success. I cannot encapsulate the breadth of growth I have undergone since stepping into the Faculty of Medicine at McGill University. I have traveled the world to pursue my unique dreams against all fears of failure. I have worked in affiliation with renowned international institutions, and further presented at national and international conferences. Before I knew it, I began transforming into a medical student leader for the aerospace industry. I began receiving support and encouragement from a variety of agencies that believed in my capabilities and the achievement of my goals. I was selected by the Canadian Space Agency and NASA to be the sole Canadian student to attend the NASA Ames Research Center on a research grant – the ultimate dream realized for an avid space enthusiast. I went on to being recognized for my leadership in the aerospace medical community by the Order of Canada mentorship program, the Canadian Medical Association, Space Medicine Association, and became a Quebec finalist in the 2011 Rhodes Scholarship selection. Through all these experiences, I have grown as a medical student and developed skills essential in international and interdisciplinary collaboration, leadership, and aptitudes required to attain my goals. However, it wasn't these successes that defined my ability to rise to the challenge, but the failures that I encountered along the way. I am a dreamer, innovator and attainer. I dream of possibilities, I create opportunities and I realize my goals through various avenues.

Space is a magical place and humanity has always been pulled towards its enchantment: from the ancient civilizations who found pantheons of gods in the blackness of space, to the later scientists who searched for universal truth and discovered the movement of planets and established the laws of physics. It is human nature to be thinkers and explorers, and space opened the human imagination because it was unknown and remains unknown to this day. Humanity's curiosity, quest for knowledge and greed led to a rich history of space exploration that set the standards for success in the space industry worldwide. And space continues to blaze new paths at the forefront of human

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understanding. My goal is to be at that frontier and begin an expedition unparalleled by any other.

To this very day, I tilt my head towards the night sky. I don't know if I will ever have the chance to become one of the select few to travel beyond Earth's gravity, but one thing I can guarantee is that I am going to make the attempt. As the frontiers of science and technology push forward, so too do the ideas, creativity and innovation of talented people. There is no boundary to space and there is no limitation to the imagination. The final frontier isn't space; I believe it's the breath of the human imagination. With that in mind, this expedition that I have embarked on is bound to be an exciting one.

It is with great pleasure the McGill Journal of Medicine Issue 13.2 will have aerospace medicine as the focus section. I hoped to share my passions for space and medicine with the community at large, and I am privileged and humbled to have participation and support from the space life sciences community.

Thank you.

**Laura Drudi** (M.D., C.M. candidate 2013) is a third year medical student at McGill University. Her interest in combining her two passions of space and medicine has led her to conduct aerospace medicine research. She will be taking a one year's leave of absence from the Faculty of Medicine and will be pursuing a Diploma of Space Studies and an MSc in Experimental Surgery prior to completing her MDCM degree. She hopes to work for the manned space program as a flight surgeon and to further continue her research in space life sciences.

**CASE REPORT**

# Kienbock's disease and juvenile idiopathic arthritis

Nicholas M. Desy*, Mitchell Bernstein, Edward J. Harvey, Elizabeth Hazel

**ABSTRACT: Kienbock's disease or osteonecrosis of the lunate is an uncommon cause of wrist pain. . Though there have been several reports of cases in patients with various rheumatologic diseases, the precise etiology has currently not been established. We report a case of Kienbock's disease that occurred in a patient with juvenile idiopathic arthritis. To our knowledge, this is the first case report with an association between these two conditions.**

*Keywords*: Kienbock's disease, osteonecrosis, juvenile idiopathic arthritis, lunatomalacia, avascular necrosis

## INTRODUCTION

The etiology of Kienbock's disease, also known as (osteonecrosis of the lunate, remains controversial. It commonly occurs in patients twenty to fourty years old and presents with pain and stiffness in the dorsomedial aspect of the wrist. Several risk factors have been established to help explain its etiology: acute or repetitive trauma, variation in blood supply to the lunate, differences in the anatomy and shape of the lunate bone, and venous congestion (1, 2). Abnormal biomechanics at the radiocarpal joint between the distal radius and ulna has also been implicated in Kienbock's disease (3, 4). Ulnar variance describes the length relationship between the articular surfaces of the radius and ulna at the radiocarpal joint. Positive ulnar variance indicates that the ulna is longer than the radius, while negative ulnar variance indicates that the ulna is shorter at the wrist joint. In neutral ulnar variance 80% of the axial load at the wrist is transmitted through the distal radius. As ulnar variance decreases to more negative values, the load transmission across the distal radiocarpal joint increases, subsequently exposing the lunate to abnormally higher pressures and potentially increasing the risk of Kienbock's disease (3, 4).

Kienbock's disease is also associated with systemic lupus erythematosus (SLE) (5-8), antiphospholipid antibody syndrome (9), sickle cell anemia (10), and Crohn's enteritis (11). Multiple hereditary osteochondromata (12), carpal coalition (13, 14) and congenital shortening of the ulna in Langer-Giedion syndrome (15), are other anatomic abnormalities that have been reported with Kienbock's disease. Rheumatic diseases, including scleroderma (16-18), rheumatoid arthritis (19), gout (20, 21) and dermatomyositis (22) have been published in association with Kienbock's, but there have been no identifiable cases in patients with juvenile idiopathic arthritis (JIA).

This report presents a case of osteonecrosis of the lunate in a patient with JIA and no prior history of trauma. Furthermore, a literature review is done to illustrate the proposed etiologies of Kienbock's disease and its association with other rheumatologic conditions.

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## CASE REPORT

A 20-year-old right-handed female with known rheumatoid factor negative polyarticular JIA presented to the clinic because of pain and limited range of motion in the left wrist.

She was diagnosed with JIA at the age of nine after a two-month history of pain and swelling in both hands and knees. She reported difficulty with recreational activities. During the course of her illness several other joints progressively became involved. During the first year of treatment, she was prescribed nonsteroidal anti-inflammatory medication and low-dose prednisolone. To help control her symptoms she required disease-modifying antirheumatic drugs. Her medications included methotrexate 20 mg weekly, folinic acid 2.5 mg weekly, and etanercept 25 mg twice a week.

Three weeks prior to presentation, the patient experienced a severe flare of her arthritis due to non-compliance with her medication. This lead to persistent left wrist pain and limited range-of-motion. On examination she demonstrated synovial thickening of her left wrist with no palpable effusion.

Magnetic resonance imaging of her left wrist showed mild synovial thickening and erosive arthropathy throughout the carpus, radiocarpal, and carpometacarpal joints. In addition, there is possible sclerosis and edema, since she had collapse of the lunate with mixed signal intensity. Plain radiographs revealed negative ulnar variance, sclerosis, and loss of lunate height (Fig. 1). The imaging was compatible with Stage 4 osteonecrosis of the lunate (23). The patient was managed non-operatively and at two-year follow-up was asymptomatic with no concomitant worsening of lunate osteonecrosis on radiograph.

## DISCUSSION

The etiology of Kienbock's disease remains unclear (Table 1). The current literature indicates that most cases of Kienbock's disease develop without a history of trauma and posit that e extraosseous and intraosseous blood supply to the lunate have a role in the disease process. The extraosseous blood supply is formed by a series of dorsal and volar vascular arches (1, 24). The intraosseous blood supply is made up of braches entering the volar and dorsal poles however the composite of this vasculature is variable (1, 25-27); branches demonstrate different anastomosis patterns inside the lunate, or the lunate may be supplied by only one dorsal or volar branch or By both a dorsal and volar arterial supply the lunate without any anastomosis (26). When an anastomosis does exist, it can be characterized as a Y, X, or I pattern, depending on the amount of vessels supplying each pole (24, 27). Depending on the intraosseous vascular anatomy


**Figure 1**: A. Coronal T1-weighted fast-spin-echo magnetic resonance image showing collapse of the lunate with mixed signal intensity suggesting sclerosis and edema consistent with Kienbock's disease (arrow). Erosive arthropathy throughout the carpus and negative ulnar variance are also noted. B. Antero-posterior plain X-ray of the left wrist demonstrates sclerosis and slight loss of height involving the lunate compatible with Kienbock's disease (arrow). Negative ulnar variance and degenerative changes are also seen.

| Current proposed mechanisms |
|---|
| Aberrant blood supply to the lunate |
| Abnormal risk biomechanics |
| Endothelial cell dysfunction |
| Increased intraosseous pressure |
| Microvascular thrombophilia |
| Trauma-induced with disruption of the blood supply |
| Venous congestion |

**Table 1:** Pathogenesis of osteonecrosis of the lunate

of the lunate, certain lunate bones are predisposed to Kienbock's disease. This concept was highlighted in a case report of Kienbock's disease associated with sickle cell anemia (10). The osteonecrosis was thought to have developed from an at-risk lunate - single volar arterial supply - along with significant vascular sickling and stasis.

Venous congestion has also been attributed to the pathogenesis of Kienbock's disease (2). During surgery, Jensen measured increased pressure inside the lunate compared with the radial styloid and capitate. He concluded that the higher pressure was caused by venous congestion leading to osteonecrosis of the lunate.

Negative ulnar variance is also implicated in the pathogenesis of Kienbock's disease (3, 4, 28). The altered relationship between the ulna and radius at the distal radioulnar joint modifies the biomechanics at the radiolunate joint and increases strains on the lunate. This postulation is still controversial because several studies, including a meta-analysis, have shown that negative ulnar variance is not a risk factor for developing Kienbock's disease, (29, 30). On the contrary,Ledoux et al. performed a finite-element analysis on cadaveric lunate bones and found that the progression of a fracture of the lunate was present with negative ulnar variance, a high lunate uncovering index, which is the amount of lunate outside the lunate fossa of the radius compared to the amount of lunate articulating with the lunate fossa, and angulated trabeculae (31). This suggests that given the circumstance, the lunate can be at risk for developing osteonecrosis due to abnormal stresses.

Further cases have also reportedpatients with conditions that may have caused altered stresses on the lunate. In particular, two cases have been reported involving carpal coalition (13, 14). It was postulated in these cases that carpal coalition caused a progressively increasing stress on the lunate, which in turn led to Kienbock's disease. Schuind et al. reported a case of Kienbock's disease associated with congenital shortening of the ulna as seen in Langer-Giedion syndrome (15). It was suggested that Kienbock's disease developed from microfractures sustained by an abnormal stress distribution (15). Multiple hereditary osteochondromata in the forearm was also found in association with Kienbock's disease and was attributed to an excess load on the lunate by negative ulnar variance, but with no carpal slip (12).

Systemic lupus erythematosus has been associated with avascular necrosis of bone. In 1977, Urman presented several cases of patients with SLE and osteonecrosis of the carpal bones, including a case report of a patient with SLE and Kienbock's disease (8). The patient also had a history of Raynaud's phenomenon and was taking high-dose corticosteroids. In SLE patients treated with corticosteroids and who developed osteonecrosis, there was one patient who developed Kienbock's disease (5). This patient was treated with large doses of corticosteroids compared to those who did not develop Kienbock's disease. Mok et al. reported a case of bilateral Kienbock's disease in a patient with SLE (6). The patient described in this case report was never treated with corticosteroids and the etiology of Kienbock's disease was thought to be due to a vasculopathy caused by either vasculitis or antiphospholipid antibodies, even though this patient tested negative for lupus anticoagulant and anticardiolipin antibodies. More recently, Taniguchi et al. described two cases of Kienbock's disease in SLE after taking high doses of steroids (7). One of the cases was of a patient who developed bilateral osteonecrosis of the lunate. Both cases attributed corticosteroid use with the development of osteonecrosis. It is apparent that the cases of Kienbock's disease in patients with SLE were either attributed to high dose corticosteroid use or to the disease itself. More over, patients with Crohn's disease who use corticosteroids to control disease symptoms are known to develop Kienbock's disease and osteonecrosis of the hip (11). The same scenario also occurred in a patient with dermatomyositis taking high doses of corticosteroids for sixteen months (22).



Scleroderma associated with Kienbock's disease was first reported by Agus et al. in a patient with bilateral osteonecrosis of the lunate (16). This patient had severe Raynaud's phenomenon and was never treated with corticosteroids. The contributing factors were hypothesized to be vasculopathy, Raynaud's phenomenon, and a lunate consisting of a single nutrient vessel. Ribbans also reported a case of Kienbock's disease in a patient with scleroderma and severe Raynaud's phenomenon (18). The vasculopathy, scleroderma, and repeated use of the patient's affected wrist predisposed this patient to Kienbock's disease. Matsumoto et al. reported three cases of Kienbock's disease in three patients with scleroderma, two without a history of steroid use and one who only used low dose steroids prior to the diagnosis of osteonecrosis (17). All three patients also had limited skin involvement, but had severe Raynaud's phenomenon. They reported that scleroderma related vascular disease was likely the cause of the circulatory impairment leading to osteonecrosis.

Mok et al. reported a patient with rheumatoid arthritis who was found to have osteonecrosis of the lunate. They believed that the Kienbock's disease occurred in this patient due to an increase in intra-articular pressure within the wrist compartment, causing impedance of venous return, vascular insufficiency to the lunate, and subsequent osteonecrosis (19).

In addition to the various risk factors mentioned above, Kienbock's disease b is prevalent in specific patient populations. Rooker et al. found an increased prevalence of Kienbock's disease in a group of patients with cerebral palsy (9.4%) (32). This was thought to be related to an abnormally flexed posture of a spastic wrist, which was present in all patients with Kienbock's disease in this study and could impede blood flow. Joji et al. also found an increased prevalence of Kienbock's disease in patients with cerebral palsy (2.7%) (33). They believed that the high muscle tone across the wrist in an ulnar negative wrist caused an increased pressure on the lunate. This cause is consistent with repeated microtrauma leading to vascular compromise and ultimately osteonecrosis.

While the association between Kienbock's disease and several of the reported cases could be coincidental, having a rheumatologic co-morbidity such as JIA could represent a risk factor for Kienbock's disease, as seen in the presented case report. The wrist is the second most common site of growth abnormality in patients with JIA (34). Several changes occur at the wrist, including narrowing of the intercarpal spaces, premature ossification of the carpal bones, and early fusion of the ulnar epiphysis leading to a shorter ulna (negative ulnar variance) (35). The wrist ultimately becomes displaced ulnarly and volarly leading to a dislocation of the wrist and bayonet deformity. Therefore, it is possible that the abnormalities in the wrist associated with JIA could lead to abnormal stresses and or pressures in the wrist that led to Kienbock's disease. Furthermore, the erosive changes in other carpal bones may lead to a change on the normal force patterns in the patient's carpus. Seven years prior to the onset of Kienbock's disease, our patient was also treated with low-dose corticosteroids which could have also disrupted circulation and led to the development of lunate osteonecrosis.

The precise etiology of Kienbock's disease remains elusive. Several theories attempt to explain its pathogenesis, which suggests that it may be multifactorial. Many risk factors have also been identified; steroid treatment, a predisposing rheumatologic disease, a variation in lunate blood supply, and possibly negative ulnar variance. Our case demonstrates the possible relation between Kienbock's disease and JIA. It also suggests that Kienbock's disease could be a possible cause of wrist pain and stiffness in patients with JIA.

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CASE REPORT

# A New Palmo-Shoulder Compression Association

Hani Sinno*, Teanoosh Zadeh

## INTRODUCTION

Carpal tunnel syndrome is a most common peripheral compression neuropathy (1). It is caused by mechanical compression of the median nerve as it traverses the carpal tunnel of the wrist. Classic signs and symptoms are numbness of the lateral three digits and weakness of the thenar muscles due to atrophy (2). Important diagnostic tests include electromyography (EMG) and nerve conduction studies. The gold standard for the surgical treatment is transection of the transverse carpal ligament.

## CASE REPORT

A thirty-eight year old right-handed construction worker presented to the McGill University Health Center Plastic Surgery clinic with complaints of bilateral carpal tunnel syndrome. He had no other relevant past medical history, was not taking any medications, and had no known allergies. On further history, he complained of a ten-year period of slowly progressing symptoms of hand numbness, pain, and paresthesias in the median nerve distribution distal to the wrist.

On physical examination he demonstrated positive Phalen and Tinel Test bilaterally. He had no obvious thenar eminence wasting and his grip strength was weakened. His EMG and nerve conduction studies demonstrated moderate to severe carpal tunnel syndrome bilaterally.

A routine open carpal tunnel release was performed on his right hand and the patient had complete resolution of his carpal tunnel symptoms with no complications. Two months later he was scheduled to have the same surgery for his left hand. At this time, he said he was having bilateral shoulder weakness for the past two years and had not sought medical attention for it sincehe attributed it to strenuous physical work and fatigue secondary to his occupation. He explained that he was unable to elevate and abduct his arms above his shoulder prior to his right median nerve decompression, at which point he regained full range of motion and strength of his shoulder.

Directly after his left carpal tunnel release the patient was able, with full strength, to elevate and abduct his left shoulder.

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## LITERATURE REVIEW

Using PubMed and Medline database, an online search using the headings "carpal tunnel release" and "shoulder abduction" was done to determine the occurrence and frequency of the observed phenomenon presented in the case report. No results were found. Further searches with headings of "carpal tunnel release" and "shoulder weakness" also revealed no published material. The same was done with "shoulder extension"and "shoulder paralysis" and resulted in the same outcome. A search using the headings "carpal tunnel" and "shoulder flexion" demonstrated one paper by Vaught et al (3). The authors have concluded that the likelihood of patients with carpal tunnel syndrome having associated thoracic outlet syndrome (TOS) is sixteen times higher than control subjects. They have demonstrated that patients with carpal tunnel syndrome may also concomitant proximal nerve entrapment. The case presented in this manuscript reveals that a distal release of an entrapped nerve compartment, in this case the median nerve within the carpal tunnel, has relieved the weakness of a proximal muscle group, the shoulder.



## DISCUSSION

The median nerve is formed from the medial and lateral cords of the brachial plexus. The nerve roots are typically C5-C7. It courses in the arm supplying flexor muscles in the forearm and lateral muscle in the hand, and is responsible for sensation of the lateral part of the palmar surface of the hand. The typical sites of median nerve compression include the carpal tunnel, specifically, beneath Struthers' ligament at the distal humerus, and in the pronator teres muscle. This results in carpal tunnel syndrome, anterior interosseous syndrome, and the pronator syndrome respectively. The median nerve and all its sites of compression have not been shown to cause shoulder weakness and an inability to abduct the arm. This is most likely due to the fact that this maneuver is the function of the axillary nerve (C5, C6 nerve root), a branch of the posterior cord of the brachial plexus.

The only reported median and axillary nerve combined weakness occur secondarily from proximal compression or defects found in obstetrical injuries, aberrant proximal rib anatomy, and traumatic injuries to the brachial plexus for example. All the described joined median and axillary nerve syndromes are a result of proximal defects. The present case presented with complete resolution of median and axillary nerve weakness after a distal nerve compression surgical procedure. The patient in the present case appears to have an aberrant connection of his median nerve with his axillary nerve or distal compression of the common nerve roots axons that could explain his upstream nerve weakness secondary to the median nerve compression in the carpal tunnel. Although it is known that proximal nerve compression such as those seen in TOS can be associated with carpal tunnel symptoms, it has never been shown that the distal release of the flexor retinaculum can relieve the proximal symptoms.

We have presented a unique case that likely shows a new peripheral nerve phenonmenon between the axillary and median nerve. This finding is of interest to family physicians, neurologists, plastic surgeons, and orthopedic surgeons who are routinely involved in the diagnosis and management of carpal tunnel syndrome. If an association of TOS is demonstrated, further proximal nerve studies should be made to rule-out this phenomenon.

We suggest a treatment through surgical carpal tunnel release for patients that present with carpal tunnel syndrome combined with unilateral shoulder abduction weakness in the case where no other proximal injuries or abnormal anatomic or neurologic etiologies are found.

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MJM 2011 13(2): 16-19


CASE REPORT

# Teenage Female with Knee Pain and Instability

Patricia Jo*, David A Leswick, Lauren A Allen

## INTRODUCTION

Congenital dislocation of the knee, resulting from an absence of the cruciate ligaments, is a condition affecting 0.017 per 1000 live births (1). Although very rare, it has drawn the attention of orthopaedic surgeons and radiologists because it is associated with other congential anomalies. This paper presents abnormalities that are isolated to the knee and without evidence of associated syndrome. The absent anterior cruciate ligament (ACL) is associated with a hypoplastic posterior cruciate ligament (PCL), a shallow femoral notch, and hypoplastic tibial spines seen with radiographic and magnetic resonance imaging. The objective of this article is to review the clinical presentation and imaging findings associated with congenitally absent ACL.

## THE CASE

A 16-year-old female presented to a pediatric orthopaedic surgeon with a history of right knee symptoms. Beginning at two years of age, her mother noticed atrophy of her right leg and abnormality in gait when she first began to walk, leading to recurrent falls. Her left leg was asymptomatic. At that time, a pediatric neurologist assessed her, and spine MRI and EMG studies were performed, showing no abnormalities. At age five, she began to function normally and she enrolled in dance and gymnastics. These activities appeared to help her with balance and strength.

At the time of evaluation, the patient was very active and played soccer. However, she described a five month history of poorly localized intermittent pain and tightness in the right knee after standing or walking long hours. Her pain was rated 4/10. She used an over-the-counter knee brace that provided some relief. She denied swelling, clicking, catching, or other symptoms of instability. There was no history of significant knee trauma or family history of similar problems.

Clinical examination revealed valgus alignment bilaterally, which was worse on the right side. The right leg was noted to be slightly smaller in girth than the left and there was no obvious leg length discrepancy. Gait demonstrated a valgus thrust and apparent instability in the sagittal plane with each step. She had full range of motion with no crepitations and no joint line or patellar tenderness. Positive Lachman, pivot shift, and anterior drawer tests were demonstrated with a negative McMurray's test. No other physical findings of interest were noted. The differential diagnosis for this patient was very limited and included traumatic or congenital absence of the right ACL.

AP radiograph demonstrated a shallow femoral intercondylar notch and hypoplastic tibial spines (Figure 1). Lateral view of patient in the right


**Figure 1**: Standing AP radiograph from a full-length leg series shows valgus knees bilaterally, worse on the right. A shallow femoral intercondylar notch (white arrow) and hypoplastic tibial spines (black arrow) are visible in the right knee.

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**Figure 2**: Lateral right knee radiograph with the patient positioned in right lateral decubitus reveals normal alignment without subluxation of the tibia on the femur. Tibial spines are hypoplastic (black arrow). Physes are closed.

**Figure 3**: Coronal proton density fat-suppressed MRI demonstrates a shallow femoral intercondylar notch (white arrow), absent intercondylar eminence (black arrow) and a downward slope of the medial tibial condyle. There is no evidence of the ACL

lateral decubitus position showed a hypoplastic intercondylar eminence in the right knee (See Figure 2). MRI demonstrated the shallow femoral intercondylar eminence and hypoplastic tibial spines. No ACL fibers were visible. There was complete hyaline cartilage covering the area where the tibial eminence appeared to be aplastic and complete cartilaginous coverage of the shallow femoral notch anteriorly. Sagittal view showed anterior subluxation of the tibia, the imaging equivalent of an anterior drawer test. This is seen on the MRI with the patient in a supine position, because this position allows the weight of the upper leg to posteriorly subluxate the tibia. Associated hyperbuckling of the hypoplastic posterior cruciate ligament is also identified (See Figures 3 and 4).

Although examination showed significant instability of the knee and imaging studies were abnormal, the patient said she was able to perform and function at a reasonable level. She was advised to follow up with her orthopaedic surgeon annually for further imaging studies and to evaluate any progression of symptoms, at which time large ligament reconstruction may be considered.

## DISCUSSION

The first suspected case of congenital absence of the ACL was reported in 1956 (2) and was later confirmed in 1967 by surgical exploration in patients with congenital dislocation of the knee (3). Since then, it has been described in several cases in association with dysplasia of other structures in the knee including the menisci (4,5), tibial spines (2,6), intercondylar notch (7), and the PCL (8). In addition, congenital absence of the ACL may coexist with other congenital anomalies as part of a syndrome complex (9-11). It is less commonly seen as an isolated abnormality (12).

Thomas et al. identified tibial and fibular dysplasia as well as dislocation of the patella as the most common radiographic findings associated with congenital absence of the ACL (8). Others have frequently found absence of the cruciate ligaments in those with congenital femoral deficiency and post-axial hypoplasia (7,13,14). Associated conditions beyond the lower extremities include thrombocytopenia-absent radius syndrome (11) and arthrogryposis (10).

Abnormalities of structures exisat within the knee joint itself. Manner et al. evaluated a series of 34 knees in 31 patients with congenital cruciate ligament abnormalities on magnetic resonance imaging (7). The author defined three patterns of cruciate ligament dysplasia: hypoplasia or absence of the ACL with normal PCL (type 1 in 56%), aplasia of the ACL with hypoplastic PCL (type 2 in 21%), and total absence of both ACL and PCL (Type 3 in 24%) (7). Aberrations of the menisci have also been de-

**Figure 4**: Sagittal proton density fat-suppressed MRI reveals anterior subluxation of the tibia on the femur, the radiological equivalent of the anterior drawer test. The posterior cruciate ligament is hypoplastic and buckled (black arrows). A single cartilaginous surface covers the majority of the tibia (white arrows).

scribed in some cases as being ring-shaped (4,12) or discoid (5,7). Moreover, osteochondritis dessicans has been identified in conjunction with absent ACL (7,15).

Embryological studies of the knee joint indicate that at approximately seven weeks post ovulation, the femoral and tibial condyles are well defined and the interzone contains a three-layered blastema (16). The menisci, capsule, and cruciate ligaments all arise from this blastema, perhaps explaining why abnormalities in these structures commonly co-exist (3).

Often times, it can be difficult for radiologists to distinguish between traumatic and congenital causes for an absent ACL, however; there may be several clues that may suggest one or the other. For children younger than fourteen years of age, injuries to the ACL are less commonly seen since the physeal plates are not yet fused and traction forces are more likely to cause epiphyseal separation, long bone fractures, or avulsions of the tibial eminence rather than a disruption of the ligament (17). History of trauma to the knee suggests a traumatic cause while the radiographic finding of a hypoplastic intercondylar eminence may support a congenital cause for ACL deficiency (18).

Manner et al. performed the largest known study examining radiographic changes in knees with arthroscopically proven aplasia of the cruciate ligaments (7). Based on tunnel view radiography, the intercondylar notch was found to be more narrow and shallow in deficient ACL knees when compared to unaffected knees (7). It is thought that the purpose of the femoral intercondylar notch is to house the cruciate ligaments and the tension created by their insertion can cause secondary development of the tibial spines (2).

In those with absent ACL and normal or hypoplastic PCL, the lateral tibial spine was found to be aplastic and the medial spine was minimally affected (7). Since the medial tibial spine is the location for ACL insertion, Manner et al. hypothesized that the lateral tibial spine is affected rather than the medial spine. He speculated this because the lateral aspect of the femoral notch was also found to be hypoplastic in those with absent ACL and this resulted in molding and underdevelopment of the lateral tibial spine (7). In those with complete absence of both the ACL and PCL, he found both tibial spines were aplastic and the tibial eminence was flattened (7). With these type 3 deficiencies, the distal femoral epiphysis appeared concave and the proximal tibial epiphysis was convex, giving a "ball-and socket"- type knee joint (7). In the same study, magnetic resonance imaging showed hyaline cartilage covering the area of the femoral notch when both cruciate ligaments were absent (7). Authors continue to debate whether the changes in the femoral intercondylar notch and the tibial spines are congenital or simply a secondary response to the aplastic cruciate ligaments.

Reconstruction of the ACL has been shown to be a viable option for symptomatic patients with absence of the ACL (19). Nevertheless, there are indeed patients who remain asymptomatic and continue to be observed. Long-term outcome of those with knee instability caused by congenital absence of the cruciate ligaments is very good and many do not develop longer-term degenerative changes (6).

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CASE REPORT

# A Man with a Neck Mass, Pleural Effusion and Hypoechoic Masses in the Right Atrium and Ventricle

Rabiya Jalil*, Habib ur Rehman

**CASE STUDY**

A previously healthy 55-year old Caucasian male presented with a two month history of flu-like symptoms, dry cough, and progressive shortness of breath. He also presented with a one and a half month history of a slowly growing painless swelling on the left side of his neck. Examination revealed normal vital signs, an erythematous, firm but mobile mass on the left side of the neck, and signs of a right sided pleural effusion.

Transesophageal echocardiography (TEE) showed a 4.5 X 3 cm echodensity in the right ventricle. Furthermore, a 3.5 X 3.5 cm sessile echodensity was noted in the right atrium. The left and right ventricles were normal in size and function with an ejection fraction of 60%. There was trace circumferential pericardial effusion.

CT scanning of the neck displayed a fungating and ulcerating soft tissue mass situated at the dermal layer measuring 3.5 X 1.7 cm and located above the level of the hyoid at the lower end of the left parotid gland. CT of the chest revealed an extensive bulky filling defect in the right atrium, right ventricle, and outflow track at the level of the pulmonary valve. Multiple low density lesions were evident in the right lobe of the liver (Figure 1). Lymphadenopathy was noted inferior to the aortic bifurcation.

In addition, biopsy of the neck mass revealed a lymphoid infiltrate with atypical features. A majority of cells were positive for CD20, CD10, CD79a, and TdT, but negative for CD34, and BCL-2 on immunohistochemical staining. Proliferation rate approached 100% for Ki-67. The morphology was consistent with a high grade B-cell lymphoma with atypical Burkitt/Burkitt-like features.

**DISCUSSION**

Incidence of cardiac neoplasia is very low (1). Most cardiac neoplasms are metastatic, atrial myxoma being the most common primary cardiac tumor. Lymphomas constitute 9% of the total metastases. Cardiac involvement by disseminated non-Hodgkin's lymphoma has been documented in approximately 20% of autopsy cases to the heart (2).

Burkitt-like lymphoma is a highly aggressive form of non-Hodgkin's lymphoma and associated with poor short-term survival. Extranodal Burkitt Lymphoma involving the heart is rare and seldom recognized clinically. Diagnosis is usually made late because of the non-specific nature of the symptoms. Right-sided heart failure, dyspnea, superior vena cava obstruction, pericardial effusion with or without tamponade, and rhythm disturbances are the usual presenting features. The average age at presentation is sixty, with a slight male predominance (3). Transesophageal echocardiography (TEE) is superior to transthoracic echocardiography (TTE) in assessment of cardiac lymphomas and typically shows a hypoechoic mass in the atria or ventricles that is often associated with pericardial effusion. Although multidetector computed tomography and magnetic resonance imaging will provide information about the staging of disease, biopsy of the mass is needed to make the diagnosis (4). Chemotherapy is the first line treatment, however complete remission is achieved in less than 60% of patients.

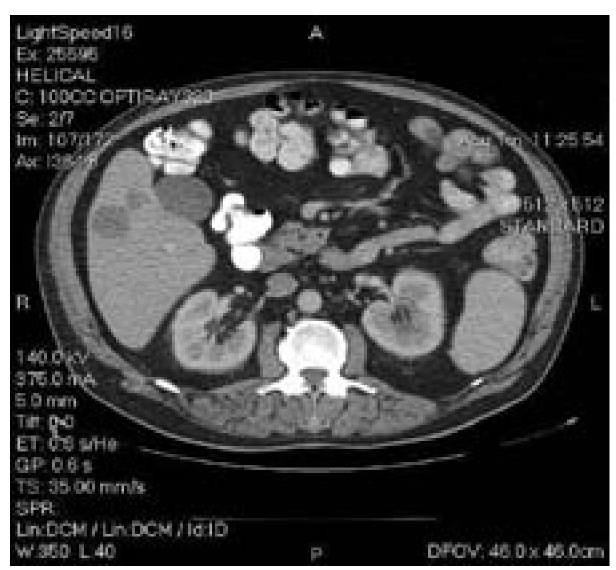


**Figure 1**:CT image showing multiple low density lesions in the liver.

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ORIGINAL ARTICLE

# Poverty Reduction Strategy Papers and their contribution to health: An Analysis of Three Countries

Sam Bartlett*

**ABSTRACT: Poverty Reduction Strategy Papers (PRSPs) represent the World Bank and the International Monetary Fund's (IMF) most recent initiative for reducing the plight of the poor. This paper examines whether the PRSPs for Liberia, Afghanistan and Haiti follow World Bank guidance on health. The health data, analysis and strategy content of the three PRSPs are assessed with respect to the 'Health, Nutrition and Population' chapter of the World Bank's PRSP Sourcebook. This guidance states that PRSPs should include: health data on the poor and a clear analysis showing the determinants of ill health and pro-poor health strategies. Unfortunately, none of the PRSPs analysed comply with the guidance and, consequently, do not adequately portray the health situation within their countries. Thus health is not given a high priority in the PRSP process and is seemingly low on the agenda of both poor country governments and the International Financial Institutions (IFIs). If the situation for the world's poorest people is to improve, health and the right to health need to be promoted within PRSPs.**

*Keywords*: World Health, Developing Countries, International Cooperation, International Agencies, Poverty, Health Policy

## INTRODUCTION

The relationship between poverty and health has been widely reported. Moreover, extreme poverty is classified as a disease in itself (1). More than one billion people worldwide live in extreme poverty, which equates to an equivalent income of less than $1.25 per person per day at purchasing power parity. Reducing poverty is an international priority and is the focus of the Millennium Development Goal 1.

The World Bank and the International Monetary Fund (IMF) are United Nations organisations. They are International Financial Institutions (IFIs) that are involved in global development, providing countries with technical, operational, and financial assistance. Poverty Reduction Strategy Papers (PRSPs) represent their most recent initiative for reducing the plight of the poor.

This paper seeks to assess whether the health content of three PRSPs, Liberia, Afghanistan and Haiti, follow the guidance provided by the World Bank. Specifically, the PRSPs are examined with respect to Chapter 18 of the World Bank's Sourcebook entitled 'Health, Nutrition and Population' (from now on HNP Sourcebook) (2) concerning health data, data analysis, and health strategies.

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## A BACKGROUND TO PRSPS

PRSPs are documents written every three years by governments of less economically developed countries (LEDCs) and are intended to "describe a country's macroeconomic, structural and social policies and programs to promote growth and reduce poverty, as well as associated external financing needs" (3). PRSPs promote 'national ownership' and place poverty reduction at centre stage (4). Governments can produce an interim PRSP (iPRSP) before developing a full PRSP, enabling them to qualify for partial debt relief without having to wait until a full PRSP is prepared (5). The World Bank and IMF analyse a country's PRSP and write a Joint Staff Assessment Note (JSAN). Countries require positive JSAN feedback to receive debt relief (6). In addition to debt relief, PRSPs represent the main mechanism for LEDCs to receive both loans from the IMF and World Bank (6) and foreign aid (7).

There are fears that countries develop PRSPs with a rushed approach, which are biased in favour of donor wishes, in order to receive much needed financial aid (5, 6). In addition, even though the countries preparing PRSPs have different economic climates, resources, and governments, PRSPs have resulted in very similar economic policies. The homogenous nature of economic policies given in PRSPs, suggests that IFIs are influencing LEDC governments and thus that there is a lack of country-ownership (8).

Both iPRSPs and PRSPs have been criticised for their inadequate health content. For example, Laterveer et al. (9) found few iPRSPs gave disaggregated health data for income and most did not identify the major causes of illness amongst poor populations. In one study, six of twenty-one PRSPs gave no disaggregated health data at all (10). This results in the PRSPs that do not discuss the inequalities in health between the rich and the poor and thus, this questions their poverty focus. Major causes of illness were identified but with scant evidence and analysis (10). In addition, there is a lack of analysis on why and how health systems are failing the poor (10). Niger and Mozambique, for example, provided disaggregated health data by district and yet the inequalities identified were not addressed in their health system strategies (10). Additionally, it is difficult to determine whether health strategies outlined in PRSPs are new and due to the PRSP process or are from existing health strategies (5, 10). It may be that governments simply 'copy and paste' existing health policies into PRSPs, possibly in an attempt to complete the PRSP as quickly as possible.

Whilst PRSPs seemingly approach health from a developmental perspective, as a tool for increasing human capital and economic growth, none address health as a human right (1, 6, 10). The right to health is enshrined in various human rights documents like Article 12 of the UN International Covenant on Economic, Social and Cultural Rights (ICESCR) (11) and within the constitution of the World Health Organisation (WHO). Furthermore, every State has an obligation to work towards a global realisation of this right.

## METHODS

All PRSPs available on the World Bank website were included in the selection process. Countries which submitted PRSPs from 2005 onwards were first selected. It is clear that countries with multiple PRSPs tended to include much more health data in the first PRSP than the subsequent papers. Therefore, this analysis was confined to a country's first PRSP. Thirteen PRSPs met these inclusion criteria and, in order to facilitate a detailed analysis, three PRSPs were selected at random from different continents. Wider determinants of health such as water, sanitation, housing and education are, in practice, intractable from this discussion, however are addressed outside of the HNP Sourcebook. In addition, although the HNP Sourcebook discusses nutrition, PRSPs commonly discuss it separately from health. Therefore, to maintain consistency and clarity, these factors are not discussed at length.

## THE WORLD BANK'S SOURCEBOOK

The World Bank defines the Sourcebook as a framework and not a blueprint, emphasising that it is not mandatory for countries to rigidly follow it (12). The HNP Sourcebook briefly discusses the relationship between poverty and health, subsequently addressing the key stages in policy design; diagnostics and analysis, government action, prioritisation, and monitoring and evaluation (2). A summary of the recommendations made by HNP Sourcebook is given in Figure 1.

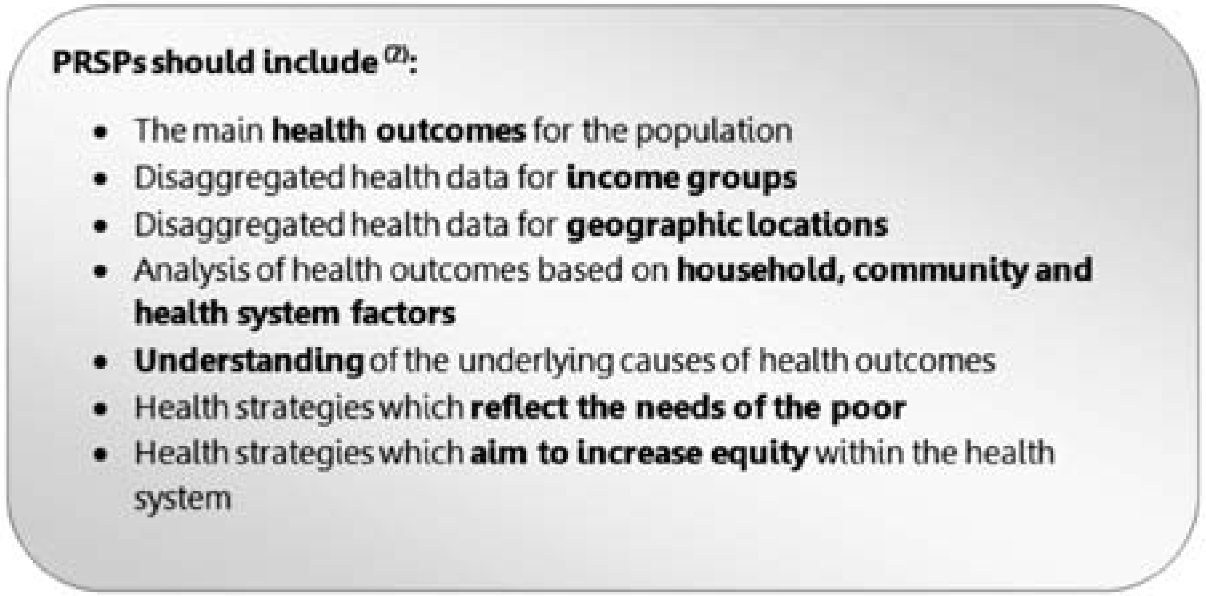


**Figure 1:** The main recommendations made by the HNP Sourcebook. Note: Examples of household factors are: household income and knowledge of health services. Examples of community factors are: cultural norms and community institutions. Examples of health service factors are: accessibility of services and human resources within services.

## THREE PRSPS: AN ANALYSIS

All three countries in this analysis (Liberia, Afghanistan, and Haiti) face challenges overcoming damaged infrastructures and dilapidated public services. Thus, they face considerable difficulties in collecting health data and subsequently developing health policy.

*Data*

All three PRSPs contain only limited health data and disaggregated data is missing despite the HNP Sourcebook emphasising its importance. Consequently, the health situation within the countries, the extent of health inequalities, and the population groups in greatest need are not reported. For example, the PRSP for Liberia gave the infant mortality rate (IMR) as 72 deaths per 1000 live births. However, it did not break this down by population group. Prior to the PRSP, the Government of Liberia conducted a Demographic Health Survey (DHS) (13) which showed that the IMR was higher for poorer households, yet this evidence was not included in the PRSP. Similarly, in Afghanistan, maternal mortality rates have been shown to vary between districts and are fifteen times higher in Ragh (rural) than Kabul (urban) (14), but this information is not included in their PRSP. Without such data, it is difficult to understand the variations in health outcomes between population groups and one cannot determine the burden of disease amongst the poor. A checklist of the data included in the PRSPs compared with the recommendations made by the HNP Sourcebook is shown in Figure 2.

*Analysis*

All three PRSPs give some aetiology of the health outcomes they provide data for, however, evidence for household and community factors is limited. This is a potential problem considering an understanding of community factors like social and cultural norms, is imperative for the design of many interventions, especially community interventions or education programs. For example, in some parts of Afghanistan, there are normalised gender inequalities such that a women must require consent from her husbands in order to visit a health facility (15). This cultural practice is which are critical to the health situation of women in this cournty, yet Afghanistan's PRSP does not mention this.

The most commonly cited health system limitations are physical accessibility and availability of human resources, the importance of which is emphasised in the HNP Sourcebook. However, all three PRSPs lacked the disaggregated data required to fully understand the barriers facing the poor.

Providing pregnant women with professional supervision at the time of delivery is important to maternal health and yet all PRSPs approached this with inadequate analysis. All three PRSPs included the percentage of births attended by a trained health worker, which was below 50% in all cases. However, there is no explanation why this is low (16-18). Furthermore, none of the PRSPs give disaggregated data by income, wealth, or region. The Liberian DHS provides disaggregated data on the percentage of births attended by a trained health worker and showed this to be lower for women who give birth at home, in rural areas and, in lower income groups (13). Once again, this data was not included in Liberia's PRSP (17) hindering potential links that could be made between health outcomes and specific limitations within the health sector.

In another example, pregnant women in Ragh, Afghanistan, are more likely to die during birth than women in Kabul (14). In addition, none of the women who died during pregnancy in Ragh had a health worker present during delivery (14). Using this information, it could be suggested that the health system is failing women in Ragh and additional information is needed to understand why. Maybe health facilities in Ragh are inaccessible to most women or perhaps pregnant women are being denied the opportunity to give birth in a health facility by their families. However, this information is missing in Afghanistan's PRSP and similar content is missing in the PRSPs of both Liberia and Haiti. All three PRSPs highlight maternal mortality as a concern and yet the gravity of maternal health is insufficiently analysed. A checklist of analyses included in the PRSPs has been given in Figure 3.

*Health Strategies*

Drawing links between the burden of disease within the countries and the health strategies they propose is difficult given the lack of data and analysis. The problem worsens in the absence of disaggregated data, making it hard to establish whether countries are targeting the poor or worse off population groups. All three PRSPs align their objectives with the Millennium Development Goals – specifically 4, 5 and 6 (reducing maternal and child mortality and the prevalence of major diseases, respectively) and all aim to improve accessibility to and the quality of health systems (16-18). Although none of the PRSPs explicitly target the poor within their health strategies, they do target rural populations, notably by aiming to improve primary health care and to increase accessibility to a basic package of health services (BPHS) (16, 17). Haiti's PRSP does not mention implementing a BPHS (18). A BPHS could be of benefit in Haiti considering nearly half of the population lack access to basic healthcare and, consequently, 80% turn to traditional medicine (19).

All PRSPs are deficient in detailed links between analysis and health strategies. In all three countries, women in rural areas are less likely to receive medical attention during labour (13, 14, 20). Accessibility to facilities amongst pregnant women is questionable. This is noted in Afghanistan's

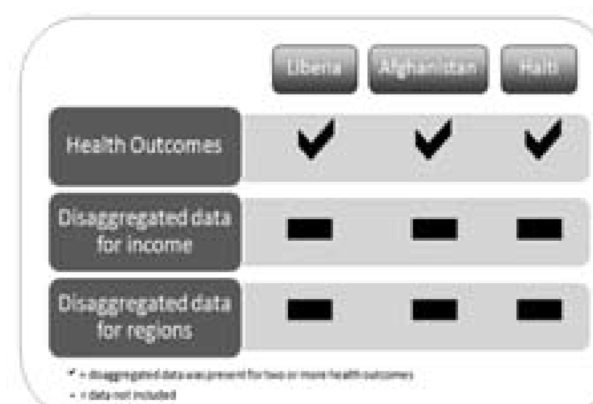


**Figure 2:** Data checklist for PRSPs vs the HNP Sourcebook recommendations

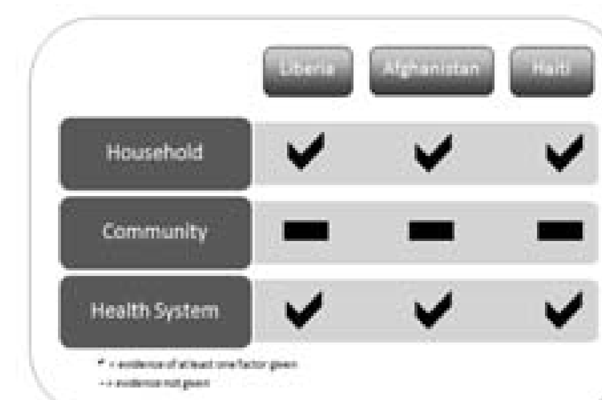


**Figure 3:** Analysis checklist for PRSPs vs the recommendations made by the HNP Sourcebook

PRSP (16) and Chatterjee (19) reports that some women in Haiti face a six hour or more journey to the nearest health facility. Because of such barriers, “many pregnant women die en route” (19). One approach to tackling the high maternal mortality in these countries could be to provide delivery care in women’s homes. If performed by a skilled birth attendant and appropriate referral mechanisms are in place, this can achieve marked reductions in maternal mortality (21). If there were greater discussion within the PRSPs, that forged links between health outcomes and their aetiologies, a better understanding of the interventions required to improve the health of those most in need could be discerned. A checklist for health strategies is shown in Figure 4.

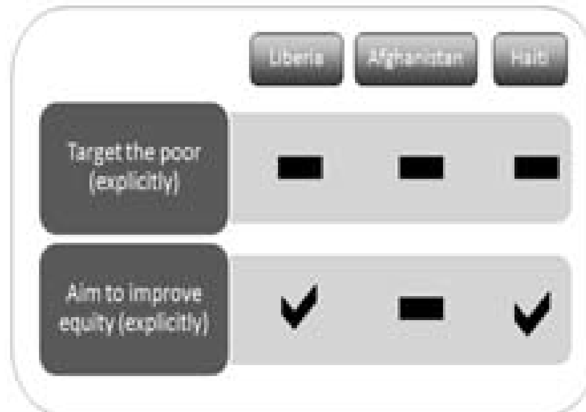


**Figure 4:** Health strategy checklist for PRSPs vs recommendations made by the HNP Sourcebook

**DISCUSSION**

This paper seeks to assess whether the health contents of three PRSPS (Liberia, Afghanistan and Haiti) are aligned with the suggestions made in the HNP Sourcebook, in relation to health data, health data analysis and health strategies. It was found that the three PRSPs contain inadequate health data (most notably disaggregated data) and insufficient analysis needed to portray the health situation in each country. Consequently, it is difficult to identify the health strategies which target the poor. This may be seen by donors as a lack of government capacity, which could threaten the aid the countries receive, with disastrous effects for the health sector. It is understandable, given the recent history and current situation of these three countries, that it may not be feasible to collect comprehensive data. However, in some instances, official data from surveys, for example, was available and was not included in the PRSPs, representing a serious missed opportunity. This suggests that governments are not paying due attention to health, which could be due to a number of reasons; governments may take a rushed approach when preparing PRSPs in order to quickly benefit from debt relief or t health may not be a high priority on the country`s domestic agenda. Governments may believe the IFIs do not consider health to be a priority for PRSPs and make conscious decisions to focus on other areas.

The feedback from the World Bank and IMF on the PRSPs of Liberia, Afghanistan, and Haiti does not comment on the absence of disaggregated health data and analysis of health outcomes or provide a critique of the health strategies proposed in the PRSPs (22-24). The World Bank and IMF have produced guidelines (25) for the staff responsible for writing the JSANs (referred to by the World Bank and IMF as ‘the staffs’), which state that these should be “selective, and present a limited number of priority areas for strengthening”. Therefore, it can be assumed the staffs did not consider the gaps in health that have been highlighted in this paper from the three PRSPs to be high priorities. It is possible, then, that the World Bank and IMF actually do not consider health to be a priority in PRSPs.

The HNP Sourcebook, along with PRSPs, does not recognise health as a human right. This further supports the hypothesis that health is not high on the IFIs agenda. Hammonds and Ooms (26) suggest that, in order to protect the right to health, LEDCs are obliged to raise sufficient funds for health. However, the World Bank and IMF recommend governments restrict the amount they spend on health in order to maintain macroeconomic stability. This can reduce the amount of money LEDCs ask for from donors and in turn reduces the amount of money they receive (26). As a result, the authors posit that the World Bank does not allow countries to raise enough money to uphold their obligations to protect the right to health. They argue that countries partial to the ICESCR - which make up over 75% of the votes on the International Development Association (IDA) board - should use their influence to compel the World Bank to align with the ICESCR and recognise health as a human right. Verhuel and Rowson (27) go further and argue that human rights should be embodied



in policies prescribed in PRSPs and that countries should reject reforms proposed by the World Bank and IMF that result in the breach of these rights.

In addition, whilst analyses of health in PRSPs have been carried out, to my knowledge no such analysis or critique of the HNP Sourcebook exists. Thus, the guidelines provided by the World Bank and used by countries to prepare the health sections of PRSPs, have not been analysed in depth and accordingly revised.

Health and the right to health require further promotion in the PRSP process and the World Bank’s agenda needs to be challenged. The WHO is responding to calls for assistance from LEDCs by developing a database to monitor health in PRSPs and by providing guidance to countries in the preparation of PRSPs (10). For this to be successful, a strong leadership is needed from the WHOin order to raise the priority of health at all levels.

**CONCLUDING REMARKS**

The three PRSPs analysed do not provide adequate health information as recommended by the HNP Sourcebook. Consequently, none of the PRSPs clearly portray the health situation in their country and thus PRSPs are not affording due attention to health. It appears that health is a low priority for the World Bank and needs further promotion through the PRSP process so that health is recognzed as a human right and is subsequently placed firmly in the centre of the development agenda. PRSPs represent an opportunity for LEDCs to bring their people out of poverty. However, if health continues to receive insufficient attention, the situation for the world’s poorest people unlikely improve.

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**ORIGINAL ARTICLE**

# Salvage Resection for Isolated Local and/or Regional Failure of Head/Neck Cancer Following Definitive Concurrent Chemoradiotherapy

## Case Series and Review of the Literature.

Patricia L. Kearney, John M. Watkins*, Keisuke Shirai, Amy E. Wahlquist, John A. Fortney, Elizabeth Garrett-Mayer, M. Boyd Gillespie, Anand K. Sharma

**ABSTRACT - *Background*: Primary management of advanced head/neck cancers involves concurrent chemoradiotherapy . Subsequently, regional and local failures are managed with resection but there have been few reports that describe the morbidity and disease control outcomes of surgical salvage in this setting. *Methods*: Retrospective analysis describes complications, survival, and patterns of failure after salvage resection of isolated local and/or regional failures of head/neck cancer following definitive concurrent chemoradiotherapy. *Results*: Sixteen patients were identified for inclusion: laryngectomy in 11 patients, oral cavity/oropharynx resection in 2 patients, and neck dissection alone in 4 patients. Ten patients required graft tissue reconstruction (6 pedicle and 4 free flap). Median post-operative hospitalization was 7 days (range 3-19), and 4 patients required hospital re-admission. At a median survivor follow-up of 15.8 months (range 4.3-34.9), 10 patients were alive (6 without evidence of disease). Seven patients experienced disease recurrence at a median 6.7 months (range 0-12.6) following salvage resection (2 with isolated distant failures). Estimated 2-year local/regional control, freedom from failure, and overall survival were 58%, 39%, and 58%, respectively. *Conclusions*: Surgical salvage after primary definitive concurrent chemoradiotherapy is feasible with toxicity and outcomes similar to prior radiotherapy alone or sequential chemotherapy and radiation. Local andregional recurrence remains the predominant pattern of failure.**

*Keywords*: Head and neck neoplasms, Combined modality therapy, Salvage therapy, Organ preservation therapy

## INTRODUCTION

Locoregionally advanced head and neck cancers are optimally treated with definitive concurrent chemoradiotherapy or surgical resection followed by radiotherapy with or without chemotherapy (1). Despite aggressive local treatment, approximately 20-36% of patients will experience locoregional recurrence within 3-5 years, representing 50-67% of all recurrences (1-3). In patients who experience disease recurrence within a previously irradiated field, aggressive salvage surgical resection is the preferred intervention (4). Previously reported series of surgical salvage have generally included patients treated with suboptimal primary

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therapy (radiotherapy alone or sequential chemotherapy and radiotherapy), while subsequent randomized trials (5-8) and a meta-analysis (9) have demonstrated superior locoregional control and survival for concurrent chemoradiotherapy over radiotherapy alone or sequential chemoradiotherapy (5), albeit associated with increased risk of adverse effects (5). Few studies have evaluated the complications and outcomes of surgical salvage of locoregional failures following modern platinum-based concurrent chemoradiotherapy (10-13).

The present study is a retrospective analysis of complications, disease control, patterns of failure, and survival in a cohort of patients treated with salvage surgical resection at the Medical University of South Carolina (MUSC).

## METHODS

### *Ethical Considerations*

Following Institutional Review Board approval at MUSC, a research spreadsheet was created with study-specific patient, treatment, and outcome data fields. Non-protected health information remained within the primary sources (departmental chart, quality assurance database(s), and/or electronic medical record system).

### *Selection Criteria*

Eligible cases were identified by review of the radiation oncology departmental quality assurance database and office management software. The database contained all patients at MUSC that were initiated on definitive chemoradiotherapy; eligible cases were identified within the database by searching for head and neck cancer patients. Surgical salvage was defined as curative-intent resection for residual disease or recurrent primary tumor, nodal disease, and/or second primary tumor within an irradiated field following platinum-based concurrent chemoradiotherapy. Primary definitive chemoradiotherapy and salvage resection and reconstruction (when necessary) were performed at MUSC in all cases. Exclusion criteria for this study included primary chemoradiotherapy at an outside institution, evidence of distant metastatic disease at the time of surgical salvage and/or post-salvage follow-up of less than 3 months (unless evidence of disease progression/recurrence and/or death). All patients included in descriptive outcomes analysis were required to have had pathologic proof of squamous cell carcinoma recurrence.

### *Patient Work-Up and Management*

All patients were initially evaluated at the MUSC Hollings Cancer Center multidisciplinary head and neck oncology clinic, with evaluations by surgical, medical, and radiation oncology physicians, as well as speech therapy and dental oncology/maxillofacial-prosthedontic specialists as indicated. Following complete metastatic workup, which consisted of chest computed tomography (CT) and/or positron emission tomography (PET or PET/CT), patients were offered surgical salvage based on feasibility surgical resection and/or patients' medical operability. When microvascular "free flap" reconstruction was required, peripheral vascular studies were performed in order to identify viable graft tissue harvest sites.

Surgical intervention was left to the discretion of the treating head/neck surgeon and reconstruction specialist. All patients underwent at least selective neck dissection at the time of salvage resection and more aggressive intervention in cases where there was neck recurrence (particularly with radiographic and/or clinical evidence of extranodal extension). When reconstruction was indicated, rotational flaps were constructed from pectoralis major and free flaps were harvested from anterior thigh, radial forearm, or fibula sites.

Following completion of treatment, patients were assessed at a minimum of every 3 months for 2 years, then every 6 months for 3 years, and annually thereafter. Surveillance fiberoptic endoscopy was performed routinely during follow-up appointments. A neck CT or MRI was generally performed 2-3 months following salvage resection, then again 6 months later and/or as indicated based upon clinical suspicion. During the follow-up period, metastatic surveillance with chest X-ray and/or chest CT was generally performed once within 6 months of salvage, then repeated in situations of clinical suspicion or at time of locoregional recurrence.

### *Endpoints and Definitions*

The principal outcome measure of this study was overall survival which was measured from date of salvage resection to last follow-up or death. Secondary outcome measures included duration of post-salvage hospitalization, post-operative complication rates, pattern of failure, locoregional freedom from failure, and overall freedom from failure. Patient status at last follow-up was recorded as "alive, no evidence of disease," "alive with disease," "died of disease," "died of treatment-associated toxicity," "died of other cause," or "died of unknown cause." Freedom from failure was measured from date of salvage resection to date of second recurrence (earliest sign of clinical, radiographic, or pathologic disease) or last follow-up if there was no evidence of disease recurrence. A patient was considered to have died of treatment-associated toxicity if there was clear association between toxicity and death or if the patient died during or within 30 days of hospitalization attributed to treatment toxicity (without other evident cause). Treatment-associated mortality was considered an event for freedom from failure. If a patient died of unclear cause, but was known to have had recurrent disease prior to death, he/she was considered to have died of disease. Patterns of failure were recorded by initial site(s) of disease recurrence.



| | Salvage Cohort ($n$=16*) | n | % |
|---|---|---|---|
| **Age** | | | |
| Median | 59 yrs | | |
| (Range) | (46-80) | | |
| ≥60 yrs | | 8 | 50 |
| **Gender** | | | |
| Male | | 12 | 75 |
| **Race** | | | |
| White | | 10 | 62 |
| **Initial Disease Site** | | | |
| Oropharynx | | 5 | 31 |
| Larynx | | 10 | 62 |
| Hypopharynx | | 1 | 6 |
| **Interval Since Definitive ChemoRT# Completion** | | | |
| Median | 7.6 months | | |
| (Range) | (1.6-27.6) | | |
| **Prior RT Characteristics** | | | |
| Median Dose | 7000 cGy | | |
| (Dose Range) | (4800-7000) | | |
| **Relation to Prior RT Field** | | | |
| In-Field | | 14 | 88 |
| Field Margin | | 2 | 12 |
| **Recurrent Tumor Site** | | | |
| Primary | | 10 | 62 |
| Second Primary | | 1 | 6 |
| Irradiated Neck | | 5 | 31 |
| **Chest Staging at Recurrence** | | | |
| None$ | | 1 | 6 |
| Chest Radiograph | | 5 | 31 |
| Chest CT &/or PET | | 10 | 62 |

**Table 1:** Patient, Tumor, and Staging Characteristics
*Excludes one patient without evidence of residual carcinoma at salvage resection. #ChemoRT=Cisplatin-based concurrent chemoradiotherapy. $This patient survived >5 years without recurrence.

### *Literature Review Search Criteria*

An Ovid Medline search was performed using the search terms "head and neck neoplasms," "local neoplasm recurrence," "recurrence," and "resection." Articles were searched for post-chemoradiotherapy salvage resection-specific experiences. A secondary search wasperformed by reviewing references from articles identified from the search.

### Statistical Analysis

The Kaplan-Meier method was used to calculate estimated locoregional control, freedom from failure, and overall survival for the entire cohort. Proportionality was tested for each covariate of interest. Those that failed were either not included or were reparameterized to adhere to the proportionality assumption. Cox regression was used to estimate the hazard ratio (HR) comparing risk of time-to-event outcomes by covariates. Disease control estimation, survival estimation, and univariate analyses were performed using R version 2.6.1 (The R Core Development Team; http://www.r-project.org).

## RESULTS

Between September 2001 and October 2007, 136 patients initiated platinum-based concurrent chemoradiotherapy for locoregionally advanced head/neck cancer. Isolated head/neck recurrence developed as the initial site of failure in 28 patients (20.6%) at a median survivor follow-up of 33.1 months (range 4.6-71.1). 17 patients underwent surgical resection as initial salvage intervention; however, one patient had no evidence of invasive disease at salvage resection (post-treatment biopsy at 5.5 weeks post-treatment completion had demonstrated residual disease). This patient was included in assessment of complications but excluded from the survival and patterns of failure analyses. Patient, tumor, and staging characteristics are shown in Table 1. All patients had been prescribed to a dose of 66-70 Gy, and all but one completed the prescribed course of therapy. Excluding this patient, the median initial chemoradiotherapy duration was 50 days (range 43-63), with one patient requiring a one-week treatment break (63 total treatment days). All but one patient had pathologic stage III-IV recurrent disease (Table 2) at salvation resection. The primary tumor adverse pathologic features of lymphovascular invasion and perineural invasion were identified in 3 and 4 cases, respectively, and 4 patients had microscopically involved margins at

| | pT0/Tx | pT1 | pT2 | pT3 | pT4a | pT4b |
|---|---|---|---|---|---|---|
| pN0 | | | 4 | 1 | 3 | 1 |
| pN1 | 3 | | | | | |
| pN2a | | | | | | |
| pN2b | | | | | | |
| pN2c | 1 | | | | 1 | |
| pN3 | | | | | 2 | |

**Table 2:** Recurrent Tumor Stage Characteristics.

salvage resection. Extranodal extension within the neck was documented in 5 cases.

Salvage surgical intervention involved total laryngectomy in 8 patients, total laryngopharyngectomy in 1 patient, supracricoid laryngectomy in 2 patients, oral cavity/oropharyngeal composite resection in 2 patients, and neck dissection alone in 4 patients. All patients' necks were surgically addressed at salvage, involving unilateral selective dissection in 5 patients, unilateral modified radical neck dissection in 2 patients, unilateral radical neck dissection in 1 patient, bilateral selective neck dissections in 6 patients, and bilateral modified radical neck dissections in 3 patients. 10 patients required flap reconstruction (6 pedicle and 4 free).

The median post-operative hospitalization was 7 days (range 3-19), with significant complications of hematoma (4), wound breakdown (3), and fistula (1). 4 patients required a median duration 13 day (range 4-30) hospital re-admission following initial dischargeReasons for re-hospitalization included pharyngocutaneous fistula, wound breakdown, neck abscess, and bleeding at the gastrostomy site (associated with supratherapeutic anticoagulation). One patient received immediate post-salvage chemotherapy and one concurrent chemoradiotherapy for adverse pathologic features (surgical margin and extranodal neck disease, respectively). 2 out of 10 patients who underwent graft tissue reconstruction at the time of salvage developed complications requiring intervention. One patient developed necrosis along the distal margin of a rotational pectoralis flap, requiring takedown and reconstruction using a second pedicle flap. No further complications were observed. Another patient experienced delayed would dehiscence of a free flap reconstruction, with pharyngocutaneous fistula formation approximately 2 months post-salvage/reconstruction. The flap was removed and the defect was reconstructed with a rotational pectoralis flap, resulting in no further complication.

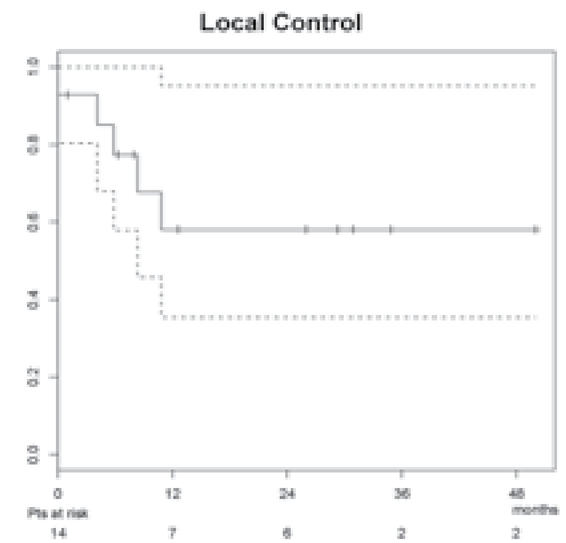


**Figure 1:** Locoregional control for salvage resection population. Fourteen patients at risk due to subtraction of two patients who died of treatment-associated toxicity within two weeks of salvage resection.

Two patients died of treatment-associated complications. One patient underwent salvage bilateral modified radical neck dissections for failure within an irradiated neck (4 months after completion of chemoradiotherapy for cT4aN2cM0 hypopharyngeal cancer originating at the pyriform sinus). Recurrent disease in the neck was significant for extension into the soft tissues of the neck as well as perineural and lymphovascular space invasion. The post-operative course was complicated by a neck hematoma requiring evacuation and an orocutaneous fistula, with a salivary leak. The patient was ultimately discharged 10 days after salvage resection but died 3 days later of unspecified cause. Another patient required surgical salvage for residual/progressive primary tumor 10 weeks following concurrent chemoradiotherapy (initial cT3N0 oropharyngeal cancer). Following salvage palatectomy with inferior maxillectomy and partial glossectomy with anterolateral thigh free flap reconstruction and bilateral selective neck dissections, the patient experienced bleeding from the oronasal and neck incisions. These complications resolved following discontinuation of heparin, after which the patient was discharged (8 days post-salvage). The patient died later that day of an unspecified cause.

At a median survivor follow-up of 15.8 months (range 4.3-34.9) post-salvage, 10 patients were alive (6 without evidence of disease) and 6 patients had died (3 of disease, 2 of intervention, and 1 of unknown cause ). Seven patients experienced disease recurrence at a median 6.7 months



post-salvage (range 0-12.6), involving 1 completely resected primary site, 1 incompletely resected primary site, 2 dissected necks, 1 resected primary and dissected neck, and 2 isolated distant failures. Secondary salvage interventions included chemotherapy in 2 patients, concurrent chemotherapy and re-irradiation in 1 patient, re-resection in 1 patient, and supportive care for 3 patients. The estimated median overall freedom from failure for the study group was 10.8 months, while the median overall survival had not yet been reached (and was thus inestimable). The estimated 1- and 2-year locoregional control were both 58.0% (95% confidence interval: 35.4%-95.2%), as demonstrated in Figure 1. The estimated 1- and 2-year overall freedom from failure were 46.9% (27.0%-81.4%) and 39.1% (20.2%-75.4%), respectively (Figure 2). The estimated 1- and 2-year overall survivals were 78.7% (59.7%-100%) and 58.3% (35.1%-97.0%), respectively (Figure 3).

Univariate analyses of patient-, tumor-, and treatment-related factor associations with locoregional control, freedom from failure, and overall survival are demonstrated in Table 3. Despite the limitation of small sample size, the pathologic nodal stage and presence of extracapsular carcinoma within the soft tissue of the neck were associated with significantly decreased rates of locoregional control and freedom from disease failure. The association of these factors with overall survival was not demonstrated at a statistically significant level; however, there was a trend toward worse survival for patients with metastatic carcinoma within neck soft tissue.

Toxicities, local control, and survival outcomes from the present study are pooled with other published series of surgical salvage following concurrent chemoradiotherapy in Table 4.

**DISCUSSION**

The role of surgical resection in locoregionally advanced head/neck cancer has evolved over time. Modern platinum-based concurrent chemoradiotherapy yields equivalent disease control, and is the preferred primary therapy when functional organ preservation is feasible (14). Despite ag-

| Factor | Locoregional Control | | Freedom From Failure | | Overall Survival | |
|---|---|---|---|---|---|---|
| | HR | p | HR | p | HR | p |
| Gender | 1.420 | 0.75 | 1.350 | 0.87 | 1.520 | 0.71 |
| Race | 0.865 | 0.87 | 0.396 | 0.25 | 0.280 | 0.26 |
| Age | 0.910 | 0.13 | 0.954 | 0.23 | 1.010 | 0.88 |
| Active Tobacco Use | 1.790 | 0.56 | 0.601 | 0.53 | 0.360 | 0.36 |
| Time to Recurrence | 1.090 | 0.098 | 1.030 | 0.38 | 0.894 | 0.22 |
| rcT-Stage | 1.000 | 0.99 | 0.883 | 0.45 | 0.852 | 0.47 |
| rcN-Stage | 1.480 | 0.056 | 1.360 | 0.058 | 1.120 | 0.62 |
| rcAJCC Stage | 1.660 | 0.27 | 1.570 | 0.2 | 1.080 | 0.87 |
| rpT-Stage | 0.953 | 0.81 | 1.050 | 0.71 | 0.847 | 0.45 |
| rpN-Stage | 1.940 | 0.024 | 1.700 | 0.012 | 1.370 | 0.19 |
| rpAJCC Stage | 2.830 | 0.086 | 2.200 | 0.083 | 1.420 | 0.57 |
| Margin at Salvage | 4.670 | 0.094 | 3.260 | 0.097 | 1.750 | 0.54 |
| Lymphovascular | 1.860 | 0.54 | 1.850 | 0.46 | 0.972 | 0.98 |
| Perineural Invasion | 2.280 | 0.51 | 2.460 | 0.31 | 1.380 | 0.73 |
| Metastatic Carcinoma in Neck Soft Tissue | 12.000 | 0.034 | 8.300 | 0.013 | 4.960 | 0.088 |

**Table 3:** Univariate Analysis of Factors Associated with Study Endpoints.

| Series | N | Methodol ogy | Site(s) | 2y Local Control | 2y Overall | Major Complications |
|---|---|---|---|---|---|---|
| Richey[11] (UNC, 2007) | 38 | Retrospect ive Review | Multiple | 42% | 27% | Fistula (1/38) Wound Dehiscence (2/38) Respiratory Failure (2/38) Sepsis (1/38) |
| Weber[10] (RTOG 91-11, 2003) | 27 | RCT | Larynx | 74% | 71% | Fistula (8/27) Wound Dehiscence (4/27) |
| Morgan[12] (MDACC, 2007) | 38 | Retrospect ive Review | Multiple | N/R | N/R | Fistula (3/38) Infection (2/38) |
| Yom[13] (Multi-Institutional, 2005) | 14* | Retrospect ive Review | Multiple | *64%** | *57%** | Wound Dehiscence (3/14) |
| Kearney (MUSC) | 17 | Retrospect ive Review | Multiple | 58%# | 58%# | Fistula (3/17) Wound Dehiscence (3/17) Flap Breakdown (2/10) |

**Table 4:** Published Series of Toxicities and Outcomes for Salvage Resection of Concurrent Chemoradiotherapy Recurrences in Head/Neck Cancer.
*Twelve of fourteen underwent surgical salvage for residual or progressive disease noted at post-chemoradiotherapy assessment, local control and survival reflect crude recurrence rates rather than 2-year estimates. #Survival data based upon 16 patients with pathologic disease at salvage, excludes one patient with squamous cell carcinoma at post-chemoradiotherapy biopsy but no evidence of disease following salvage laryngectomy.

gressive combined-modality therapy, approximately 20-36% of patients still experience locoregional recurrence within 3-5 years, representing approximately half of all recurrences (1). In patients who experience disease recurrence within a previously irradiated field, aggressive salvage surgical resection is the preferred intervention, yielding 55% local control and 32-39% survival at 5 years (4,15). These have primarily included patients treated with radiotherapy alone or sequential radiotherapy and chemotherapy, which have demonstrated inferior disease control when compared with concurrent chemoradiotherapy (5-10).

Few reports have focused on the complications, disease control, and survival outcomes for concurrent chemoradiotherapy patients. The RTOG 91-11 study provides the best comparative data for salvage resection in the setting of radiotherapy alone versus sequential chemotherapy/radiotherapy versus concurrent chemoradiotherapy (5). Of 517 patients initially randomized, 129 required total laryngectomy (95% for recurrent/residual cancer) (10). While pharyngocutaneous fistula formation was less common in the radiotherapy alone arm (15%) compared to the the concurrent chemoradiotherapy arm (30%), this did not reach statistical significance (p>0.05). Similarly, the overall incidence of major and minor complications was not significantly different between treatment groups (52-59%). These consisted mainly of fistulae formation, infection, wound dehiscence, dysphagia and/or inability to take fluids, which are consistent with complications reported by other published series (10-12). Within the RTOG concurrent chemoradiotherapy group, the rate of fistula was somewhat higher than that described in single-institution series (30% versus 5-8%) (10-12). This may be associated with inherent differences between the



studies (disease site, reconstruction techniques) and inconsistent scoring of self-limited or “minor” fistulae in the retrospective analyses relative to the RTOG 91-11 analysis. If only “major” fistulae are considered for the RTOG study, the rate (11%) is more consistent with the retrospective series. Within our own series, 2 of the 3 fistulae were self-limited salivary gland leaks which resolved with conservative measures. Thus, the overall risk of significant fistula formation after surgical salvage for concurrent chemoradiotherapy failures is approximately 5-10%. Graft tissue reconstruction may have a beneficial impact on reducing these major complications. A single-institution analysis of salvage laryngectomy following radiotherapy or chemoradiotherapy demonstrated a reduced risk of fistula for free flap reconstruction compared with primary closure (18% versus 50%, p=0.08) (16). Similarly, the risk of stricture and feeding tube dependence was reduced with free flap reconstruction. It should be noted that this analysis was restricted to patients whose disease was generally limited to the larynx, excluding patients for whom partial pharyngectomy or total laryngopharyngectomy would have been required. Within the present study population, complications were similar regardless of graft tissue reconstruction (4 of 11 reconstructed patients versus 2 of 6 primary closure patients).

The present study demonstrated an estimated 2-year overall survival of 58%, which is comparable to other single-institution series of post-chemoradiotherapy salvage resection (11,13) as well as mixed-treatment populations (4). Patients with smaller tumor burden (rT1-2) appear to have improved survival over larger tumors, as do laryngeal recurrences over pharyngeal sites (4,10,15,17,18). Within our own population, all 4 patients with long-term disease-free and overall survivals (>2 years) were locoregional failures of larynx primary sites, despite locally advanced disease at recurrence (rpT4aN0 in two patients, rpT3N0 in one, and rpTxN1 in one). The interval from primary therapy completion to disease failure does not appear to impact disease control or survival outcomes (4). Though limited by small numbers, no association was identifiable within the present study population.

The role of immediate post-salvage chemotherapy and/or re-irradiation remains to be determined. A recently published French trial randomized 130irradiated patients to adjuvant chemoradiotherapy or observation following salvage resection (19). Despite improved local control and disease-free survival, no overall survival benefit was observed, and severe late toxicities (including subcutaneous fibrosis, osteoradionecrosis, and trismus) were higher in the adjuvant chemoradiotherapy arm (39% vs 11% at 2 years). It is possible that the benefit may be limited to a specific “high-risk” subset of patients requiring salvage resection. One single-institution series of post-chemoradiotherapy failures demonstrated a trend toward poorer survival in patients with the specific

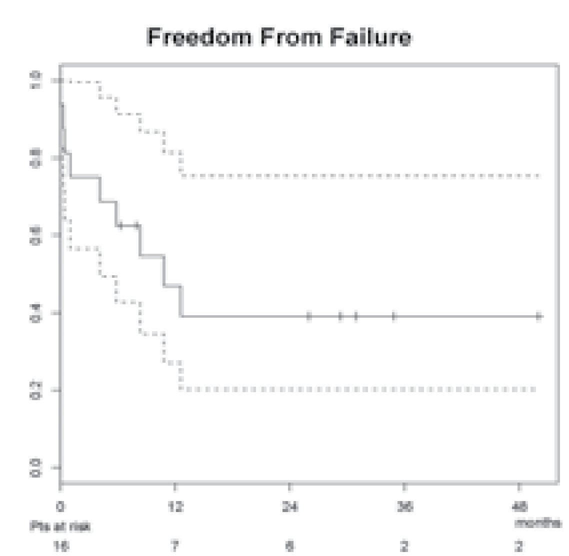


**Figure 2:** Freedom from disease failure for salvage resection population.

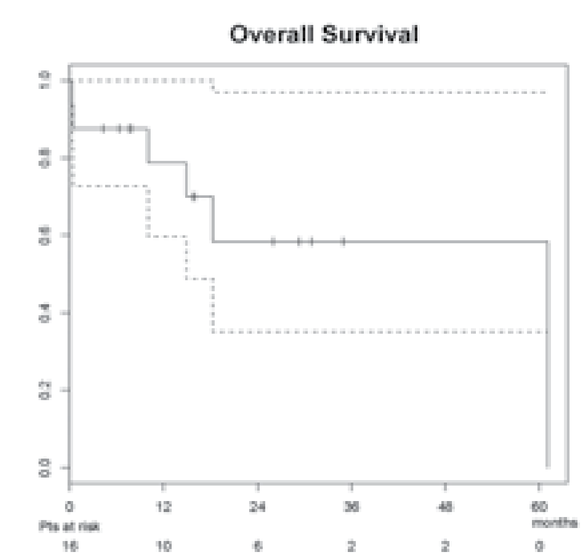


**Figure 3:** Overall survival for salvage resection population.

high-risk features of involved surgical margins and/or extranodal neck disease (11). Alternatively, these patients may simply have more advanced disease and would have a worse prognosis regardless of post-salvage intervention. Within the present study, two patients underwent immediate post-salvage therapy for high-risk pathologic features. One patient received immediate chemotherapy for involved surgical margins and another underwent concurrent chemotherapy and re-irradiation for extranodal carcinoma within their previously irradiated neck. Neither patient experienced significant post-salvage complications; however, both experienced local disease failure within 6 months.

Despite aggressive surgical salvage, the majority of disease recurrences involve the primary tumor site. Of 7 patients from the present series who experienced disease recurrence, 5 recurrences involved the tumor bed. This is consistent with other published data (11); however, the pattern of failure appears to shift toward more distant metastasis for advanced node-positive recurrences (11,13) and those treated with radiotherapy alone (10,20). The timing of post-salvage disease failure was also consistent with previously published series (median 9 months) (11,18); all but one patient within the present series failed within one year (isolated distant failure at 12.6 months). As suggested by Goodwin's comprehensive review (4), the rapidity of post-salvage recurrence may be attributable to advanced stage at initial recurrence presentation. Specifically, the analysis demonstrated an inverse relationship between recurrent disease stage and post-salvage median disease-free survival (>22.1, >11.5, 14.4, and 5.5 months for stages I, II, III, and IV disease, respectively). Within the present series, all patients who experienced post-salvage disease failure had recurrent pathologic stage III (n=2) or IV (5) disease.

Salvage resection of local and/or regional head/neck cancer failures following platinum-based concurrent chemoradiotherapy is feasible and can provide the opportunity for disease control and survival. Post-operative complication rates, timing and patterns of disease failure, locoregional control, freedom from disease failure, and overall survival rates are similar to those described in series of surgically salvaged patients treated with prior radiotherapy alone or sequential chemotherapy and radiation.

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REVIEW ARTICLE

# Evolutionary approaches to autism- an overview and integration

Annemie Ploeger*, Frietson Galis

**ABSTRACT: Autism is a highly heritable neurodevelopmental disorder, which greatly reduces reproductive success. The combination of high heritability and low reproductive success raises an evolutionary question: why was autism not eliminated by natural selection? We review different perspectives on the evolution of autism and propose an integration which emphasizes epistatic interactions between the effects of genes during development. It is well-established that autism is a polygenic disorder, and that the genes contributing to autism interact. If a disorder is polygenic, it is likely that the genes underlying the disorder are also involved in traits that are beneficial for the individual. For example, it is possible that genes involved in the development of autism are also involved in the development of intelligence. As intelligence is positively correlated with reproductive success, genes involved in autism can possibly spread in the population. We propose that in most individuals, the interactions between genes result in normal or high intelligence and the absence of autism. However, in some unlucky situations, often in combination with spontaneous negative mutations, the interactions between genes can lead to the development of autism (or other pathologies). Thus, the combination of high heritability and low reproductive success in autism can be explained from an evolutionary developmental perspective that emphasizes the role of epistatic interactions in polygenic disorders.**

*Keywords*: Autism, evolutionary psychology, heritability, epistatis

## INTRODUCTION

Autism is a highly heritable neurodevelopmental disorder (1-2), with deleterious effects on reproductive success (3). The combination of high heritability and low reproductive success raises an evolutionary question (4): why was autism not eliminated by natural selection? In this paper we present an overview of theories that address the evolution of autism, and we formulate an integration of these different theories.

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## Autism as the result of an extreme male brain

The extreme male brain theory of autism postulates that affected individuals are extremely focused on systemizing as opposed to empathizing (5-6). Men, on average, appear to have a more systemizing brain than women, i.e., they are more interested in and better at analyzing variables in a system, and at deriving the rules that govern the behavior of a system. Women, on the other hand, seem to have a more empathizing brain, i.e., they are better at inferring mental states in other people, and to respond appropriately to these mental states. Empirical support for the extreme male brain theory of autism comes from several sources. First, more males are affected by autism than females (7). Second, high-functioning affected individuals



(i.e., with an average or above average IQ) tend to outperform unaffected people with similar IQs on systemizing tasks (8). Third, the behavioral differences between people with and without autism are mediated by differences at the anatomical level of the brain (9). Fourth, prenatal exposure to testosterone (i.e., an androgen) is positively related to the development of autistic traits (10).

From an evolutionary point of view, in ancestral times, men with well-developed systemizing skills and under-developed empathizing skills may have had an advantage over other men (11). It is generally accepted that most humans used to live in hunter-gatherer societies, in which men fulfilled the role of hunter, and women the role of gatherer. Systemizing may have been important in developing tools and weapons, in hunting, tracking, and trading. Empathizing may have been disadvantageous in situations where rivals had to be eliminated, and in situations where one had to tolerate solitude, while being far away from home for hunting. For women, empathizing may have been more important because of mothering, making new friends (women used to marry into new groups), gossiping, and inferring the thoughts of a possible mate (to discover whether he is willing to invest in offspring). So having an extreme male brain, a condition which we strongly associate with autism, may have had practical advantages given demands of ancestral times. These advantages would have conferred greater reproductive success, thus ensuring the continued existence of this condition.

## Autism as the result of an extreme imprinted brain

A second theory on the evolution of autism is the imbalanced genomic imprinting theory (12). Genomic imprinting refers to the expression of genes from only one of the two parental chromosomes (13). We inherit two copies of every allele, a maternal and a paternal copy. In most cases both copies are functional, but in some exceptional cases one of the copies is turned off (i.e., silenced) and thus not functional. This may be the consequence of imprinting: maternal imprinting ensures that only the maternal copy is expressed, and paternal imprinting ensures that only the paternal copy is expressed. Imprinted genes show 'parent-of-origin effects' in the inheritance of traits: maternally expressed genes are inherited down the matriline, whereas paternally expressed genes are inherited down the patriline.

The evolutionary function of imprinted genes is unknown. It has been suggested that genomic imprinting originates in a conflict between the sexes about the amount of investment of the mother in the child (14). Paternally expressed imprinted genes tend to promote fetal growth, whereas maternally expressed imprinted genes tend to suppress fetal growth. From the father's point of view, it is beneficial that the mother invests as much as possible in the child. From the mother's point of view, it is important to preserve her resources. This implies that it is beneficial for her to invest in the child only as much as is necessary.

It has been shown that imprinted genes are highly expressive in the central nervous system, and that they are involved in neurodevelopment (15). There is some evidence that maternally imprinted genes are expressed in the cerebral cortex and hippocampal regions, brain areas involved in cognitive processing, whereas paternally imprinted genes are expressed in the hypothalamic and septal brain areas (16), brain areas involved in emotional processing; however, this finding has not been replicated (17). Imprinted genes are often implicated in disorders, because a single change can dysregulate their function (18-19). Genomic imprinting has been linked to several disorders, including autism. Crespi and Badcock hypothesized that autism reflects reduced maternal brain functions, and enhanced paternal brain functions (12). This hypothesis is supported by the sex ratio in autism; more males are affected than females (7). A second source of evidence is provided by genome scans, which show that many of the genes involved in autism contain imprinted genes or genes that interact with imprinted genes (12).

Crespi and Badcock suggested that autism is the low-fitness extreme of a condition that is beneficial for the father (20). Children with autism impose additional demands compared to normal children, especially on mothers, who tend to be the primary caregiver. These demands include dealing with tantrums, attempts to control others, lack of cooperative behavior, and lack of empathy. Normal children who display such behavior also impose additional demands on the mother, which is beneficial from the point of view of the father, because the mother will spend more of her time and resources on the child. However, in the case of autism, the behavior of the child assumes pathological proportions which no longer benefit either the mother or the father.

## Autism as a low-fitness extreme of a parentally selected fitness indicator

A third theory postulates that autism is the low-fitness extreme of a parentally selected fitness indicator (21). A fitness indicator is a trait that takes considerable energy to develop, maintain, and display. This cost makes it a reliable indicator of fitness, because the energy demands ensure that the indicator characterizes mainly the individuals who are sufficiently fit to meet them. The peacock's tail is a famous example of a fitness indicator that does not contribute to survival, but does help to attract mates. The peacock's tail is a sexually selected trait. It is likely that there are also parentally selected fitness indicators; parents are likely to invest more of their resources in offspring that are more likely to survive and reproduce. Thus, it is possible that parental selection resulted in offspring traits that evolved to win parental resources. Shaner and colleagues proposed that parental selection could have caused some aspects of the social repertoire of infants to evolve as a fitness indicator and that autism could represent its low-fitness, poor quality extreme. They termed the overall trait 'charm' and suggested that it may include babbling, smiling, and creative play. Infants that are characterized by high genetic quality (i.e., a low mutation load) and that are reared in a favorable environment would be able to develop the complex brain systems required for highly charming behavior. Infants that are characterized by low genetic quality (i.e., a high mutation load) would not be able to develop these complex brain systems as well, therefore would not display the charming behaviors (at least not to the same degree). In a few, the behavioral deviations would be so severe that we would associate them with autism. Evidence for this theory is that infants develop charm at the time when mothers start to show signals of weaning (22), and that autism is correlated with early weaning (23).

## Autism as the result of a reptile brain

A different perspective on the evolution of autism is provided by the Polyvagal theory (24). Polyvagal theory postulates that through three stages of phylogeny, mammals, especially primates, including humans, have evolved a functional neural organization that regulates emotions and social behavior. The vagus, i.e., the 10th cranial nerve is a major component of the autonomic nervous system that plays an important role in regulating emotions and social behavior. The three stages of phylogeny reflect the emergence of three distinct parts of the autonomic nervous system, each with a different behavioral function. In the first evolutionary stage, the unmyelinated vagus emerged, which regulates immobilization for death feigning and passive avoidance. These are typical responses to dangerous situations in reptiles, but atypical in mammals, including humans. In the second stage, the sympathic-adrenal system emerged, which is characterized by mobilization as a response to dangerous situations. In the third stage, the myelinated vagus emerged, which is involved in social communication, self-soothing and calming. It is proposed that people with autism minimize the expression of the mammalian response, i.e., social communication. Rather, they rely on the defensive strategies that include both mobilization and immobilization.

While normally primates and humans have a well-developed ability to shift adaptively between mobilization and social engagement behaviors, individuals with autism lack this ability. The resulting behavioral features lead to adaptive benefits in focusing on objects, while minimizing the potentially dangerous interactions with people. Without a readily accessible social engagement system, the myelinated vagus is unable to efficiently inhibit an autonomic state and is poised for flight and fight behaviors with the functional outcomes of frequently observed emotional outbursts or tantrums. The combination of a nervous system that favors defensive behaviors, and the inability to use social communication with people, places the autistic individual outside the realm of normal social behavior. Thus, due to the inability to engage the myelinated vagus to calm and dampen the defensive system (through social interactions), the nervous system of the autistic individual is in a constant state of hypervigilance or shutdown. These are generally adaptive responses in reptiles, but are severely maladaptive in mammals.

## Towards an integration of different approaches on the evolution of autism: Autism as the result of epistatic interactions between the effects of genes

Each theory described above has its merit; each theory explains some part of the phenotype of autism, and is supported to various degrees by empirical evidence. Is it possible to integrate these theories to arrive at a sensible account for maintenance of a highly heritable disorder, which is characterized by low reproductive success?

It is well-established that autism is caused by many interacting genes (25-26). As nearly 30



genes have been associated with autism (27), autism is clearly no Mendelian (single gene) disorder. An evolutionary theory of autism should take into account the developmental effects of both its polygenic nature and of interactions among the genes (i.e., epistatic interactions) (28). Assume that there are 30 genes involved in the development of autism (this number is likely to be larger), and that this same set of genes is involved in the development of intelligence. Given the evidence that intelligence is positively correlated with potential reproductive success (29), the 30 genes that are involved in autism can potentially spread in the population, thanks to the link with intelligence. In most people, interactions between these 30 genes result in an individual with normal or high intelligence, without autism. However, some unlucky interactions, especially in combination with negative spontaneous mutations (30-31), lead to the development of autism, low intelligence, or other pathologies. With regard to autism, the unlucky effects of interactions between genes are negatively correlated to survival (32) and reproductive success (3). However, most of the time, interactions between the 30 genes lead to higher fitness (because of higher intelligence), and consequently, genes involved in autism can be beneficial. Thus, the combination of high heritability and low fertility in autism can be explained from an evolutionary developmental perspective that emphasizes the role of epistatic interactions in polygenic disorders.

There are several lines of evidence that support this idea. The first line concerns the relation between autism and intelligence or other exceptional abilities. A behavioral genetic study showed that there is substantial overlap between genetic factors that influence individual differences in autistic traits and intelligence (33). In addition, on certain intelligence tests, individuals with autism show equal or better performance levels compared to normal individuals. These tests include the Raven's Progressive Matrices test (34) and the block design test (35). There is also evidence for the relation between autism and exceptional abilities, with some famous examples of autistic savants (36-37). The co-occurrence of savant syndrome and autism is an example of the effect of epistatic interactions between genes, in which potentially beneficial effects of genes are nullified by the negative effect of autism, mental retardation, or other disabilities, on reproductive success (38).

The second line of evidence is the relation between assortative mating and autism (39). Assortative mating refers to the tendency of mating with individuals who are phenotypically similar. It was found that mothers and fathers of children with Asperger syndrome, one of the autism spectrum disorders, scored highly on the Embedded Figures test, a test that is often included in IQ test batteries (40). Both mothers and fathers of children with Asperger syndrome tend to have jobs that require high intelligence (41). Other studies revealed a positive correlation between the score of fathers and mothers of children with autism on measures of autistic traits (42-43), although another study did not confirm this (2).

A third piece of evidence for the involvement of epistatic interactions between genes in autism is the co-occurrence of autism and several other disabilities. There is ample evidence that autism co-occurs with medical syndromes (44), and minor physical anomalies (45). There is also considerable comorbidity with other psychiatric conditions (46). Epistatic interactions between the effects of genes can explain the diverse array of phenotypes associated with autism spectrum disorders: in people with severe autism, which often co-occurs with mental retardation and physical disabilities, the effects of interactions between genes are extremely unlucky and most likely co-occur with spontaneous mutations.

The proposal that the combination of high heritability and low fertility in autism can be explained by the effects of epistatic interactions between genes that are involved in both intelligence and autism, provides an integration of the different approaches to the evolution of autism discussed above. The extreme male brain theory of autism is consistent with this proposal, as systemizing can be regarded as a subset of intelligence. The extreme imprinted brain theory of autism can also be integrated in the proposal, as imprinted genes are known to be highly epistatic (47). The theory that autism is a low-fitness extreme of a parentally selected fitness indicator is also consistent with the proposal, as it is likely that unlucky combinations of genes result in detectable indications that the individual is not fit. The co-occurrence of autism and syndromes is an example, but these signals can be more subtle, such as physical asymmetry. Some evidence suggests that autism is positively related to asymmetry (48-49), with symmetry being regarded as a signal of high fitness (50). Finally, the theory of autism as a consequence of a reptile brain describes what may have gone wrong with the brains of people with autism at the neurobiological level, and how this can be explained from a phylogenetic point of view. It does not explain the genetic background and the heritability of autism, so the reptile brain theory needs some extension to give a full explanation of the evolution of autism. The theory is not in disagreement with the idea that autism is the result of epistatic interactions between the effects of genes, so combining the two ideas may lead to a more complete account of the evolution of autism.

To sum up, this paper proposed a new theory that may explain the evolution of autism, which is a puzzle because of the combination of high heritability and low reproductive success. Epistatic interactions between potentially beneficial effects of genes may lead to unlucky gene expression that eventually leads to the development of autism. Earlier theories on the evolution of autism are not necessarily in disagreement with this new theory, but the new theory may serve as an integrative framework for different views on the evolution of autism.

## ACKNOWLEDGEMENTS

We would like to thank Conor Dolan, Stephen Porges and Andrew Shaner for their valuable comments on earlier drafts of the manuscript.

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REVIEW ARTICLE

# Breaking the Scope-of-Practice Taboo: Where Multidisciplinary Rhymes with Cost-Efficiency

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## INTRODUCTION

In the past century, medical care in the western world has evolved tremendously. While in the early 1900s, healthcare was mostly a private affair, it has now become a major expense for all developed nations. Complex structures have emerged: modern-day healthcare professionals now evolve in highly diverse environments ranging from small private clinics to highly specialized teaching hospitals. With the rising costs of healthcare and the rapidly increasing demand for healthcare services, governments need to find new ways to render the delivery of healthcare services more cost-effective without compromising the quality of care or patient and healthcare worker satisfaction. The challenge is superb; obstacles are numerous and solutions are often complex.

In recent years, many commissions and reports have strived to explore these obstacles and solutions. In Canada, the Final Report on the State of the Healthcare System (1), published in 2004, is one of many sources which support that the rigidity of healthcare structures and scope-of-practice rules—the rules defining which tasks different categories of healthcare professionals are permitted to perform—represents an ominous barrier to increasing productivity in healthcare. Another important Canadian report published in 2002, the Romanow Report (2), also highlights the need for change in the way healthcare services are delivered. By placing a special emphasis on "collaborative teams and networks of providers" the Romanow Report suggests that "traditional scopes of practice need to change [thereby suggesting] new roles for nurses, family physicians, pharmacists, case managers and a host of new and emerging health professions". While a certain number of studies have shown that a growing number of physicians (especially primary care doctors) are very receptive to the idea of sharing part of their responsibilities with their fellow healthcare professionals (3, 4, 5), many others, often in fear of losing some of their autonomy, exclusivity and prestige are still reluctant to support initiatives aiming to restrict or redefine the scope of their practice (6).

In order to increase cost-efficiency in healthcare, the taboo surrounding physicians' rigid scope-of-practice should be broken; this would promote a stronger and more integrated multidisciplinary approach to medicine. The evidence supporting this thesis is growing at a breathtaking pace and revolves around five main themes. First, alterations to scope-of-practice rules fall into the very promising realm of catalytic innovations. Second, the redefinition of roles for healthcare practitioners—with a special emphasis on doctors, nurses and pharmacists—allows for better patient and healthcare practitioner satisfaction and improved healthcare resource utilization. Third, a new generation of physician assistants can successfully help address the issue of rising healthcare costs. Fourth, smartly organized multidisciplinary teams can lead to better outcomes and resource utilization in healthcare. Finally, a certain number of compelling examples from the literature illustrate how multidisciplinary approaches have a high potential for encouraging better cost-effectiveness in healthcare.

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## CATALYTIC INNOVATIONS AND ALTERATION OF SCOPE-OF-PRACTICE RULES

Thanks to advances in technology, medical research is now able to target such complex issues as heart transplants, gene therapy and robotic microscopic surgery. Because of the impressive



amounts of human and material resources involved in such "high-end, high-tech" innovative techniques, medical innovations tend to increase rather than decrease the costs of medical care (7). In an article published in the Harvard Business Review, Clayton M. Christensen, one of America's most influential business thinkers and writers, describes such innovations as "sustaining innovation" (7). In his opinion, sustaining innovations are necessary to solve complex medical problems affecting small groups of patients in specialized medical chimneys, but they do not lead to decreases in medical costs. Christensen also goes a step further in affirming that in most developed countries, the omnipresence of sustaining innovations has led to the maintenance of the status quo by way of an excessive amount of resources being allocated to organizations that are "wedded in their current solutions, delivery models and recipients"(8).

In an interview with Mark D. Smith (9), Christensen describes another category of innovations: disruptive innovations. Contrarily to sustaining innovations, disruptive technologies or services are available at much more affordable prices than existing alternatives. They "disrupt" the market by changing the approach to a problem and by bypassing more complex alternate solutions. They also allow the opening of a whole new market formed by purchasers who traditionally could not afford such products and innovations. In the same interview, Christensen depicts a third category of innovations—catalytic innovations—which he describes as being even more beneficial than disruptive innovations in the context of modern day healthcare. This third category of breakthroughs not only lowers the prices of products or services, but also focuses on bringing social change through scaling and replication (9). By making changes to rigid scope-of-practice rules, healthcare systems have the opportunity of creating a great number of catalytic innovations. For example, by allowing nurses or other healthcare practitioners to conduct a certain number of simple and highly reproducible medical acts that were traditionally completed by doctors, clinics can allow patients to be treated at lower costs while avoiding long waits. Yes, this perspective allows for the possibility that patients might receive healthcare services of an inferior quality due to the fact that the healthcare professionals who are providing them do not have the same level of training as physicians. However, in a North American context of limited resources where no less than 25% of doctors willingly affirm that their scope-of-practice is too wide (5), such catalytic innovations should definitely be considered as a promising avenue for addressing some of the most complex issues in healthcare.

## REDEFINING THE ROLES OF HEALTHCARE PRACTITIONERS

In the past few decades, with the progressive lengthening of life expectancies and an ongoing "medicalization" of western societies (10), healthcare practitioners—and especially doctors—have been brought to play wider and wider roles in the lives of individuals. As mentioned above, this has led to important discrepancies between what healthcare professionals think their scope-of-practice should comprise of and what their workload consists of on a day-to-day basis. To illustrate this point, an article which was recently published in the American journal Health Affairs (3), maintains that American doctors, if asked the question: "what percentage of your time do you perform functions that require a medical degree?" would most likely provide a figure neighbouring 50%. Building on this example, let's now further analyze how scope-of-practice issues specifically impact the work of four groups of key players of the healthcare workforce: physicians, nurses, pharmacists and other healthcare professionals.

### *DOCTORS*

Acknowledging the fact that physicians are highly trained professionals and that they represent one of the most important healthcare expenses for most industrialized nations (11, 12), there is no doubt that their time should be used wisely and that their practice should focus on what they do best. There appears to be a consensus in the medical literature regarding the fact that where physician attention is the most essential is in the treatment, diagnosis and management of complex medical issues (7). Who other than highly trained specialists or experienced family physicians would be able to correctly perform a cardiac bypass surgery or detect a rare congenital disorder bringing subtle changes in a long followed patient's health?

However, this simplified view of what physicians should be responsible for overlooks the fact that there are many levels of specialization inside the medical profession itself. While general practitioners and medical specialists might at first glance be assumed to work in collaboration—referring patients to one another when issues are either too broad or too specialized for their scope-of-practice—recent evidence has shown that confusion often prevails when it comes time to determine who should be taking which role in the management of a patient's illness (5). Before moving on to redefining the scope-of-practice rules for nurses, pharmacists and other healthcare professionals, it is important to keep in mind that the medical profession itself has a highly varied array of members, each possessing different skills and levels of expertise. Thus, the elaboration of a strong stepped-care approach, where the right patients are directed to the right physicians for optimal healthcare, accompanied by the installation of adequate financial incentives for doctors to follow this approach, might very well be the necessary first step to any healthcare reform aiming to address scope-of-practice redefinition (5).

*NURSES*

While the diagnosis of medical conditions has traditionally been thought of as the most important aspect of a doctor's practice, there is a growing body of evidence showing how simpler illnesses presenting with an easily identifiable pattern and consistent clinical findings can be managed very efficiently by nurses without the need for doctors to intervene directly (13). In fact, healthcare teams in which registered nurses work independently, yet in tight collaboration with practising physicians, have not only been reported to provide adequate healthcare services and diagnoses to patients; they have also been shown to do so with equal or increased levels of patient satisfaction, with no significant differences in clinical outcomes. Most importantly, these teams also yield the promise of improved cost-efficiency allowing for more medical acts to be performed by lower paid professionals (4).

Whereas doctors are often thought of as the ones who treat patients, nurses are often considered as the ones responsible for caring for patients. This observation is usually correct, since over 60% of registered nurses in Canada possess a college-level diploma and focus mostly on providing supportive attention to patients in hospitals and out-patient settings (14).

However, increasing numbers of nurses who are trained and recognized as nurse practitioners are leading the way towards a new definition of nurses' roles. Benefiting from a higher level of education, nurse practitioners can be defined as "unique healthcare providers […] who engage in advanced practices in a variety of specialty areas such as family, adult, paediatric, gerontologic, women's health, school health, occupational health, emergency, neonatal care and acute care" (13). Due to the great complexity and to the large number of areas where they can be affected, nurse practitioners (also referred to as nurse clinicians) typically complete their training in one of many different medical specialties. In Canada, most nurse practitioners complete a two year graduate university course which allows them to assess and manage a certain number of medical problems. For instance, their training can allow them to prescribe common pharmacological agents, make simple medical diagnoses or take charge of the management of patients with acute and chronic diseases while discussing such essential issues as health promotion and the importance of maintaining a healthy lifestyle (13). Also, taking advantage of their close relation with patients and of the larger amount of time they can spend with them (when compared to doctors) nurse practitioners can develop highly efficient individualized care plans in collaboration with their patients (15).

Unfortunately, even though the early implementation of a new generation of nurse practitioners in healthcare institutions has led to very promising results in most industrialized countries (13), numerous obstacles including financial arguments and considerable opposition from organized medical associations are slowing down the process of training more advanced practice nurses. Some authors have brought the idea that one of the main reasons for the slow speed of development of specialized nursing training programs—which can very well be considered as high-yield catalytic innovations—might be that in the context of limited financial resources, nursing fellowships are not as "glamorous" as, say, the purchase of a new glistening MRI scanner or the development of a new artificial heart (8). Nonetheless, the fact that many governments are still adding more resources in highly specialized medical innovations which only pertain to a limited number of patients indicates that the much higher potential for innovations such as programs reforming nurses' scope-of-practice rules and advanced nursing training programs for decreasing healthcare costs is all too often ignored.

*PHARMACISTS*

Most North American pharmacists work in the private sector, often owning or co-owning their own pharmacy. For many patients, doctors, nurses and other healthcare practitioners, this has led to the idea that pharmacists are not necessarily considered integral members of multidisciplinary healthcare teams (6). However, a converging body of recent publications has shown that increasing the degree of involvement of pharmacists in patient care yields tremendous potential. Whether they act autonomously as independent outpatient case managers or as part of multidisciplinary inpatient teams, pharmacists can most definitely represent a very valuable resource in an environment where pharmaceutical products are becoming increasingly diverse and more difficult to understand.

When working in tight collaboration with physicians, pharmacists can allow for a much more comprehensive and cost-effective way of prescribing pharmaceutical products. In fact, in settings where pharmacists have successfully been integrated in family healthcare teams, doctors report: "an improved availability of easy-to-interpret […] drug information, an advantageous access to fresh perspectives regarding new and competing pharmaceutical products, more confidence about prescribing medications and more productive work relationships with pharmacists"(6). Furthermore, from the patient standpoint, this has allowed major improvements in patient education through ways of a facilitated access to high quality drug-related information.

In two separate American studies observing the effects of integrating pharmacists in the care of patients with type 2 diabetes mellitus and chronic hypertension, pharmacists have been shown to lead the way towards better evaluation and modification of pharmacotherapy, better self-management of illness, improved reinforcement of screening for medical complications and better patient follow-up (16, 17). Also, in cases where pharmacists were involved in patient care they have been proven to allow better glycemic control, more sustainable lifestyle modifications and greater decreases in systemic blood pressure than in cases where patients with chronic illnesses were cared for following a traditional physician-managed approach. Once again, as it was the case for nurses, all of these results have been obtained with a high potential for significant cost reductions and improved overall cost-effectiveness.

In light of these benefits, one might wonder why systematic reforms aiming to fully integrate pharmacists in healthcare teams haven't yet been undertaken. Once again, as it was the case for nurses, resistance from physician associations, which hesitate to disrupt the existing status quo, and the lack of appropriate financial incentives seem to be the major obstacles (6). One of the most commonly mentioned arguments relates to the increased time commitment required for physicians to interact with pharmacists on a regular basis. As one might readily predict, this argument loses much of its significance once a short period of adaptation has been completed.

*OTHER HEALTHCARE PROFESSIONALS*

While a great number of authors focusing on the effectiveness of multidisciplinary teams in healthcare have strived to describe the importance of programs involving such healthcare professionals as dieticians, physical therapists, occupational therapists, psychotherapists and social workers in teams affected to direct patient management, there is still a lack of evidence regarding the cost-effectiveness and the changes in clinical outcomes related to the implementation of such programs (18). However, there is no doubt that these highly trained professionals can play an important role in the management of patients in situations concerning their field of expertise. For instance, how often are family physicians required to provide nutritional, psychological or social counselling to patients in a setting where they have very little time to do so? How often are patients given a note to consult a dietician, a psychotherapist or an occupational therapist without there being adequate—if any—follow-up from their family physician? If patient access to the healthcare professionals who are best able to help them is facilitated and if adequate financial incentives to stimulate collaboration are created, there is a high potential for successfully decreasing the often overwhelming burden assumed by family doctors.

Finally, although the medical literature very seldom mentions the importance of well-trained and efficient administrative staff in assuring the effective functioning of healthcare institutions, these actors can also contribute enormously to making their workplaces much more cost-effective. Taking care of responsibilities which can otherwise be perceived as very cumbersome tasks for other healthcare professionals (3), they should be more readily considered by their peers as essential members of a well-oiled medical team.

**A NEW GENERATION OF PHYSICIAN ASSISTANTS**

In the US and in an increasing number of OECD countries, a new generation of healthcare professionals has recently made its entrance on the healthcare market and is being considered by many as a very appealing solution for addressing cost-efficiency issues in healthcare in the context of limited financial resources. These professionals, most commonly referred to as physician assistants, first entered the American medical system in the late 1960s.

Physician assistants, with their intermediate status, which places them somewhere in between doctors and nurses, have many advantages. Mainly, they allow palliating for an increased need for healthcare resources by taking over some of the tasks that were traditionally performed by sleepy-eyed junior doctors, overwhelmed primary care physicians or overworked nurses (19). In the early 2000s, there were close to 50 000 fully trained physician assistants in the US. Thanks to favourable governmental incentives and to the emergence of more and more specialized education programs across the country, this number is rising consistently from year to year.

Most commonly, physician assistant degrees consist of 2 years of graduate university education training following a previous degree, most commonly in the area of biomedical sciences, physiotherapy or occupational therapy. Students usually enter the program with a strong GPA, certain amounts of clinical work experience and strong interpersonal skills (20). In 2007, there were 136 state-recognized physician assistant programs in the US; 76% of them were at the master's level and offered what is often considered a broad-based "condensed medical degree" while the remaining 24% of the programs offered doctoral or physician assistant training specializing in a certain medical domain.

In the US, physician assistants usually work under the close supervision of fully certified physicians. While many of their tasks can overlap with nurses' job descriptions, they are usually not assigned to continuous patient care on hospital wards. Rather, their tasks are primarily directed toward outpatient groups or short interventions and most commonly include: taking patient histories, completing full physical examinations, making simple clinical diagnoses, ordering laboratory tests, prescribing specific medications, suturing, applying casts, providing comprehensive patient education and doing rounds in nursing homes (20).

The results of physician assistant implementation in healthcare teams have been extremely promising throughout the world in all or most countries where they are present (19). In the UK, a small team of physician assistants has successfully provided a large number of patients with similar quality healthcare services as residents and doctors. When asked, patients reported that they were highly satisfied with the attention they had received and were impressed by the empathy with which their healthcare providers had treated them. In addition, the doctors working with the team of physician assistants reported excellent professional interactions with their new staff members, showed no resistance to the prolongation of their contract and were very appreciative of the help that they were providing them. Hence, by borrowing some of the simpler elements of physicians' scope-of-practice, the wide scale implementation of physician assistants worldwide might be one of the well-needed catalytic innovations which will allow a shift towards more cost-effective healthcare.

## ADVANTAGES AND POTENTIAL HURDLES OF THE MULTIDSCIPLINARY APPROACH

### *ADVANTAGES*

Once all the players of a well-designed healthcare team have had a chance to collaborate in providing services for a certain period of time, the advantages of a multidisciplinary approach to healthcare are tremendous. However, achieving such a feat as the establishment of a well-functioning multidisciplinary team is all but a simple walk in the park. According to Regina E. Herzlinger, professor of Business Administration at Harvard, healthcare is still a tremendously fragmented industry (21). Nevertheless, Herzlinger writes that in the cases where successful horizontal integration of independent players is achieved, multidisciplinary care can generate economies of scale by considerably increasing efficiency while at the same time improving quality of care.

Multidisciplinary care has been shown to allow a stronger emphasis on preventative healthcare, patient education and patient self-care. For example, the efficient management of chronic illnesses such as diabetes mellitus type II and hypertension requires an important component of patient education, which is considerably time and labour-intensive. When physicians are forced to deal with such complex issues as lifestyle changes and ensuring patient compliance to medical treatment without the help of other healthcare professionals, the costs of adequate disease management are quite astounding (4). In cases like these, the benefits of a strong collective approach to chronic



disease management not only diminishes physicians' workload; it has also been proven repeatedly to bring comparable or superior clinical outcomes such as lower levels of glycosylated haemoglobin A1C—the main laboratory indicator used for long-term monitoring of blood sugar control in diabetic patients (15, 17).

Another reason for why improved healthcare outcomes can be reached when multidisciplinary approaches are used comes from the fact that teams comprising nurses, social workers and dieticians allow for patients to meet with healthcare professionals in a different setting than in a doctor's office, where they are more likely to understand and initiate meaningful lifestyle changes essential to the management of their medical conditions. This will often allow them to manage their illness without needing to consult a doctor on a regular basis, thus avoiding considerable healthcare expenses (9).

Finally, one of the most important aspects of multidisciplinary care comes from the fact that it allows the elaboration of more comprehensive and efficient case management plans for patients. By definition, case management represents a "collaborative process that assesses, plans, implements, coordinates, monitors, and evaluates the options and services required to meet an individual's health needs, using communications and available resources to promote quality and cost-effective outcomes" (17). For instance, these "communications and available resources", sometimes referred to as telemedicine, comprise such practices as telephone counselling, email exchanges and web-based health services, all of which can be delivered effectively by more than one member of healthcare teams. The number of studies assessing the cost-effectiveness of intensive case management is sill very limited. Nevertheless, a fair number of trials have suggested that when patients are taken in charge by a multi-tiered team, they are much more likely to stay away from acute medical situations, thus saving the medical system considerable amounts of healthcare resources (4, 18).

### *POTENTIAL HURDLES*

Multidisciplinary approaches to healthcare can also come with significant drawbacks, a large number of which have been reported on many occasions in the medical literature and the object of which is beyond the scope of this article. In fact, all of the above-mentioned advantages of team-based practice cannot be obtained without overcoming a significant number of hurdles. Most importantly, individual physician and physician association approval needs to be obtained before any major changes to healthcare systems and organizations can be made. When it comes to changes of this nature, doctors have traditionally adopted a very conservative mentality and usually request considerable amounts of "rock-hard" data before even envisioning undertaking major shifts in their practices (22). Furthermore, the risks of obtaining sub-optimal results in early stages of multidisciplinary care program implementation and in the period of time following scope-of-practice changes are often considered as an unbearable short-term gamble which healthcare authorities are not always ready to take, especially without the presence of solid evidence. Thus, even though very promising trials and initiatives are starting to trace a clear path towards the advancement of multidisciplinary healthcare, there is still a pressing need for more credible and unbiased evidence comparing the two sides of the medal in order for industrialized nations to move ahead with ambitious multidisciplinary healthcare reforms.

## PROMISING EXAMPLES FROM THE MEDICAL LITERATURE

More and more healthcare practitioners and entrepreneurs are starting to acknowledge the potential of catalytic multidisciplinary healthcare reforms and innovations. In North America alone, many states and provinces have made clear mention of their intention of embracing new multidisciplinary paths or have clearly underlined the need for a redefinition of scope-of-practice rules (1, 2). Here are three examples of promising Canadian and American initiatives which have recently made their way into the medical literature.

### *ONTARIO FAMILY HEALTH TEAMS*

In 2009, almost 2 million Ontarians had access to comprehensive family healthcare through an extending network of Family Health Teams (23). These teams, created by independent groups of healthcare practitioners since the beginning of the years 2000, have received numerous incentives and generous support from their provincial government. In fact, seeking to improve accessibility to primary healthcare for its citizens, the Ministry of Health of Ontario has created a vision allowing physicians, nurse practitioners and other members of the team to practice in a productive working environment where cooperation and knowledge exchange are extremely important. Among other roles, Family

Health Teams are meant to promote disease management programs for chronic illnesses, self-care programs, health promotion, patient-centered care and facilitated navigation and care coordination for patients seeking services in multiple healthcare institutions.

Although the implementation of Family Health Teams in Ontario has been welcomed almost unanimously by citizens and healthcare practitioners, there still exists an important gap between the reality of practising in a team-based setting and what is taught to medical and nursing students in Ontarian medical and nursing schools (24). Hence, even though they are extremely promising, multidisciplinary approaches to medicine need not only be implemented on the field; they also need to be accompanied by pertinent reforms in healthcare education in order to ensure that the new generation of workers will be better equipped to deal with the new challenges of team-based practice.

*MINUTE CLINICS*

In the US, a very popular example of how scope-of-practice rules have been changed in order to provide patients with more affordable and convenient healthcare services is the advent of so-called “Minute Clinics” (21). These clinics are run entirely by nurse practitioners who use software-based protocols in order to offer vaccinations and basic medical attention for a limited set of health problems. If a patient presents with an illness that is beyond the scope of the nurse’s expertise, he or she is immediately referred to a doctor’s office or emergency room.

Many factors can explain the booming success of this catalytic innovation which has successfully reformed scope-of-practice rules for nurses in the US. First, Minute Clinics offer cheaper, quicker and more accessible healthcare for a great number of illnesses allowing patients to avoid more costly and inconvenient visits to the hospital. Second, these clinics have not met any significant resistance from physicians, simply because they are not seen as a threat to their practice; rather, they allow for the shortening of waiting lists and allow doctors to focus on more complex cases requiring more of their competencies and skills. Third, minute clinics are often used by uninsured, underserved populations who otherwise would not have access to other healthcare resources. Finally, according to surveys, patients are equally if not superiorly satisfied with the quality of care they receive in Minute Clinics. (8).

*KAYSER PERMANENTE*

A recent article published in The Economist, entitled Another American Way, draws an extremely flattering picture of Kaiser Permanente, an integrated American healthcare firm which offers managed care packages to 8.6 million Americans via highly efficient primary healthcare teams (25). Each team follows a group-practice model composed of 3 to 5 clinicians (physicians, nurse practitioners or physician assistants), 2 registered nurses, 1 to 2 receptionists or clerks and 6 to 7 registered practical nurses or medical assistants that provide care to a sample of 8000 to 15 000 patients (22). One of Kayser Permanente’s biggest strengths is that it offers all of its employees a comprehensive training in team-oriented care prior to their first day of work. Also, teams have the freedom to adapt to the needs and conditions of their patient population. For instance, a team can decide to hire more or less physicians, more non-physician clinicians or more support staff depending on the patterns of illness contracted by the population it serves. In addition, each primary healthcare team receives a thorough report of its activities every three months, outlining patient and staff satisfaction as well as clinical outcomes. Monetary incentives and feedback are then provided by Kayser Permanente’s headquarters with the effect of promoting constant progress and improvement among healthcare teams.

**CONCLUSION**

Considering the size of the challenge of controlling healthcare expenses in a context of growing healthcare needs and aging demographics, the application of new ways to improve the cost-effectiveness of healthcare systems is essential. One of the most promising avenues suggests that doctors should be encouraged to review the rules regulating the scope of their practice in order to promote a stronger multidisciplinary approach to healthcare. In order for this solution to yield the most effective results, healthcare institutions should strive to follow the model of catalytic innovations, a model encouraging both simpler and more affordable solutions with a special emphasis on social change. In addition, scope-of-practice reforms should not be limited to physicians; rather, they should extend to all healthcare practitioners. Also, the potential benefits of training a new generation of physician assistants should be acknowledged. All of these elements have the potential of giving rise to an efficient and visionary multidisciplinary approach to healthcare. Based on the large



number of positive accounts taken from the medical literature, reforms that follow the idea of multidisciplinary approaches to healthcare should definitely be undertaken: the benefits of such enterprises seem to widely out-measure the potential obstacles and hurdles which might affect their implementation.

At this point on the road, one might wonder: Where to start? What should be the next big step? While governments are striving to adapt their healthcare systems to the realities of the 21st century, the answer to these questions might very well lie in the hands of those who are in the best position to implement change in the years to come: students. If medical and nursing students become aware of the potential benefits of redefining the scope of their practice and breaking the taboo which has traditionally surrounded the matter, they might just become the much needed vectors of change capable of increasing the cost-efficiency of 21st century healthcare.

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**CROSSROADS**

# The Canadian Space Agency Space Learning Grants

Jason Clement*

The Canadian Space Agency (CSA), via its Space Learning Program offers a bevy of opportunities that Canadian university students may wish to leverage.

Through the Space Learning Grants Program, the CSA provides funding to upwards of 200 students each year – the majority being undergraduate and graduate students – which supports their participation in space-focused learning initiatives. This grant program, designed to assist students with funds to help cover travel, registration and living expenses, is open to students from primary school right up to the doctorate level, so long as the student is either a Canadian citizen or permanent resident of Canada.

Over the past year, funding awarded through this program has allowed students to participate in a wide variety of initiatives covering an array of fascinating disciplines - from an annual Aerospace Medical Association Meeting, and international Lunabotics competitions to Solar-Terrestrial science conferences.

While individual requests for funding can be submitted and considered, budget-permitting, on an ad-hoc basis year-round, there are also two opportunities both earmarked and funded through this program on an annual basis.

The first is the International Astronautical Congress (IAC) – the largest annual international space conference. Each year in February, students are asked to submit abstracts to the CSA on relevant conference topics that will also allow them to highlight their research at the congress. Each abstract undergoes an internal evaluation by CSA scientists, engineers and medical professionals with those achieving the highest rankings forwarded to the International Astronautical Federation (IAF) – the organization responsible for the IAC - for final selection. In 2011, close to 60 abstracts were submitted for consideration to be included at the congress in Cape Town, South Africa, with 21 Canadian students ultimately being selected for funding by the Canadian Space Agency to share their work with the conference delegation of international space professionals and other students. For anyone interested in applying to the 2012 edition of IAC , to be held in Naples, Italy, information on the application process will be posted on the student (17+) section of the CSA web site in the late fall.

A second learning opportunity funded by the CSA is the NASA Academy summer program. NASA Academy provides students at the upper undergraduate or early graduate levels with an opportunity to spend 10 weeks paired with a researcher at one of the NASA centres. Students selected to participate are given the extraordinary opportunity to conduct space research with an experienced researcher in addition to developing their own group project with fellow students.

NASA Academy participants are treated to a wonderful introduction to the space field through a series of presentations, meetings and visits at the various NASA centres across the United States. In the past two years, two McGill students have been selected through this competitive process - Medical student Laura Drudi in 2010 and Atmospheric Science student Alexandra Anderson-Frey for the summer of 2011. Information for those interested in applying to the 2012 NASA Academy will also be available via the student section of the CSA web site in the fall.

Finally, the My Research section of the CSA website profiles the next generation of space leaders, providing a showcase for students involved in space-related research. The profiles

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featured in this section are constantly evolving and are written by the students themselves, with each profile sharing with the reader the individual's story of where they came from, what they are currently doing and where they see themselves headed in the future. This section also provides a great opportunity for space industry representatives to identify some of the country's brightest students who may be at the forefront of leading the next wave of Canadian innovation.

For more information on any of these programs, as well as many other learning opportunities, please visit the student section of the CSA website at: http://www.asc-csa.gc.ca/eng/youth-students/17/

**Jason Clement** (B.A. Cultural Studies'98) currently works as a Communications Officer for the Space Learning Program at the Canadian Space Agency (CSA). Prior to joining the CSA in December 1999, Jason worked in the promotions department at what is now Virgin Radio and wrote his own section- called "Fresh Meet" - in a national magazine titled Fresh, which profiled people in the 18-34 demographic from a variety of interesting fields. At the CSA, Jason is responsible for the coordination of the Space Learning Grants & Contributions Program, the Student and Educator Professional Development Workshop Program, the Student/Youth section of the website as well as a variety of special projects including the development of student programming for a number of space-related international conferences. Jason also represents Canada at the Working Group level of the International Space Education Board.

 MJM 2011 13(2): 55-58 

CROSSROADS

# Medical Education for Exploration Class Missions

## *NASA Aerospace Medicine Elective at the Kennedy Space Centre*

Gregory E. Stewart*, Laura Drudi

### BACKGROUND OF AEROSPACE MEDICINE ELECTIVE

For over a decade, the Canadian Space Agency (CSA) has selected Canadian medical students & residents to attend NASA's prestigious Aerospace Medicine Elective at either the Kennedy Space Center (KSC) on the Space Coast in Florida or the Johnson Space Center (JSC) in Houston, Texas (1). Selected students have the privilege to learn from pioneers and leading experts in space life sciences about the physiologic adaptations that occur during space-flight as well as the preparations and medical support required for a Space Shuttle launch to the International Space Station (ISS).

### INTRODUCTION

The spaceflight environment poses many challenges to astronauts. Understanding the effects of long duration space travel and how a crew medical officer (CMO) operates in this extreme environment was the focus of the research project. The knowledge and skills set for future CMOs as the endeavours to space exploration continue, and Canada's involvement in this initiative was further assessed in this project.

Physicians are often chosen to be astronauts; however, non-physicians are often the CMO on the ISS. Forty hours of CMO training occurs during the two-year period leading up to the actual mission and there is no protocol for maintaining medical skills during a long duration mission (2,3). Therefore, procedural skill decay will be an important issue worth considering for long duration space missions, and effective countermeasures should be developed for CMOs to manage arising medical events. Also, extensive equipment and supplies for the medical interventions cannot be provided due to the severe weight and volume constraints of spaceflight (4,5,6). Thus, risk management strategies dictate that only those situations that are the most severe, or the most easily diagnosed and treated will be anticipated and supplied.

The greatest medical concerns to a crew on an exploration class mission include (i) radiation exposure (ii) human behaviour and performance and (iii) physiologic alterations in the reduced gravitational environment (2,4,5). With the cancellation of the Constellation program, the current plan for NASA is to support the extension of the ISS through 2020. Thus, the ISS will serve as a platform for space life sciences research as well as preparation for future exploration class missions by increasing our understanding of space physiology (6,7).

The standard of care on the ISS is to support the crew 24/7 from Mission Control and to stabilize & transport an astronaut to Earth for definitive medical care (2). For future exploration class missions, however, the medical care system will need to be very autonomous and self-sufficient due to the communication delay and extremely long separation from definitive medical care. Furthermore, procedural skill decay will become a mission-threatening medical consideration, as the expected rate of a significant medical event extrapolated to a 2.5 year Mars mission involving 6 crew members is approximately 1 event/mission (8).

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Current countermeasures for procedural skill decay include efficient and structured medical training design (9). Specifically, the educational experience can be enhanced by designing realistic simulations, also known as High-fidelity Environment Analog Training (HEAT) (10,11). Similar to flight simulators, medical simulation allows effective training and maintenance of skills, and has been successful in improving the training of physicians in safety critical environments including the Emergency Department, the Operating Room and the Intensive Care Unit (12,13). NASA has also developed a flight-ready human patient simulator that can operate in simulated microgravity (i.e. KC-135) and potentially spaceflight (14,15,16).

The importance of simulation based learning is highlighted by the Dual process model which describes efficient reasoning and judgment as distinguishing crew characteristics in safety critical environments (17). Essentially, the model describes two cognitive systems for problem solving:

System 1: characterized by intuitive, rapid reasoning.

System 2: characterized by deliberate, careful reasoning.

Thus, simulation based learning allows the student to develop essential reasoning and judgment skills (i.e. develop System 2) while continued practice allows unfamiliar situations to become more automated and efficient (i.e. develop System 1). This allows advancement to more complex tasks once competence in basic skills has been shown.

Ideally, efficient training design mitigates human error and the risk of an adverse event to a safe and acceptable level. In aviation, it is accepted that errors and mistakes by crewmembers will occur in any flight and a non-blame approach to error is emphasized (18). By shifting the focus from blame to safety, the error is dealt with as any other threat to safety, and the best course of action is discussed in an open atmosphere to determine the most appropriate response to the new situation (19). This philosophy of error management has been formalized into simulation based training entitled Crew Resource Management. It was developed in the late 1970s when it was found that up to 70% of aviation accidents were due to crew issues including failure in communication, lack of situational awareness and poor error management (20). Similarly in medicine, communication issues have been implicated in 70% of perinatal deaths and injuries (21). Also, it was found that 30% of neonatal resuscitation steps are not performed or performed incorrectly. Certainly, check-lists can be a helpful memory aid in these safety critical environments, especially when all relevant human factors are not addressed (22).

Human factors engineering is the study of the interaction between humans and their working environment (20,23). More specifically, its goal is to understand how human limitations, capabilities, characteristics, behaviours and responses will affect performance in a given environment. Furthermore, the application of our understanding of human factors to the design of an intuitive system will minimize risk and optimize performance (24,25).

For example, telemedicine has been used in the design of a model for safe technology transfer to community surgeons in Southwestern Ontario, Canada (26). The study used a preceptor guided training schedule to meet minimum case requirements. The preceptor allowed progression from direct “scrubbed-in” supervision to “verbal-only” supervision and finally to telementoring only when competent skill and judgment was observed. The study demonstrated the feasibility of a training program for laparoscopic colon surgery that shortens hospital stays and ultimately improves patient outcomes.

Telemedicine can also be applied to space travel. A case in point is Just-In-Time telemedicine for ultrasound exam, as it provides a means to investigate a wide variety of conditions in remote & austere environments (27). For the ISS, the training design uses a pre-mission familiarization with the equipment followed by on-board CD-ROM based skill enhancement, as well as remote expert guidance for patient exam. This telemedicine training algorithm developed for spaceflight has also been used to rapidly train medical and non-medical personnel to perform complex procedures (28). Furthermore, it has been used to confirm the diagnosis of High Altitude Pulmonary Edema (HAPE) in mountain climbers on Mount Everest (29).

## CANADA’S INVOLVEMENT IN THE FUTURE OF SPACE EXPLORATION

A unique contribution Canada can make to future exploration class missions is to develop a remote medical training program for crew medical officers. This could be a niche sector for the Great White North as it offers a vast and largely uninhabited geographic area, harsh climate and established medical infrastructure necessary to support the training of future astronaut-physicians.

Thus, as the International Space Station nears completion, it demonstrates how teamwork and collaboration foster the motivation and determination to overcome even the greatest of obstacles. Ultimately, efforts to better our world will undoubtedly inspire the next generation of scientists and explorers to improve their world as well. No matter how large or small the contribution, all those involved with the international space exploration effort can be proud of their motives.

## ACKNOWLEDGEMENTS

Dr. Stewart could not have taken part in the Aerospace Medicine Elective without the dedication and hard work of the individuals at NASA’s Kennedy Space Center and the Canadian Space Agency who made this incredible experience possible.

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**Laura Drudi** (M.D., C.M. candidate 2013) is a third year medical student at McGill University. Her interest in combining her two passions of space and medicine has led her to conduct aerospace medicine research. She will be taking a one year’s leave of absence from the Faculty of Medicine and will be pursuing a Diploma of Space Studies and an MSc in Experimental Surgery prior to completing her MD. She hopes to work for the manned space program as a flight surgeon and to further continue her research in space life sciences.



CROSSROADS

# Ultrasound: From Earth to Space

Jennifer Law*, Paul. B. Macbeth

**ABSTRACT: Ultrasonography is a versatile imaging modality that offers many advantages over radiography, computed tomography, and magnetic resonance imaging. On Earth, the use of ultrasound has become standard in many areas of medicine including diagnosis of medical and surgical diseases, management of obstetric and gynecologic conditions, assessment of critically ill patients, and procedural guidance. Advances in telecommunications have enabled remotely-guided ultrasonography for both geographically isolated populations and astronauts aboard the International Space Station. While ultrasound has traditionally been used in spaceflight to study anatomical and physiological adaptations to microgravity and evaluate countermeasures, recent years have seen a growth of applications adapted from terrestrial techniques. Terrestrial, remote, and space applications for ultrasound are reviewed in this paper.**

*Keywords*: Ultrasound, Spaceflight, Telemedicine, Telesonography, Remote consultation

## INTRODUCTION

The use of ultrasound to diagnose and facilitate therapeutic interventions has become routine in many areas of medicine and surgery (1). With advances in computing power and probe design, ultrasound systems have become a widely available imaging modality. Traditionally, ultrasound is best known for its assessment of pregnancy and fetal growth. A growing number of applications have developed to include detailed assessments of almost every organ system. Clinicians have also identified benefits in trauma, critical care, and remote diagnostics. Ultrasound is an ideal diagnostic tool as it is noninvasive, low-cost, and highly portable. Image generation and interpretation, however, is highly user-dependent. As a result, ultrasound has traditionally been limited to expert users. With new advances in ultrasound technology and personnel training, the use of ultrasound has expanded beyond these traditional boundaries and has become an extension of the physical examination to many. Bedside ultrasound assessments have enhanced physicians’ capabilities to accurately diagnose and understand patient physiology with the benefit of real-time feedback (2).

In this review we discuss the development of ultrasound technology and its expanded assessment of patients. A detailed description of its applications will be highlighted with discussion of its remote capabilities and utility for human space exploration.

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## BACKGROUND

*History of ultrasound*. The origins of ultrasonography can be traced back as far as the early 1800s, when Swiss physicist Jean-Daniel Colladon accurately determined the speed of sound through water. In the late 1800s, Pierre Curie and Jacques Curie demonstrated the connection between voltage and pressure in crystalline materials now known as the piezoelectric effect. This breakthrough led to the creation of the modern ultrasound transducer. It was not until the late 1930s when Austrian psychiatrist Dr. Karl Dussik demonstrated the clinical utility of ultrasound by generating images of brain tumors. A decade later, Dr. George Luwig characterized the differences of sound waves in different tissues. Early clinical applications primarily focused on clinical assessment of pregnancy and fetal development. As the technology matured, more clinical applications were identified. In the late 1970s, Europeans began using ultrasound in the assessment of critically ill trauma patients. It was nearly 15 years later when this application became more widespread in North America. Within the last two decades, ultrasound technology and technique have matured, allowing for wide availability. New techniques and applications continue to be developed.

*How ultrasound works.* In contrast to radiography, computed tomography (CT), and magnetic resonance imaging (MRI), the acquisition and interpretation of ultrasound images are interconnected, as the ultrasonographer must be able to identify important structures and pathologies while scanning. As such, ultrasonographers require an understanding of the basic physical principles of ultrasound. Fundamentally, ultrasound image generation relies on the interaction of ultrasound waves with different tissues. Ultrasonography is based on the piezoelectric effect where quartz crystals are electrically stimulated, causing the crystals to change shape and produce sound waves. Conversely, when reflected sound waves hit the crystals, they produce electrical signals, which are used in combination to generate an image. Image generation relies on impedance differences between different tissues. These tissue interfaces result in the reflection of transmitted ultrasound waves, creating an echo. Many of the objects seen in ultrasound images are due to the physical properties of ultrasonic beams, such as reflection, refraction, and attenuation. The ultrasound computer measures the time to detect the reflected wave, then calculates the distance to the reflected surface. These signals and calculations are then combined to generate a two-dimensional real-time image on the screen. In a typical ultrasound, millions of pulses and echoes are sent and received each second. A probe is positioned on the surface of the body and moved to obtain various views. Ultrasound waves pass easily through fluids and soft tissues, however they are unable to penetrate bone or gas. Therefore, ultrasound is of limited use for examining regions surrounded by bone, or areas that contain gas or air. Despite this, ultrasound has been used to examine most parts of the body. Understanding these interactions is important for establishing a clinical diagnosis.

**TERRESTRIAL APPLICATIONS**

Ultrasound is an essential tool for diagnostics and interventional procedures and has been used to characterize almost every organ system in a variety of patient populations and specialties.

*Trauma.* The Focused Assessment with Sonography for Trauma (FAST), originally described in 1999 by consensus definition, is used to rapidly evaluate patients with blunt or penetrating thoracoabdominal trauma (3). The FAST examination is based on evaluation of dependent portions of the peritoneal cavity—the splenorenal, hepatorenal, and rectovesical/rectovaginal recesses—for evidence of free fluid (as illustrated in Figure 1) and the pericardium for evidence of pericardial effusion or tamponade. The purpose of this assessment is to extend the physical examination to rapidly identify diagnoses that require emergent interventions such as laparotomy or pericardiocentesis. In the setting of an unstable patient, the use of ultrasound for rapid diagnostic assessment is far superior to conventional CT or MRI modalities. The FAST examination is widely used in North America and has become standard teaching for emergency medicine and surgical trainees. Recently this evaluation technique has been expanded to include examination of the pleural surfaces to assess for the presence of fluid (hemothorax) and air (pneumothorax). This technique is referred to as the extended FAST (EFAST) originally described by Kirkpatrick, et al (4, 5). Other descriptions of using ultrasound in assessment of trauma patients include identification of intraperitoneal free air (6) and pulmonary contusion (7), assessment of elevated intracranial pressures by sonographic characterization of the optic sheath (8), identification of a ruptured globe (9), and diagnosis of maxillofacial fractures (10). Despite these advances in application and technique, further development is ongoing (11-18).

**Figure 1**: A positive Focused Assessment with Sonography for Trauma (FAST) examination. Ultrasound image demonstrating a small amount of free fluid adjacent to the liver in Morrison's pouch.



*Medical and surgical applications.* Ultrasound is increasingly being used in the emergency department for medical resuscitations. Various protocols have been described to evaluate the undifferentiated hypotensive patient, generally involving sonographic windows of the abdomen, heart, abdominal aorta, inferior vena cava, and pleura (19-21). In less emergent settings, comprehensive transthoracic or transesophageal echocardiograms are used to evaluate the anatomical structure and functioning of the heart, yielding information including valve integrity, ejection fraction, and disease states such as endocarditis, hypertrophic cardiomyopathy, and pericardial effusion. Other applications for ultrasound include diagnosis of arterial and venous thrombosis, biliary tree disease such as cholelithiasis and cholecystitis, appendicitis, hydronephrosis, testicular torsion, and soft tissue infections.

*Obstetric and gynecological applications.* Ultrasound, which does not expose patients to ionizing radiation, has traditionally been the modality of choice for the confirmation of intrauterine pregnancy, monitoring of fetal growth, and evaluation of pregnancy-related complications including placenta previa and abruption. Ultrasound also enables excellent visualization of the uterus and adnexa to diagnose such conditions as uterine fibroids, ovarian cysts, and ovarian torsion.

*Procedural guidance.* The application of ultrasound in interventional procedures has seen significant growth. Its use has become an established component of interventional procedures to assist physicians in the safer delivery of invasive procedures such as central venous access, arterial lines, chest tube placements, percutaneous fluid drainage including thoracentesis and paracentesis, abscess identification and drainage, and regional nerve blocks (1, 22). The use of ultrasound for central line placements has reduced procedure-related complications and is now considered standard of practice in many institutions (23). Ultrasound has also been shown to significantly improve speed, patient satisfaction, and safety for difficult peripheral vascular access in the emergency department (24, 25). Ultrasound guidance for fracture reduction is currently under investigation (26). Demonstration of remote guidance of interventional procedures has been described and is presented further in the next section.

**REMOTE ULTRASOUND**

Ultrasonography is inherently well suited for remote application with transmission of signals for expert interpretation. The development of remote ultrasound capabilities has expanded beyond terrestrial based activities to include applications in human spaceflight on the International Space Station (ISS). The benefits to patients on Earth are delivery of diagnostic and interventional capabilities in geographically isolated sites, where experts are not always available or there is a need for second opinion when diagnosis is difficult. In many remote locations, ultrasound may exist as the only potential imaging modality available. Several studies have documented utility using ultrasound for the detection of chronic, sub-acute and acute medical problems in isolated areas where advanced imaging capabilities are not available (27). Recent literature suggests that non-radiologist operators can reliably perform focused ultrasound examinations to facilitate on-site diagnosis (28).

*Ground-based.* Geographically isolated patients often have limited access to health care resources including ultrasound services. This lack of access has resulted in programs to provide telesonography to remote communities. The portability and low cost of ultrasound equipment make it ideal for this application. Global telecommunication networks, using ISDN (ground based) or D or V SAT (satellite) protocols, allow transmission of communications signals between almost any two points on Earth. These established global networks enable transmission of ultrasound images for interpretation by a remotely located expert (29).

Existing telesonography programs have focused mainly towards diagnosis of chronic or sub-acute medical conditions and follow-up assessments (30-33). Applications in remote areas of Australia and Canada have demonstrated its use for assessment of pregnancy and fetal health (34, 35). Recent advances have allowed for remote diagnostic and intervention guidance in critically ill patients (36, 37). A program based in Calgary, Alberta, has created a telemedicine link between a remote resuscitating hospital and the emergency department of a tertiary care trauma centre in the management of acutely injured patients. Using two-way video conferencing and one-way ultrasound transmission, the receiving physicians are able to mentor the remote clinician through the assessment of a trauma patient. These technologies have also been described in providing diagnostic capabilities in the battlefield.

*NEEMO.* Remote ultrasound has been evaluated and tested aboard Aquarius, an underwater habitat off the Florida Keys, as part of the NASA Extreme Environment Mission Operations (NEEMO). The life sciences mission NEEMO 7 investigated the role of ultrasound examination of the abdominal organs and structures. Ultrasound-trained and untrained aquanaut crewmembers conducted a series of diagnostic and interventional procedures under remote guidance from experts over 3,000 km away (38). Researchers demonstrated that mean efficiencies were slightly higher with telementoring than with the use of a procedure manual.

*Robotic-guided ultrasound* . The capabilities of ultrasound using an audio/video link with a remote expert have also been augmented with robotic control and guidance of the ultrasound probe. Several groups are working on the development of master-slave type remote ultrasound diagnostic systems (39-41). These systems, based on a communications link between two robotic systems, allow the expert ultrasonographer to extend a virtual hand onto the ultrasound probe. The motion of a master manipulator is controlled by the expert and is reproduced by a slave manipulator carrying an ultrasound probe. Haptic technologies have also been developed and integrated into these systems to remotely provide the expert with tactile feedback. Currently, these systems are prohibitively expensive and used primarily on a research basis.

## SPACE APPLICATIONS

Ultrasound is currently the only medical imaging method available aboard the ISS, which hosts an ultrasound system in its Human Research Facility (HRF) that is capable of high-definition sonographic imaging for cardiac, vascular, general/ abdominal, thoracic, musculoskeletal, and other ultrasound applications, with remote guidance from experts in the Mission Control Center (MCC) (42). While to date ultrasound has been primarily used to characterize anatomical or physiological changes in microgravity and evaluate countermeasures (43), terrestrial applications for ultrasound are increasingly being adapted for spaceflight, for diagnostic purposes. In microgravity, organs may shift position and free fluid does not pool in dependent areas, so many existing ultrasound techniques require modification. Parabolic flight offers the opportunity to refine adapted techniques before they are used in space.

*Cardiovascular.* Prolonged exposure to microgravity can result in cardiac deconditioning and orthostatic intolerance upon return to Earth due to fluid shift and loss. The first ultrasound system in space, Argument, was flown on Salyut 6 and 7 to study chamber sizes and left ventricular systolic function. More advanced systems, ranging from the American Flight Echograph to the HRF Ultrasound System (HRF US), have subsequently enabled more complete evaluation of the heart in flight. On ISS Expedition 7, a study demonstrated the feasibility of coupling the HRF US to the cycle ergometer to perform stress echocardiography (42). To measure fluid shift, systems such as the French Compact Doppler System have been used to evaluate cerebral and femoral blood flow before flight, during reentry and landing, and post-flight (43).

*Musculoskeletal. Many* musculoskeletal complaints such as back pain, contusion, and strain are common among space crews. Ultrasound has demonstrated that the intervertebral distance between L1 and L5 increases significantly in microgravity (44), which may be one of the contributing factors to back pain in space. Ultrasound can theoretically be used to evaluate any tendon, ligament, and bursa (42). A specific protocol for sonographic evaluation of the shoulder, including the articular cartilage surface and the biceps and supraspinatus tendons was demonstrated by the Expedition 9 crew (45).

*Trauma*. Blunt and penetrating trauma can occur when astronauts engage in tasks such as extravehicular activity, habitat construction, and vehicle operations. The FAST examination has been evaluated both in parabolic flight and aboard the ISS. In the former case, fluid was introduced to the peritoneal cavity of restrained porcine models and it was found that fluid in the subhepatic space was the most sensitive in microgravity (46). In the latter case, a crewmember was able to perform the exam on herself without difficulty (47). Sonographic diagnosis of pneumothorax, hemothorax (48) and ultrasound-guided percutaneous aspiration of intraperitoneal fluid to treat peritonitis (49) have also been demonstrated in porcine models in parabolic flight.

*Genitourinary*. Urinary tract infections, urosepsis, urinary retention, and nephrolithiasis have all occurred in past space flights. The HRF US has been used to conduct renal and bladder surveys for evaluation of the renal anatomy, vascular flow, and ureteral patency (50, 51). Ultrasound-guided percutaneous bladder catheterization to relieve urinary obstruction was demonstrated in porcine models in parabolic flight, which can be adapted to space in case luminal catheterization is not possible (52).

*Ocular*. Ocular foreign bodies are a common problem in microgravity, where small particles float freely, sometimes undetected. During the Shuttle-Mir Program, there was also an incidence of blunt trauma to the orbit when a bungee cord restraint system broke (53). Recently, a non-physician crewmember was able to use the HRF US to perform a comprehensive



ocular examination on himself with remote guidance from the MCC, visualizing the anatomical structures of the globe, iris, and pupil (54).

*Sinuses.* Astronauts in space are predisposed to sinusitis due to cephalad fluid shift and altered drainage of the sinuses in microgravity; superinfection of the sinuses may result in acute bacterial rhinosinusitis. Beninnger et al. introduced fluid to porcine sinuses in parabolic flight and found that in microgravity, fluid could be visualized on ultrasound as a 2 to 3 mm thick air-fluid interface distributed along the entire sinus cavity. The authors further noted that ultrasound-guided sinus drainage procedures were possible (55).

*Decompression sickness*. Space crews are susceptible to decompression sickness (DCS) when they transition from one environment to a more hypobaric environment, such as an extravehicular (EVA) suit. When the ambient pressure decreases, nitrogen dissolved in the bloodstream comes out of solution and forms bubbles, which may circulate in the body or get trapped, causing local symptoms. Nitrogen bubbles are readily seen on Doppler ultrasound. An in-suit system has been recommended by the NASA Medical Operations EVA Integrated Product Team to better understand bubble formation and arterialization in flight to quantify the risk of DCS (56).

*Future applications*. For future Exploration Class missions, astronauts will require autonomous medical capabilities given communication delays between the crew and medical support staff on the ground; real-time remote guidance will likely be replaced by one or more trained physician-astronauts onboard. Timely evacuation to Earth will not be possible. Thus, ultrasound will play a greater role in the medical armamentarium for diagnosis and treatment of medical contingencies in space. Sargsyan et al. (42) has catalogued an extensive list of ultrasound applications that have been tested in microgravity and/or with remote guidance, as well as those that are potentially feasible in space. In addition to the previously described applications, more novel uses for ultrasound include evaluation for dental periapical abscesses, thyroiditis, and retroperitoneal hematoma. Finally, low-intensity ultrasound has been suggested to promote bone formation in vitro (57) and may one day be used as a countermeasure against microgravity-induced osteopenia.

## CONCLUSION

Ultrasound is a well-proven diagnostic modality on Earth and is becoming increasingly useful in space. Its versatility, portability, noninvasiveness, lack of ionizing radiation, and tele-transmittability make ultrasound an ideal imaging method for space crews. Although ultrasound does not provide the same resolution for evaluating gas-filled or osseous structures as CT or MRI, the role of ultrasound continues to expand, both on Earth and in space. New applications being investigated for spaceflight may be adapted for use on Earth, especially in remote environments that do not have ready access to advanced imaging modalities or expert radiologists, and vice versa. Indeed, ultrasound shows much promise in benefitting both astronauts and patients on Earth.

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CROSSROADS

# Medical Care in the Arctic and on Orbit

David Saint-Jacques*

I joined the Canadian Space Program in 2009. I am currently undergoing basic astronaut training leading, hopefully for a future mission aboard the International Space Station (ISS). My perspective is therefore that of a newcomer without spaceflight experience. I do, however, have some experience working as a family physician in northern Canada and, as my understanding of how medical care is provided on orbit grows, it has been interesting for me to see the parallels with my former practice.

*MacGyver spirit*

The first thing that comes to mind when discussing medical care "up north" is that, compared to their colleagues working in large centers, northern first-line physicians are more on their own. The absence of readily available consultants has a big impact on their practice; there is a strong incentive to strive for maximum autonomy and to stay current on as many topics as possible. Diagnostic tools and therapeutic pharmacopeia are also limited, and sometimes you just have to make do with what you have!

All of that is also true of the Crew Medical Officer (CMO) on a space mission. Readiness, inventiveness, outside-the-box thinking and a broad knowledge base are important to all physicians, but are particularly key to those working on their own in remote locations. Incidentally, there is not always a physician on-board the ISS; every crewmember receives basic emergency medical training, and the designated CMO receives more advanced training.

**Figure 1:** Intubation training at the McGill Simulation Center with fellow CSA astronaut candidate, Major Jeremy Hansen, a former CF-18 fighter pilot.

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**Figure 2:** Patient transfer by plane in Nunavik. These sturdy DeHavilland DHC-6 are used for regular passenger transport between northern communities, but can be quickly turned into an ambulance and carry a stretcher or an infant incubator.

*Telehealth*

Of course, up north, one is not completely alone: help is always available in one form or another thanks to telehealth. For physicians working in northern communities, telehealth most often simply means a phone call to a specialist. Satellite internet now allows the transmission of clinical photographs and locally obtained x-rays. Where and when videoconferencing bandwidth permits, one can even perform ultrasound under the live guidance of a remote specialist. This has, for example, revolutionized pre-partum care for Inuit women, who don't have to fly "south" just for a regular exam. Telehealth is also a great way for specialists to provide mentoring to remote personnel.

All these tools currently apply to on-orbit medical care. There is always a flight surgeon available for advice, and selected imagery can be downlinked to Earth. For example, commonly transferred images include cardiovascular ultrasound loops, fundoscopic images and dermatological photographs. X-Ray, MRI and CT are not available due to the prohibitive launch weight of the required equipment. Interestingly, telehealth is a good example of bidirectional technology transfer, where tools and protocols developed for terrestrial applications are used on-orbit, and vice-versa.

However, as we contemplate deep-space missions back to the Moon, and on to Mars, the trade-off between support from Earth and medical autonomy becomes an issue. Basically, the further away, the more autonomy is required.

This is driven firstly by the increasing delay in communications. Since we can't transmit radio signals faster than the speed of light, from Mars it could take up to 40 minutes to get an answer back, making consultations very cumbersome. Secondly, increasing distance makes an emergency medical evacuation less and less practical. Whereas evacuation from the low-earth orbit where ISS is located would be expensive but possible, an evacuation from Mars would probably not be an option.

*Environmental and cultural issues*

There are other obvious parallels between medical practice in northern Canada and on-orbit. One is the harsh and unforgiving nature of these beautiful environments; this modifies the frequency of various pathologies and drives the requirements for preparedness. For example, up north, the occurrence of exposure is relatively high, whereas on orbit decompression accidents are a threat - fortunately, this has not happened yet!

The other parallel one can draw is the cross-cultural element. Physicians working in northern Canada serve an Inuit population with different lifestyles and different expectations towards healthcare compared to urban Canadians. The physician must adapt to these differences and avoid imposing his own perspective. The same is true on orbit, with crews generally of international composition.

*Risk management*

Living in a remote area is a health risk in itself: for example, the chances of surviving a major head trauma are several orders of magnitude lower when the nearest neurosurgeon and ICU are several hours away by flight. Remoteness also drives the way we organize patient follow-up for more benign ailments: northern physicians tend to err on the conservative side, in general, to further minimize risks of complications.

The local population understands and accepts these risks; the challenge for northern health care providers, and the responsibility of the healthcare system, is to ensure these discrepancies are minimized, within reason. To quote an Inuit participant to the Romanow Commission: “I believe that the success of our Health Care System as a whole will be judged not by the quality or service available in the best urban facilities, but by the equality of service Canada can provide to its remote and northern communities.”

Similar concerns apply to on-orbit medical care. For example, in deciding the content of the on-board medical kit, one must decide what pathologies the crew could likely treat successfully. Deciding whether a particular illness or injury is survivable or not on-orbit is a matter of ongoing speculation and debate. This uncertainty is essentially what drives the requirement for crewmembers to undergo such stringent medical screening, in the hope of minimizing risk.

Again, as we envision deep-space missions wherein medical evacuation is not an option, the sobering consideration of what one should realistically prepare to treat only gets more relevant.

**David Saint-Jacques** (MD, PhD) is an astronaut candidate with the Canadian Space Agency. He and is currently in basic training at NASA’s Johnson Space Center in Houston, Texas. He was selected in 2009 while he was working as a family physician in the Inuit community of Puvirnituq, in Nunavik, Northern Quebec. He received a B.Eng in engineering physics from École Polytechnique in Montreal, and worked as a biomedical engineer in Paris, France. He subsequently obtained a PhD in astrophysics at Cambridge University, UK and worked as an astrophysicist in Tokyo, Hawaii and Montreal. He then returned to pursue an M.D. from Université Laval, and completed a residency in family medicine at McGill University.



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CROSSROADS

# Physicians as Astronauts

Robert Thirsk*

In 2009 I had the good fortune to fly on a long duration space mission. With two crewmates, I launched aboard a Russian Soyuz rocket from the Baikonur Cosmodrome in Kazakhstan. When our spacecraft reached orbit nine minutes later, we were traveling at a speed of 28,000 kilometers per hour through an environment devoid of air, water and anything familiar. Two days later we rendezvoused with the International Space Station (ISS) at an altitude of 350 km. As our Soyuz vehicle docked with the Station, we began an incredible space odyssey as members of the ISS Expedition 20/21 crew.

This Expedition marked the first time that the ISS hosted a permanent crew of six. My international crewmates (from Russia, the United States, Japan and Belgium) and I performed an unprecedented amount of multidisciplinary research (Figure 1). We also performed complex robotic operations, spacewalks, and maintenance and repair work of Station systems and payloads (Figure 2).

Six months later my Soyuz crewmates and I undocked from the Station and landed back in Kazakhstan. During our stay in space, we completed 3,000 orbits of the Earth and traveled 125,000,000 km. It was truly an odyssey.

This ISS expedition as well as my earlier Space Shuttle mission have enriched me in ways I can never fully explain. I often reflect on the career path that took me from medicine to the cosmos. To some of my medical colleagues, this path seems incongruous. They ask, “What does the practice of medicine have in common with space exploration?“.

In the following paragraphs, I describe the astronaut profession and its commonalities with medicine. Astronaut training is certainly a transformative experience and the spaceflight environment is alien to anything in the clinical world. However, a career transition to space exploration after investing so much time and effort in a medical career is not unusual. A well-trained astronaut exhibits many of the same knowledge, skills and professional attributes of an exemplary physician. Indeed, a medical background forms an excellent foundation for a career in astronautics.

**Figure 1**: European astronaut Frank De Winne performs echocardiography on Robert Thirsk, MDCM. This experiment investigated cardiovascular adaptation to weightlessness.

## SELECTION

An astronaut career begins with selection. The process to become an astronaut is even more protracted, competitive and rigorous than it is for medical school. The Canadian Space Agency’s most recent recruitment campaign in 2008/09 lasted 12 months and saw 5,300 people apply for only two available positions.

Astronaut candidates represent a wide spectrum of professionals such as test pilots, engineers, scientists, educators and physicians. Candidates who have considerable experience working

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**Figure 2**: Robert Thirsk, MDCM, performs maintenance on the Station's Water Recovery System. This recycling system processes waste water and crew urine into potable water.

in a team setting and who habitually work outside their comfort zones are highly regarded (Figure 3).

Like prospective medical students, astronaut candidates complete questionnaires and submit university transcripts, letters of reference and a personal essay ("why I want to be an astronaut") as part of the application process. During the latter stages of the selection process, a series of interviews are conducted with the selection committee. A very thorough medical evaluation is performed since many medical conditions that are considered to be minor on Earth can become problematic in a spaceflight environment.

The work of an astronaut regularly takes us to the limits of our physical, mental and emotional abilities. Accordingly, the selection process includes physical fitness, cognitive and psychiatric evaluations. Hours of psychometric tests and psychological interviews ensure that the chosen candidates have the motivation, personalities and support mechanisms to do well in the demanding training and flight environments.

Aptitude tests assess a candidate's team skills, creativity and tolerance to stress. During the most recent recruitment campaign, the candidates' potential to learn specialized skills such as robotics, EVA (Extra Vehicular Activity) and foreign languages was also considered.

Finally, interpersonal and communication skills are evaluated. In addition to operational duties, astronauts function as spokespersons for the Canadian Space Agency. We advocate for a national economy based upon innovation and advanced training. In the same way that we were inspired by explorers and scientists when we were young, it is our responsibility to engage the public and to instill a passion for discovery in Canada's next generation of leaders.

**KNOWLEDGE**

Following selection (a gratifying day for a fortunate few!), astronauts begin the first phase of our education called Basic Training. This phase typically lasts a couple of years. Basic Training provides each new astronaut (no matter what prior professional background) with a common knowledge base and builds the foundation for more advanced training to follow in the ensuing years. Each new recruit acquires broad background knowledge about the scientific, technical and operational aspects of human spaceflight.

The structure of the basic training program for an astronaut shares a lot in common with a medical school curriculum. Our training resources include manuals, lectures, computer-based instruction and field trips.

The first couple of years of medical school were challenging for me due to the massive amount of knowledge that needed to be learned quickly. The same is true in astronautics. Astronaut training is like drinking from a fire hose. The Russian Soyuz and the American Space Shuttle are complex space vehicles. Even more challenging to understand and operate is the International Space Station (Figure 4). This marvel of engineering has a mass of 420 tons, dimensions that are two times greater than that of a CFL football field, and living space equivalent to a four-bedroom house. 120 telephone-booth-size racks house spacecraft systems and research experiments. The Station's onboard computers process four million lines of code.

A systems approach is used to instruct astronauts about space operations. We consider the composition of our spacecraft to include thermal control, electrical power, life support and many other systems. Just as no system in the human body operates independently, each spacecraft system interacts with several others.



Physicians and astronauts would be equally handicapped if we could not resort to our unique mnemonics. Acronyms and jargon pepper our conversations with colleagues. I smile to myself whenever I encounter a new space acronym that shares a meaning from my medical past (e.g. ER, D&C).

**SKILLS**

Having acquired the fundamentals of spaceflight operations, astronauts next begin a training phase known as Advanced Training. This phase of training is analogous to clinical clerkship and residency since we learn highly specialized skills that are unique to our profession. It is fast-paced and fulfilling.

We learn skills that allow us to launch to and return from orbit, to rendezvous and dock with other spacecraft, to perform spacewalks (also known as EVAs) and to operate robotic systems such as the Canadarm2. After acquiring proficiency in a skill, we become mentors to the next trainees. 'See one, do one, teach one' is a mantra that also applies to spaceflight.

Practice makes perfect. We train thousands of hours for nominal as well as off-nominal situations. Crew coordination, situational awareness and speed of reaction are critical factors to save our lives, the spacecraft and the mission under contingency situations.

It is during Advanced Training that simulators play a major role. In fact, simulators are the basis for much of our skills acquisition. They are used to prepare astronauts for a variety of flight situations.

For instance, the robotics simulator at the Canadian Space Agency in Montréal uses virtual reality to model Canadarm2, other robotic systems and the Space Station environment. Astronauts from all ISS partner nations use this facility to develop skills such as Station assembly and the capture and berthing of cargo vehicles.

The Neutral Buoyancy Laboratory (NBL) in Houston, Texas is another type of simulator. It is basically a huge pool (much larger than an Olympic swimming pool). We exploit water buoyancy to simulate the weightless condition experienced by astronauts during space walks. Small flotation devices or weights are strapped to the space suits

**Figure 3**: During her STS-42 Shuttle mission Roberta Bondar, MD, begins an experiment to investigate visual and vestibular responses to head and body movements.

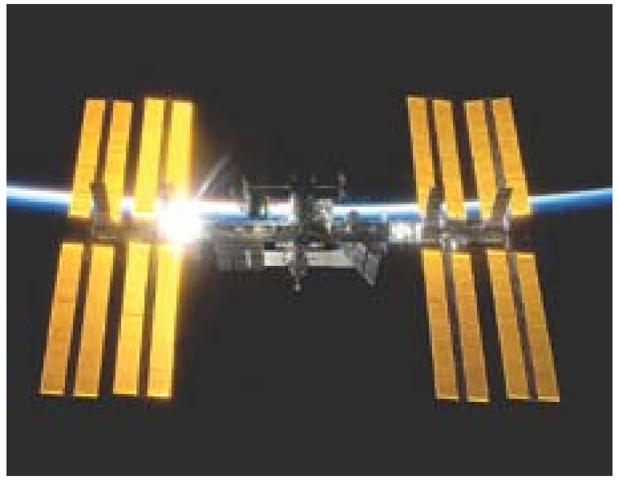

**Figure 4**: The International Space Station viewed from the Space Shuttle at orbital sunset.

of astronauts so that we are neutrally buoyant and so that our movements in water are similar to what they would be in space (except for the effect of water drag). The NBL is an essential simulator to familiarize us with space walk plans and procedures (Figure 5).

The Gagarin Cosmonaut Training Centre near Moscow has an impressive centrifuge with a rotating arm that is 18-meters long (the largest in the world). The distal end of the arm contains a functional mock-up of the Soyuz cockpit. This is where cosmonauts sit. As the arm rotates, the centrifuge creates the g-forces similar to what we experience in our capsule during atmospheric re-entry. The level of g-force induced by the centrifuge is determined solely by the re-entry profile that we manually fly from the controls in the cockpit. In other words, we pay for any piloting mistakes we may make with a high g-load! Talk about incentive for the trainee to get it right!

There are many other simulators used for astronaut training and they come in a variety of appearances and functions. No single simulator can recreate all conditions of spaceflight. However, each is able to simulate one or more features in high fidelity. By integrating our training experiences across all of these simulators, we are well prepared for what we will encounter on orbit.

Another valuable training resource is NASA's fleet of T-38 high performance jets (Figure 6). These aircraft are not simulators; they provide real-life dynamic training. Jet flight, like spaceflight, involves interaction with complex, data-rich systems in a fast-paced, unforgiving environment. Flight time in high performance jets sharpens decision-making skills and crew coordination.

**ATTITUDES**

An ISS crew of six possesses all the necessary skills to deal with any onboard situation. Each crewmember fulfills a certain role and is proficient in several specialized skills (in addition to generic crew skills). For instance, during Expedition 20/21, I functioned as a flight engineer, and my specialized responsibilities included medical care for the crew, payload science and robotics. While the crew commander had overall responsibility, each crew member played a leadership role for specific aspects of the expedition.

The harmonious teamwork exhibited by my Shuttle and Station crews is something I fondly remember. In addition to his or her own busy schedule of duties, each of my crewmates became involved in the successful completion of others' tasks. We anticipated each other's unspoken needs in the same way that an operating room nurse anticipates the next instrument required by a surgeon. After completing our own tasks, we then looked for opportunities to help our crewmates with theirs. For instance, I would arrive at a worksite aboard the Station and find that someone had already gathered the tools that I would require for my upcoming task. What a team!

Everyone helps out with everything. Accordingly, when one crew member successfully completes a complex operation, we all share in the satisfaction. This kind of crew interaction enhances our productivity and makes our activities seem tightly choreographed.

Like all health care practitioners, astronauts are vigilant and precise about everything we do. During spaceflight there is often only one chance to perform a task correctly. The speed of the spacecraft, the constraints of orbital dynamics or the tight mission timeline often mean that there are no second chances.

Launch, rendezvous and re-entry are phases of flight to be particularly vigilant. Thoughts about the next possible failure pre-occupy our minds while executing engine burns and on-orbit maneuvers. Monitoring our instruments for system malfunctions is not enough; we also need to anticipate the next failure, its impact and our reaction.

Most astronauts are not familiar with the clinical precept "Primum Non Nocere" but we do adhere to its intent. When a crewmate begins a critical task, we often admonish her or him with the



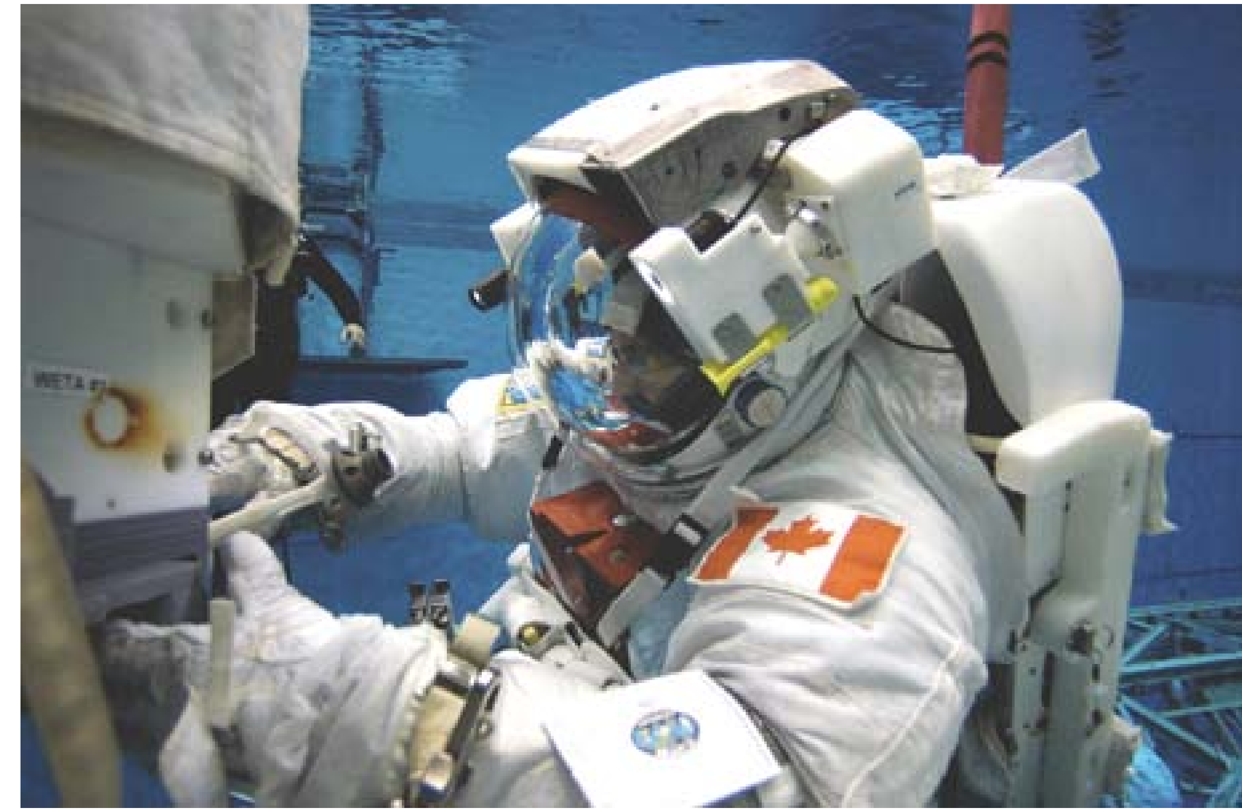

**Figure 5**: Dave Williams, MDCM, rehearses EVA procedures in the Neutral Buoyancy Facility prior to his STS-118 Shuttle mission.

words "don't become famous!" If the name of an astronaut becomes well known, it is often because she or he made a mistake while on-orbit. In the following years, our instructors on the ground will lightheartedly mention the goof-up and our name to forewarn the next classes of astronauts about potential operational pitfalls. I would be happy to complete my career as an unknown!

Doctors do not work in isolation from the rest of the hospital staff. Clerks, orderlies, technicians, social workers, physiotherapists and the omniscient head nurse are key members of the patient care team. Astronauts also do not work in isolation. Thousands of kilometers away at mission control centres around the world, hundreds of engineers, scientists, technicians, flight surgeons and managers (known collectively as 'flight controllers') continuously monitor our spacecraft's telemetry, video and audio signals. The flight controllers have great insight into the status of our vehicle's systems and payloads, and are ready to spring into action if an in-flight anomaly should occur.

Anomalies and hardware failures can be expected during the course of every mission. For example, during Expedition 20/21 our oxygen generation and carbon dioxide removal systems failed. At these times I considered the flight controllers as specialists and regarded my role in space as their eyes, ears, and hands. Oslerian observation and communication skills that I had developed as a physician became useful. Having completed the 'history' and examination of the failed system, I then communicated my observations concisely to the flight controllers and anticipated what other information they would need to diagnose the problem. Working together, we successfully repaired these critical systems. Flight controllers are integral members of our team and I have great confidence in their capabilities.

Physicians may be the most senior practitioners on a hospital ward and astronauts may be the most visible participants of a mission, but we are only small subsets of large talented teams devoted to success.

A space mission continues even after we return to Earth. Astronauts spend several weeks after landing in medical testing and physical rehabilitation. We don't consider the mission complete until the debriefings are finished.

No mission has ever been flown perfectly. Hardware inevitably breaks down and contingency situations arise. Every astronaut will admit in hindsight that she or he could have executed a particular task more effectively. During debriefing sessions (our version of Grand Rounds), we recount our experiences for the benefit of instructors, flight controllers and program managers. This kind of feedback facilitates planning for future missions and enhances the training for the crews who will fly next. We learn and improve from our insights and errors.

**CONCLUSION**

Back on Earth, I often reflect on my medical school years and residency. Both were positive experiences. As a student I couldn't foresee the opportunities that my medical training would someday offer to me both on and off this planet.

It behooves space agencies, in summary, to recruit physicians for our unique training experiences and for the operational capabilities that we hone on hospital wards. Of Canada's ten astronauts, four are physicians. Three of these four physicians are graduates of McGill University's medical school (Figure 7). Not a bad batting average!

The knowledge, skills and attitudes of a clinician are valuable but not sufficient, of course, to be an astronaut. A burning passion for space exploration is also required. We take our inspiration from John F. Kennedy who, when the United States was initiating its Apollo moon program, declared "We choose to go to the moon, not because it is easy, but because it is hard, because that goal will serve to measure the best of our energies and skills."

For some people, the benefits of space exploration do not out-weigh the arduous work and risk. For physician-astronauts, they clearly do.

**Figure 6**: David Saint-Jacques, MD, returns from a training flight in a T-38 jet. These jets develop operator skills and crew coordination in a dynamic environment.



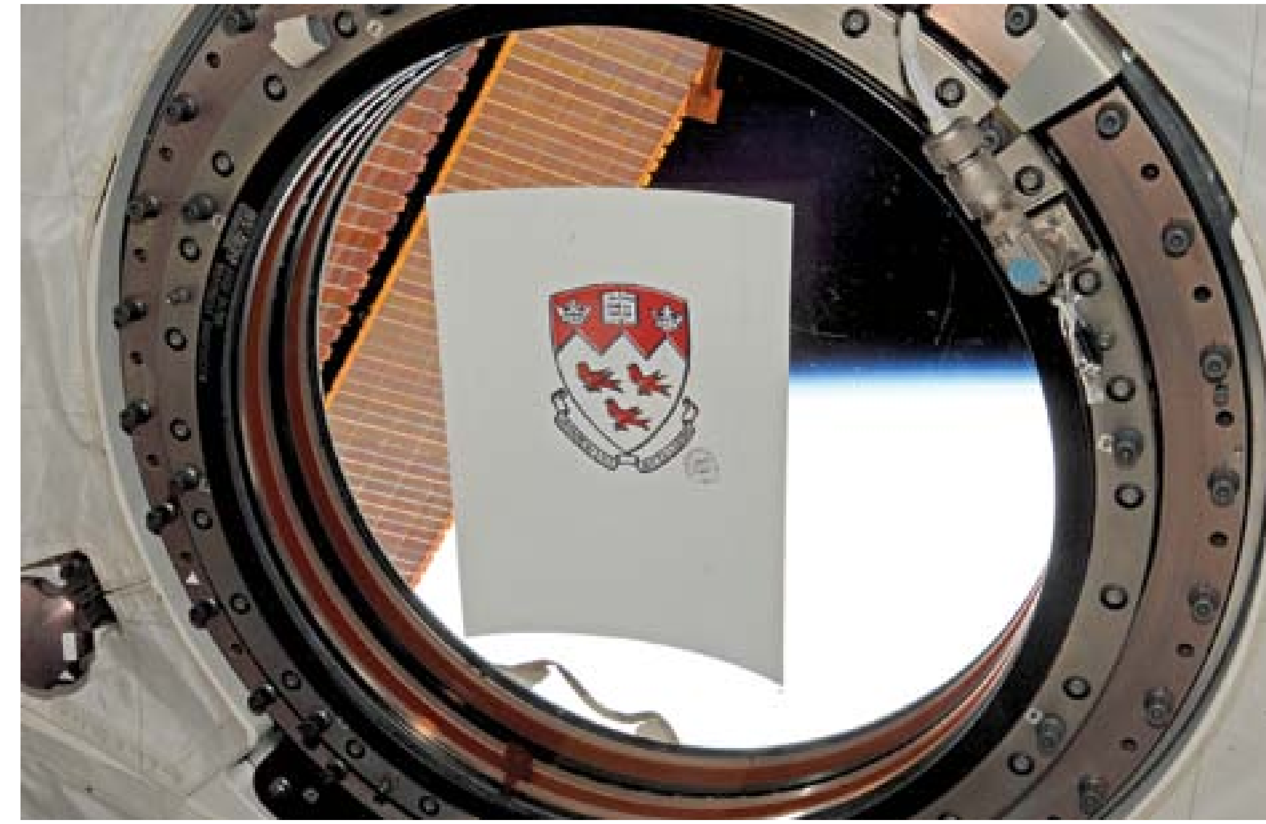

**Figure 7**: A McGill University crest was flown aboard ISS Expedition 20/21 to recognize the close ties between the McGill Medical School and Canada's astronaut corps.

**Robert Thirsk** received a Bachelor of Science degree in Mechanical Engineering from the University of Calgary, a Master of Science in Mechanical Engineering and a Master of Business Administration from the Massachusetts Institute of Technology, and a Doctorate of Medicine from McGill University. Robert has flown twice in space: a 17-day mission in 1996 aboard the Space Shuttle Columbia and a 188-day expedition in 2009 aboard the International Space Station.

 

CROSSROADS

# Human Space Exploration The Next Fifty Years

David R. Williams and Matthew Turnock*

**ABSTRACT: Preparation for the fiftieth anniversary of human spaceflight in the spring of 2011 provides the space faring nations with an opportunity to reflect on past achievements as well as consider the next fifty years of human spaceflight. The International Space Station is a unique platform for long duration life science research that will play a critical role in preparing for future human space exploration beyond low earth orbit. Some feel the future path back to the Moon and on to Mars may be delayed with the current commitment of the United States to support the development of human-rated commercial spacecraft. Others see this as a unique opportunity to leverage the capability of the private sector in expanding access to space exploration. This article provides an overview of the past achievements in human spaceflight and discusses future missions over the next fifty years and the role space medicine will play in extending the time-distance constant of human space exploration.**

*Keywords*: Human spaceflight, space medicine, career astronauts, spaceflight participants, commercial spaceflight

The past five decades will stand for eternity as that period in history when humans became a space faring species. From the first flights of Yuri Gagarin and Alan Shepard in the spring of 1961 to the Apollo 11 lunar landing in 1969, people throughout the world were mesmerized by the incredible progress of space exploration. The decade culminated with the achievement of President Kennedy's vision of human exploration of the lunar surface and safe return to Earth. Meeting this goal required the combination of sophisticated engineering, life science and medical research with a dedicated team committed to making what appeared impossible, possible.

From a clinical perspective, bioastronautics (1) and space medicine (2) (3) research demonstrated that humans could survive in space, work in space and perform complex scientific missions on the surface of another celestial body. After the exponential growth in short duration flight objectives of the sixties, the past four decades have focused on the development of a long duration capability for human spaceflight. The vision of sending humans farther into the solar system was shared by many experts within the United States and Russia. For that vision to become reality, the acclimation of humans to space had to be studied over the course of months not days. The Russian Salyut series of space stations and the NASA Skylab (4) (5) (6) program that highlighted the next decade of human spaceflight were used to evaluate the capacity of humans to live and work in microgravity for long periods of time. Both programs provided fundamental data on space physiology (7) relevant to space medicine, but they also demonstrated the need for extended long duration missions on board a new generation of space stations.

The scientific utilization of space stations as microgravity research platforms provided an additional technical challenge in developing the capability to bring payloads to and from low earth orbit. The Space Shuttle was designed to meet this unique requirement along with additional roles as an autonomous science platform and as a vehicle that could be used to launch and repair satellites. The need for onboard robotics as a critical enabling technology was identified and Canada was invited to design and produce a robotic arm for the Shuttle program. Referred to as the Canadarm, or "the arm" for short, this contribution to the Shuttle program led to the first selection of six Canadian astronauts in 1983, with the prospect of a series of three flights for Canadian scientist astronauts referred to by NASA as payload specialists. Twenty-five years ago, Mark Garneau became the first Canadian to fly in space aboard the Space Shuttle Challenger. A number of dedicated Canadian experiments were selected for the STS-41G mission, creating an opportunity for Canadian scientists to obtain first-hand experience with microgravity research. These experiments were referred to with the acronym CANEX, a descriptor which was used for the remaining two flights of Canadian payload specialists that took place in 1992.

By this time, the concept of a partnership of the major space faring nations working together to create a world-class orbiting research platform had become a reality, and the newly emerging space station program led to the need for, and selection of a second group of Canadian astronauts. During a six-month selection process, the Canadian Space Agency used a complex set of selection criteria to hire four new astronauts that would train as mission specialists for long duration missions on board the space station. Roberta Bondar and her back-up Ken Money retired after participating in the International Microgravity Laboratory (IML-2) mission in January 1992, leaving Marc Garneau, Bob Thirsk, Bjarni Tryggvason and Steve Maclean to be joined by Chris Hadfield, Julie Payette, Mike McKay and Dave Williams for mission specialist training and potential assignment to shuttle flights or space station construction missions. This was a pivotal time for the Canadian Space Agency that had raised the Canadian profile as a major space faring nation, now with an expanded team of 8 astronauts, two with mission experience, capable of leveraging the Canadian robotic and scientific expertise.

The initial design requirements for the proposed space station included a health maintenance facility (HMF) (8) in recognition of the potential medical issues that could arise during long duration missions in low earth orbit. In addition to the HMF, the proposed airlock design provided both a hypobaric capability necessary for suited astronauts to egress the station for spacewalks as well as a hyperbaric capability to treat potential episodes of decompression sickness (DCS) that could arise during a space walk. The designated operating pressure of the space station was 1 atmosphere (14.7 p.s.i.), similar to that of the Space Shuttle, while the suit pressure of the extravehicular mobility unit (EMU) was 4.3 p.s.i. thereby introducing the risk of DCS while transitioning to the lower suit pressure. Despite the rigorous design requirements for on board healthcare, these facilities were not implemented in the construction of the International Space Station primarily due to cost constraints.

Historically, during the Shuttle era, the clinical approach to prevention, diagnosis and treatment of illness and injury in space had a strong emphasis on prevention. This was accomplished through medical selection criteria, regular medical screening, and the development of countermeasures to mitigate the many physiologic changes associated with exposure to microgravity. This approach evolved from the early work in the Mercury, Gemini and Apollo programs that was based primarily on a preventive strategy with rudimentary on orbit diagnostic and treatment capabilities based on the use of small medical kits with support from flight surgeons in mission control. The Skylab program provided an excellent opportunity for biomedical research during long duration missions that helped further delineate the physiologic changes associated with exposure to microgravity. These results were used to develop the exercise, cardiovascular and neurovestibular countermeasures implemented in the early Shuttle program and led to a further series of life science experiments conducted on dedicated Shuttle research missions. These studies were concluded by the launch of the first element of the International Space Station (ISS) in the fall of 1998 and were published a year later as a comprehensive extended duration orbiter medical project (EDOMP) (9) (10).

Canadian researchers participated in a number of collaborative Shuttle experiments throughout this time to help understand the many physiologic changes associated with acclimation to microgravity and to evaluate potential preventive countermeasures. In addition, researchers at the Canadian Space Agency (CSA) worked in collaboration with experts in DCS at the Defence Research and Development Canada Centre in Toronto to participate as one of three NASA supported research sites to develop the new pre-breathe protocols for use in preparation for spacewalks from the Interna-

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tional Space Station. This led to widespread recognition among the international partners of Canadian expertise in life science and space medicine research, which has continued into the current phase of ISS utilization.

The first twenty missions to the ISS were made up of three international crew members living aboard for approximately six months. Last year the crew configuration was extended to the original design requirement to accommodate six crew members for long duration missions thereby extending the capability to utilize the station as a research platform. During crew rotation Shuttle missions the number of crew increases to up to 13 during docked operations. With increased utilization, the probability of an on board medical event increases. While the preventive approach to reducing the risk of significant illness and injury has been effective, some believe it is a matter of time before there is a medical emergency in space. In addition to the career astronauts and cosmonauts living and working in space, a new generation of space flight participants (SFPs), or space tourists, have been visiting the space station since 2001.

Extending the opportunity to visit the ISS to space tourists challenged the space medicine community to decide whether or not a similar approach to pre-flight medical screening would be used for the SFPs. While these individuals were paying millions of dollars for the privilege of visiting the ISS, a significant on board medical event could have a profound mission impact and it was decided that a pre-flight medical assessment was needed as a risk mitigation strategy. Seven SFPs have visited the ISS the most recent being Guy Laliberte from Canada, and to date no significant medical events have been reported.

Space medicine can be defined as the area of medical practice that deals with the provision of healthcare in partial and microgravitational environments. The scope of care not only deals with the prevention, diagnosis and treatment of illness and injury in space, it involves pre-flight medical selection and conditioning as well as post-flight rehabilitation. The expansion of commercial space operations to include SFPs and potentially career astronauts flying on commercial spacecraft in suborbital and orbital flights presents a number of potential issues to the space medicine community. The FAA has released a series of requirements for crew and SFPs on commercial spacecraft in support of the Commercial Space Launch Amendments Act of 2004. These requirements are similar in nature to those used in commercial aviation with the additional stipulation that prospective SFPs sign an informed consent prior to flight (CFR 14 Part 460) ([NO STYLE for: ]). The FAA does not have a mandate to regulate passenger health or preflight medical screening on the proposed commercial spaceflights. Guidelines for screening SFPs have been published by the international space medicine community (12), yet it is uncertain whether or not commercial operators will implement them. Career astronauts utilizing commercial spacecraft to access low earth orbit will likely be governed by preflight screening and a quarantine process similar to currently used protocols, yet this also remains to be determined.

Despite rigorous screening programs, the increased size of the ISS crew coupled with the long duration missions and the increasing frequency of flights by SFPs suggests that the frequency of on-orbit medical events may increase. While the majority of these events include space adaptation syndrome, motion sickness, back pain, musculoskeletal problems and disrupted sleep, the potential for a more significant medical event exists. For this reason, there has been considerable interest and research in developing and testing innovative diagnostic and therapeutic modalities over the past decade that will continue throughout ISS utilization.

The current paradigm for provision of healthcare on the ISS is based on dedicated crew medical officers (CMOs) utilizing the resources of the Crew Health Care System (CHeCS) to prevent, diagnose and treat on orbit medical events. A number of integrated medical kits are available on the ISS to treat the common medical problems that arise in space as outlined in the Integrated Medical Group medical operations checklist for expedition flights. In some cases the CMO is a physician, but for the most part, they are crew members that have received additional medical training in preparation for the mission. CMOs provide care under the direction of Flight Surgeons in mission control based on voice/video private medical conferences. This approach has been extremely effective in managing the medical events that have taken place in space.

Additional equipment exists on the ISS to augment the CHeCS capability. The Human Research Facility - 1 (HRF-1) is equipped with a space-adapted, rack-mounted version of the HDI-5000 Ultrasound System (ATL/Philips, Bothwell, WA). This unit has been used for a number of research studies (13) (14) evaluating various diagnostic ultrasound protocols but is also available for clinical diagnostic use as needed. The portability and ease of use of diagnostic ultrasound have led to its adoption as the diagnostic imaging modality of choice in space. With current technology, other diagnostic imaging (DI) technologies are not practical for use in space. Further research on the role of diagnostic ultrasound and the development of alternative DI technologies is as important as an exploration enabling capability for future missions beyond low earth orbit.



Current on-board laboratory investigations are limited compared to terrestrial medicine. A number of research projects focus on developing portable blood analyzers (http://www.nsbri.org/NewsPublicOut/Release.epl?r=89) that will be a valuable adjunct to both researchers and clinicians in the future. In the interim, flight surgeons rely heavily upon a clinical history and physical examination to formulate a differential and primary diagnosis.

Past research efforts have focused on understanding the physiologic acclimation to microgravity with the development of a series of preventive countermeasures leading to further work that will continue to improve this preventive strategy. However, there is a tremendous amount of clinical research that is needed. The pharmacokinetics of drug use in microgravity and partial gravitational environments is an important area of further research (15) (16) while the effects of spaceflight on the pathophysiology of disease are either the subject of speculation or largely unknown. Building on the known physiologic acclimation to space, the pathophysiology of different diseases in space may be predictable, but some illnesses such as DCS may be fundamentally different in microgravity (17).

For the most part, therapeutic interventions in space involve the administration of medications orally, intramuscularly or intravenously. Foley catheters have been inserted for isolated cases of urinary retention (18) and intravenous access has been used for research studies and for some clinical interventions. There are no reported cases of wound repair using sutures or wound cement in humans, but anecdotal reports following animal surgery suggest that successful wound healing takes place with the use of wound cement. While a number of studies of more advanced medical and surgical interventions have been evaluated in parabolic flight, further research and documentation of microgravity techniques for common interventions is warranted.

The future of human spaceflight will likely include increased accessibility and utilization of low earth orbit for commercial ventures and continued use of the ISS, ultimately leading to a transition back to exploration missions potentially involving lunar return or missions to Mars. The need to further develop mission-specific medical capability involves discussions of the balance between the need for a “stand-and-fight” capability and the utilization of a “load-and-go” approach to returning to Earth for definitive medical care. Currently approaches to on orbit health care use both approaches with the combination of immediate clinical care combined with the potential for an urgent or emergent deorbit and landing for definitive medical care. As humans travel farther into space, a medical abort to Earth scenario becomes less practical and at some point transitions to continued flight to the destination. This raises a number of questions about defining the appropriate level of care, the effect of longer signal transmission to Earth on crew autonomy and the role that new technologies will play in the delivery of healthcare during the different phases of the mission.

On the ISS, as the complexity of medical interventions increases, there is greater reliance on ground expertise through the use of telemedicine, a fundamental component of linking the flight surgeon in mission control to the CMO for health care delivery in space (19). Telemedicine is the use of information and communication technology in near real-time to support medical providers at a distance. Many attempts have been made to evaluate and validate various protocols in extreme and remote environments that replicate the resource deficient and psychologically demanding conditions of human spaceflight (20). This has included a range of procedures from telementor-guided ultrasound to remotely operated surgical robotics (21) (22). As human space exploration extends further out into the solar system, the latency of communication will pose significant challenges to the remote medical support of health care delivery in space.

Planning for future exploration class missions should include characterizing the impact of communication delay with existing telemedicine technology on real-time flight surgeon CMO coordination, defining the future skill sets and training requirements for CMOs, as well as expanding the current capabilities to meet the future needs for space medical systems. For this reason, a comprehensive assessment of the likelihood and impact of potential medical conditions should be conducted based on a combination of historical data, expert opinion, analogue studies and epidemiological studies from other related high-risk occupations (23) to facilitate development of future medical protocols.

Unfortunately, the rarity and complexity of medical illness during spaceflight makes it difficult to evaluate the effectiveness of these protocols and new medical technologies. High-fidelity medical simulation has been suggested as an effective tool to assess the performance of high-level medical systems and interdependent medical teams (24). Electromechanical robotic mannequins can be used to simulate a wide variety of physiologic parameters, medical emergencies and illnesses in a controlled, reproducible, and risk-free environment to evaluate clinical protocols. Beyond research and testing, medical simulation is also an ideal platform for providing medical education and training opportunities for CMOs who may not be exposed to the required breadth of clinical experience necessary for supporting a space mission. In addition, it provides a context-specific opportunity for CMOs skill retention during a mission, or to provide just-in-time medical training to deal with an in-flight medical emergency.

The next decade provides an opportunity for further ISS research to develop new diagnostic and treatment capabilities, assess new technologies and evaluate strategies for CMO skill retention and just-in-time training. This research will be important to prepare for exploration class missions beyond low earth orbit in addition to developing on board clinical care for commercial space complexes. Based on the terrestrial approach of providing on-board healthcare for commercial ocean cruises, it is likely that commercial space complexes will have an on-board clinic with a physician or other health care professional providing clinical care. The evolution of commercial space travel in the decades to come will extend the scope of space medicine beyond the realm of the government supported human spaceflight into the realm of civilian spaceflight. While the objectives of human space travel will differ between the government and commercial groups, there will be a shared interest amongst practitioners of space medicine in developing the best approaches to prevent and treat illnesses and injuries during a mission. Clearly, the future opportunities for those interested in space medicine are very exciting.

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CROSSROADS

# Exploring the Possibility for a Common System for Joint Aeromedical Standards

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**ABSTRACT: The Physical qualification standards for aviation service used by the United States Army, Navy/Marine Corps, Air Force, and Coast Guard developed in parallel, diverging in many instances due to differences ranging from terminology to mission. Presently, standards and requirements for waiver vary widely between the services, in spite of minimal differences in aeromedical concerns for any given medical condition. Standardization or increased concordance between the services would have several advantages leading to more efficient and effective delivery of aviation medical support to the operational forces. This is particularly true in an increasingly joint operational environment. The authors have identified four major hurdles that must be overcome before the concept of joint aviation physical standards can be explored. These include: a difference in terminology including aviator classification, a difference in mission definitions and requirements, a difference in the processes of policy development, and a difference in the review and application of those policies. These hurdles are explored, and suggestions for their mitigation are presented with open discussion following.**

*Keywords*: Aerospace Medicine, Aviation Medicine, Physical Standards, Military Medicine

## INTRODUCTION

The clinical practice of Aviation Medicine in the U.S. Military revolves around an administrative landscape of aeromedical policy and physical standards which are specific to the four main branches of the U.S. Armed Forces including the U.S. Air Force, U.S. Army, U.S. Navy/Marine Corps, and the U.S. Coast Guard. In today's operational environment, military Flight Surgeons are increasingly practicing in a joint military environment in which service members from different services must collaborate in order to accomplish the mission. In this joint military environment, Flight Surgeons are expected to be equally well versed in the policies and procedures of their sister services, as they provide aeromedical care for aviators and aircrew members from all services. Despite commonalities in aeromedical concerns, each service's aeromedical policies have diverged over time, resulting in an often confusing and unnecessarily complicated joint framework for aviation physical standards. There is increasing pressure from high levels of U.S. Department of Defense administration to consolidate practices across services in many areas of support including but not limited to aviation medicine. This paper explores the hurdles encountered in developing a set of joint Aeromedical physical standards and administrative procedures and proposes potential solutions to some of these problems. While these proposals are not intended to be comprehensive in nature, they are presented to raise awareness and initiate dialog between administrators throughout the aeromedical communities, with the goal of moving toward the authors' vision of a single common system of aeromedical administration for the U.S. Military. The scope of this article is limited to the U.S. Military for the sake of brevity, but parallel analysis with our international brethren is invited, as many of the same lessons clearly apply in the international military aviation medicine community.

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## BACKGROUND

The idea of a unified approach to medical service for all branches of the U.S. Armed Forces is not new. With four separate medical departments in the U.S. Navy/Marine Corps, U.S. Army, U.S. Air Force, and U.S. Coast Guard, the efficient delivery of health care to armed service members and their dependents has long been complicated by stovepiping of resources and programs. One of the most energetic attempts to consolidate US Department of Defense medical services was put forth by Major General Norman Kirk in 1947. While Kirk did not originate this idea, he materialized the concept in a detailed plan that he presented to the Senate Armed Forces Committee (13). Since that time, several more attempts have been made to propose a sweeping unification of all the armed forces medical services into one integrated service. In fact, the Civilian Health and Medical Program for the Uniformed Services (CHAMPUS) was a direct spin-off of these attempts.

Efforts to establish physical standards for selection and retention in aviation date back to World War One when Allied Forces were wrestling with integration of the airplane into normal operations. Recognizing the need for standardization in aviation medicine, Drs. Theodore Lyster and Isaac Jones developed a system of physical standards and education throughout the U.S. Army, which laid the foundation for the standardized approach to physical qualification for aviation service which we utilize today in all branches of the U.S. Armed Forces (6). Those early efforts of Doctors Lyster and Jones evolved into the modern practice of aviation medicine in the military, and as the Air Force broke off from the Army Air Corps in 1948, this framework for aviation medicine carried forward. But with five United States armed forces entering the modern era of aviation, Aeromedical policies and physical standards have necessarily diverged to meet operational demands of the specific service.

Advances in technology drive the evolution of military tactics, which in turn results in changes to organizational structures, changes in Techniques, Tactics, and Procedures (TTPs) and the application of Combat Services Support on the battlefield. Changes in our current operational climate dictate the need to reconsider the practice of aviation medicine in the military. Increasingly, Flight Surgeons and aircrew are deployed in settings where crewmembers must rely on Aeromedical support from sister service Flight Surgeons. Under current practices, Flight Surgeons are rarely trained and are even less frequently familiar with the aeromedical standards of their sister services. As a result, they will do their best to wade through the necessary bureaucracy in order to meet the mission, frequently without achieving success and often failing to meet requirements. Differences in administrative frameworks between military aviation medicine programs unnecessarily inhibit the Flight Surgeon's ability to provide needed services.

Proponents of unification of aeromedical systems across service boundaries tout an increased efficiency of care and decreased costs of administration. These advantages may be particularly true during peacetime, and in stationary military medical facilities. Opponents to unification rightly point out the differences in mission and operational environment between the services, and the requirement for medical assets organic to individual units that are able to provide optimal and timely care in these unique settings. Frequently, this requires divergence in training in order to provide an operationally relevant product.

While the authors do not necessarily advocate the unification of the medical services as a whole, the adoption of a common language and a set of common tools within the aeromedical communities of the individual services has several advantages. Issues as simple as which form to use for a flight physical, or which labs to order, or as complex as how to classify an aeromedical disposition or how to process a waiver evaluation frustrate the Flight Surgeon and often lead to duplication of work, or worse. Standardization or increased concordance between the services would lead to more efficient and effective delivery of aviation medical support to the operational forces both at the individual Flight Surgeon level as well as at the program administration level.

Clearly, each service has both shared (e.g. rotary wing) and unique (e.g. carrier landings) aviation functions, and each operational environment places unique physiological and psychological stresses on the aviator. However, equally clear should be the reality that the vast majority of medical conditions (e.g. cardiovascular disease) will have the same implications in an aviator who straps into any aircraft, regardless of type or paint color. Evidence-based practice mandates that Flight Surgeons separate their aeromedical analysis from political service-based policy boundaries, and continue to delineate with the highest degree of fidelity which conditions, and to what degree these conditions will have a different impact on aviators operating from different platforms based on valid medical evidence. By and large, this work has lacked the broader perspective of military aviation medicine as a whole. Increasing collaboration and improved distribution of labor will lead to improved policies and improved Risk Management for the entire military aviation community.

Our vision is very simple. We are advocating and have been working in what has proven to be a very political realm towards the simple goal of having one system in which flight surgeons can experience true interoperability, providing aeromedical services across service boundaries—an operational reality and necessity which we believe can no longer be ignored.

To this end, in 2002, the authors began a series of posters, panel discussions and working groups presented at international conferences including the Aerospace Medical Association Scientific Meeting and Medicine in Challenging Environments which brought together aviation medicine representatives from all of the U.S. Armed Services in order to discuss and further delineate the possibilities for improved collaboration in the development of Aeromedical policy and practices. As a result of these and many other sidebar discussions, we are happy to report several significant movements in the direction of Aeromedical jointness. In 2009, the U.S. Navy, U.S. Army, and U.S. Coast Guard have adopted a common administrative framework


**Figure 1:** The Aeromedical Decision Making Process

in the Aeromedical Epidemiological Research Office (AERO) for the workflow of flight physicals, and the U.S. Coast Guard and U.S. Army have agreed to share a common system of physical standards for aviation. Other special duty communities within the Army are also evaluating these systems as a viable solution to parallel processes within those communities. While there is still significant work to do in the areas which will be explored in this article, these landmark decisions mark a significant and growing support for the vision of one common system of Aeromedical administration.

## AEROMEDICAL DECISION MAKING PROCESS

Critical to the process of joint aeromedical administration, must be a common system of evidence based decision making and analysis. Doctors Sauer and Woodson described the Aeromedical Decision Making Process (1) as an analog of Operational Risk Management applied to aviation medicine clinical and policy decisions.

The goal of the Aeromedical Decision Making Process is to "prevent aviation mishaps due to physical or medical deficiencies…without unnecessarily restricting [military] aviation." It is the method that Flight Surgeons employ in order to evaluate specific conditions and crewmembers for entering or remaining on aviation service.

Within this framework, aeromedical policy and physical standards for aviation service are viewed as risk management controls to increase aviation safety. The effects of a given medical condition must be evaluated on an individual and population basis in order to assess the impact upon severity and probability of contributing to a mishap or mission failure.

When applied to policy development, this process provides an objective means by which to evaluate the common Aeromedical concerns for a given medical condition which all sister services share, while attending to the specific differences in mission requirements free from the individual bias which has long skewed aeromedical policy. It should be noted that mission differences, rather than service differences, drive this aeromedical risk assessment process based on the real and observed aviation operating environment. The commonalities between service-specific considerations for a specific mission or platform type far outweigh the differences.

The first hurdle to overcoming service boundaries in aviation medicine may very well be to adopt a common framework for the discussion and evaluation of aeromedical concerns. This model provides such a framework and may supply



an efficient means for converting available medical evidence into better risk controls and aeromedical policies which serve all aircrew and flight surgeons regardless of nationality or service membership.

## HURDLES TO JOINT AEROMEDICAL STANDARDS

Each of the U.S. armed services enjoys its own unique culture and challenges. These may range from simple differences in language to more complex significant mission requirements such as accounting for the additional challenge of performing an aircraft carrier landing. An effective joint system for aeromedical administration must account for these differences. Before moving forward with any type of program implementation, we must first reach consensus on what hurdles these differences present. As this question has been analyzed, the authors have identified four primary hurdles: 1) a difference in terminology including aviator classification, 2) a difference in mission definitions and requirements, 3) a difference in the processes of policy development, and 4) a difference in the review and application of those policies.

## DIFFERENCES IN TERMINOLOGY

Individual service cultures and administrative landscapes have contributed to the development of non-standard terminology in aviation medicine. While the meaning in most cases translates in the same manner, it is difficult for members of one service to understand a sister service's policy stance for no other reason than differences in language. Before moving forward with common policy or programs, we must begin to adopt standard terminology or "common language."

The wide variation in terminology used illustrates our incongruities. Even simple concepts such as the retention of a service member on active duty, the status of an individual's physical and mental condition for flight, or identification of the service member's work code specialty each have different nomenclature between the services. For example, the Army and Navy may refer to "Retention" while the Air Force may refer to "continued military service." The Air Force may refer to an aviator who does not meet designated physical standards for aviation as "Not Qualified" while the Army refers to the same aviator as "Disqualified" and the Navy as "Not Physically Qualified (NPQ)." The Army and Air Force will describe physical limitations as "profiles" (based on a system of physical profiling as outlined in the regulations) while the Navy will describe "Limited Duty." Similar terminology differences abound in the regulations across service boundaries.

Most of these language differences are not critical in nature. Certainly, a common meaning is normally inferred. The important thing to recognize is that they can be misleading and cumulatively, they do create confusion when working in a cross-cultural aviation medicine environment. More importantly, such language will have to migrate towards commonality as joint policies, procedures, and systems are developed.

More troubling than differences in language is the variance in aeromedical classification systems of the different services. Looking at the differences between the Army/Coast Guard, Navy, and Air Force aeromedical classification systems, different approaches are immediately evident (Table 1).

Aeromedical policies are designated for specific classes of aviators as outlined in Table 1.

| Air Force | Navy | Army/Coast Guard |
|---|---|---|
| Flying Class I: Selection for Pilot Training<br>Flying Class IA: Selection for **Navigator** Training<br>Flying Class III: non-rated duties<br>Categorical Flying Class II<br>• FC IIA: Low-G aircraft (tanker, transport, bomber)<br>• FCIIB: Non-ejection Seat<br>• FCIIC: Specified restrictions | Class 1: Pilots (Naval Aviators)<br>• Service Group I: unrestricted (including night carrier operations)<br>• Service Group II: no shipboard operations (except helicopter)<br>• Service Group III: dual-control only; with SG I/II copilot<br>Class 2: All other aircrew (Naval Flight Officer, Flight Surgeon, etc.)<br>Class 3: Air Traffic Controllers, UAV operators, etc. | Class 1A: Initial pilot applicant (Commissioned)<br>Class 1W: Initial pilot applicant (Warrant)<br>Class 2: Rated aviator<br>Class 2F: Flight Surgeon, Aeromedical Physician Assistant<br>Class 3: All other aircrew (crew chiefs, gunners, flight medics, aerial observers, maintenance aircrew, altitude chamber technicians, UAV operators)<br>Class 4: Air Traffic Controllers |

**Table 1:** Aeromedical Classification Systems

Aeromedical disposition in each service is grounded in its own aeromedical classification system, each of which have developed through an amalgam of service culture and regulatory framework entirely outside the realm of aviation medicine. It is fairly easy to recognize that these classes are defined in each service based on fundamentally different frameworks. In many cases, the difficulty in interpreting aeromedical physical standards is rooted in the differences in these classification systems.

It is difficult to see a truly joint aeromedical system that uses the current service-specific aircrew classification structure. Standardization of this system into a common inter-service aircrew classification would seem the only plausible solution to this problem and a vital step towards unification of aeromedical systems in the U.S. Military.

Several solutions may present themselves, but one potential solution could be based upon crewmember type and basic aeromedical distinction. There are only four essential types of individuals who require aeromedical clearance, each of which represents unique job-related physical requirements: 1) flight crew who control aircraft , 2) flight crew who do not control aircraft 3) crewmembers who perform ancillary duties in flight (aerial observers, weapons system operators, equipment operators, etc) unrelated to the control of the aircraft 4) individuals who perform flight-related duties, but not involving actual flight duties (ground crew, ATC, UAS operators etc). Accordingly, one potential interservice classification system might look like that seen in table 2a, which separates mission specific considerations and initial vs. retention considerations from the basic element of disposition classification. A second option could link aeromedical risk to aeromedical threat (Table 2b).

| Aircrew Class | Description |
|---|---|
| Class A | Non-flight crew performing aerial duties |
| Class B | Non-flying, flight related personnel |
| Class C | Flight Crew, Pilot in Control, single-control aircraft |
| Class D | Flight Crew, Pilot in Control, dual-control aircraft |
| Class E | Flight Crew, Non-pilot |

**Table 2a:** Proposed Interservice Aircrew Classification System, version 1

| | In-Flight Crew | Ground-based |
|---|---|---|
| **Flight Critical** | Class A | Class C |
| **Flight Important** | Class B | Class D |

**Table 2b:** Proposed Interservice Aircrew Classification System, version 2version 1

Any classification system will require the Flight Surgeon to make decisions based on individual crewmembers and their specific job requirements, but an effective classification system must account for differences in physiological requirements. The key point is that adoption of a common inter-service classification structure such as that presented in tables 2a or 2b would facilitate cross-service communication and allow for a common framework of aeromedical regulations, moving us much further down the road towards a unified joint aeromedical system.

## FRAMEWORK FOR STANDARDS DEVELOPMENT (MISSION VS. PHYSIOLOGY)

The major services of the U.S. Armed Forces frequently distinguish themselves based upon their stated mission. On the most basic level, these missions may be categorized based upon service distinct missions (e.g. land-based vs. carrier-based in the Navy), the platform flown (e.g. fixed vs. rotary wing) or the complement of crew (e.g. single pilot vs. multi-crew aircraft). However, each type of aviation platform places its own unique set of physical demands on the aviator, while many demands are common to all aviation platforms.

Aeromedical concerns are more appropriately described in reference to the mission the aircrew member is serving than to the branch of service of which he or she is a member. There is no doubt that due diligence must be paid to the physiological demands of specific missions and equipment on the crewmember. It must be noted, however, that these demands are grouped into categories that transcend service boundaries. The present system effectively prevents aeromedical categorization of missions across the services. More importantly, it frequently does not even account for actual physical stresses on different categories of crew members within a given service. An effective framework for aeromedical standards would appropriately account for differences in physiological demands based on mission, equipment, environment and other job requirements.

One example of the failure to consider mission specific physical demands is illustrated by looking at the standards for stereopsis in Army aircrew. Current policy allows deficiencies in stereopsis for crewmembers (non-pilots) but not for pilots (9,11). This may represent a leftover policy from the primarily fixed wing days of Army aviation medicine and is probably based on reasonable rationale: pilots need advanced stereopsis on final approach and landing phases of flight which are within the



stereoptic range, and back-end helicopter crewmembers' duties would not routinely call on their stereoptic capability as they manage payload. Yet evidence supports the idea that monocular pilots (without stereopsis) do just as well as binocular pilots in landing aircraft (15,16) and mission analysis readily demonstrates that the army crewmember may require greater degrees of stereopsis than the front end crew as he controls aircraft position in fine detail during air assault, fast-rope, sling-load, and routine hot-loading operations. The basic (reasonable) premise for this inversion of standards is most likely based on a general impression that pilots require higher standards than non-pilots.

This is a seemingly simple oversight, but it highlights the difficulties encountered when we fail to consider the actual physical demands of mission and equipment on crewmembers. Compound this phenomenon by comparing the differences between high-Gz platforms, carrier-based landings, rotary wing platforms, and Unmanned Aerial Systems (UAS). Other critical differences in demands exist based on differences in operating altitude and G-Forces.

One approach to developing a functional joint system would be to examine the unique physiological aspects of broad categories of aircraft (Table 3).

When examining physical standards from this perspective, a more suitable framework for physical standards emerges; one which would serve the needs of all services, and would be based on physiological demands rather than political boundaries. A very important consideration is that each service does not necessarily operate within its own traditional boundaries; missions traditionally reserved for one service may be conducted by aircrew from another service. One commonly cited difference is the Navy requirement for carrier-based operations, an obviously demanding aviation task. Yet Army, Coast Guard, and Air Force rotary wing aviators are often called on to land on ship-based platforms. Current aeromedical administrative structure would not account for these challenges and their associated physical demands. If modified to address platform and mission based differences, a new joint aeromedical structure would allow us to speak the same aeromedical language across service boundaries and would better reflect an evidence based approach to aviation medicine.

An aeromedical evaluation of an aviator could be made in the context of platform/mission-based parameters. A pilot, flight officer or aircrew member can be effectively authorized or restricted to fly on different types of missions, based on the

| Rotary Wing | Fixed Wing – Low Gz (tanker, transport, bomber) | Tactical Jet – Hi Gz | Unmanned Aerial Systems (UAS) |
|---|---|---|---|
| • Lower Gz<br>• Vibration (2-35 Hz)<br>  • Intervertebral disc dz 4-5 Hz)<br>  • Pregnancy<br>• ↓ Hypoxia Concern<br>• Visual Acuity<br>  • Contrast sensitivity<br>  • Close proximity to the ground<br>  • Constantly clearing for obstacles, wires<br>  • Ground Target acquisition<br>• Monocular displays/NVG<br>  • Binocular rivalry<br>  • Stereopsis eliminated (Terrain within limit)<br>  • Neck pain<br>  • ↓ Acuity (20/40)<br>  • ↓ Fields of view (40 deg)<br>  • Color vision eliminated<br>  • ↑ Ocular Motility demand<br>• Depth perception<br>  • NVGs<br>  • NOE flying<br>• MOPP<br>• Living conditions/Heat stress | • Lower Gz<br>• Long Duration Missions<br>• Large Crews, often dual piloted<br>• ↑ Hypoxia Concern<br>• Stereopsis less critical<br>• Decompression (also pressure suits)<br>• Radiation (high altitude recon)<br>• ↑ Circadian rhythm shifting | • High, rapid-onset Gz<br>• ↑↑ Hypoxia Concern<br>• Long Duration Missions<br>• Decompression<br>• Visual Acuity<br>  • Increased visual demand for tactical mission<br>  • Close proximity to the ground<br>• Air Target acquisition<br>• Ejection Seats | • Ground Based<br>  • No Hypoxia Concern<br>  • No pressure differentials<br>• Color Vision critical<br>• Stereopsis not required<br>• Dual Pilot<br>• Potential for in-flight crew changes<br>• Increased demands on decision making and situational awareness challenge traditional views of UAS requirements<br>  • Flying in Class A Airspace<br>  • Weapons and targeting systems |

**Table 3:** Aeromedical Aspects of Broad Categories of Aircraft

| |
|---|
| ***Aircraft***<br>☐ Rotary ☐ Fixed-wing prop ☑ Fixed-wing jet |
| ***Environment***<br>☑ High G (>3G) ☐ Low-G (<3G) |
| ***Base of Operations***<br>☐ Land-based Flight Ops ☑ Sea-based Flight Ops ☑ Ground-Based Ops |
| ***Crew Complement (pilots only)***<br>☐ Single pilot ☐ Dual pilot |
| ***Further Limitations:***<br>***none*** |

**Figure 2:** Example of Proposed Up Chit (Recommendation for Flying Duty)

corresponding aeromedical stressors and that person's physical and mental capabilities. More appropriately, the categories may be organized so that the service member is fully qualified for all categories except for those indicated. One example of this classification, as it might appear on a joint aeromedical clearance chit (up slip) is seen in Figure 2.

Such a system would allow classification of pilots, flight officers and enlisted crewmembers, regardless of service, based upon physical and mental capabilities from an aeromedical perspective. With the increasing incidence of exchange tours, particularly among pilots between the services, this system would allow a common basis of categorization, further helping to eliminate the "language barriers" that exist between the aeromedical branches of the Army, Navy and Air Force.

## DIFFERENCES IN THE PROCESSES OF POLICY DEVELOPMENT

Currently, each service maintains parallel analogous organizations which develop and implement aeromedical policy (Code 42, Army Aeromedical Activity (AAMA, Aeromedical Corporate Board, Aeromedical Consult Service, Aeromedical Advisory Council, etc). Each service also maintains its respective process for submission, review, and disposition of aeromedical standards as well as policy development. These organizations and processes serve a vital role in maintaining safety and quality in aviation medicine.

As we consider the convergence of aeromedical systems, each service must ensure that its administrative aeromedical system continues to serve its own interests. Migration towards a common process and waiver guide is a step-wise approach and must ensure that these interests and representation are maintained. The authors do not advocate for or suggest a radical course change, but rather a common effort towards commonality. We have already begun to work toward this end and are sharing information better than ever before. In today's aeromedical environment, waiver policies are usually modified with at least some modicum of collaboration between the services. Joint policies are in some cases being adopted, and convergence into common electronic systems is evolving. (Some of these will be discussed later in this article.)

Ideally, however, services could eventually move (when collectively ready) towards some system of formal "joint aeromedical council" or board which could manage a truly joint aeromedical waiver guide and/or disposition system. This idea may seem alarming to some, but the important thing to recognize is that there is an entire spectrum of possibilities to consider, including formal and informal processes and systems. In order to sustain a joint process we will need to establish some kind of mechanism by which Aeromedical policies are developed, considered, implemented, and modified while protecting the interests and concerns of all the services. While clearly not comprehensive, Table 4 illustrates a stepwise approach which could move us carefully in the joint direction.

## DIFFERENCES IN REVIEW AND APPLICATION PROCESS

While medical conditions may be interpreted differently by each service, or in aircrew members flying different mission platforms, most Aeromedical Physical Exam requirements are (and should be) based on sound medical/public health screening principles, and should not vary by service or mission.

One of the easiest and highest yield obstacles we can overcome is that of unifying the actual requirements for initial and periodic aeromedical



evaluations across services and mission platforms. Wading through the service-specific regulations and instructions, we identify a grossly incongruent set of physical exam requirements. Differences exist in issues as simple as who is required to undergo ECG testing, or who must have a G6PD, urinalysis, or lipid panel. Chest X-rays do not share common mandates and each service has its own variation of anthropometric testing and cardiac risk profiling. Yet, we all seek the same outcome. Most of these differences probably reside not in the medical merit of the tests themselves, but in the differences in policy development as outlined previously. Yet these differences are extensive; they are the culprit in wasting numerous man-hours when an aviator from one service is forced to complete a flight physical with a sister-service flight surgeon which does not meet his service standards.

Adoption of a single, unified set of diagnostic testing requirements for initial applicants and established aircrew members should be fairly simple to achieve and would represent tremendous progress toward commonality. The net effect of this one change would be a dramatic improvement in interoperability of the flight surgeon in the joint environment.

Another hurdle which presents a fairly simple opportunity for convergence is found in the paperwork drill. In spite of Department of Defense level efforts to standardize the physical exam forms in the DD2807 and DD2808, we have not seen universal adoption of these forms in aviation medicine. Additionally, our abbreviated physical exam forms for interim flight physicals remain distinct. Forms represent a standardized method of collecting and presenting basic clinical data and are critical "glue" for the aviation medicine program. In addition to the joint up chit described previously, adoption of a common "short form" and agreement to utilize the DD2807/8 for comprehensive physicals in all services would appear an easy fix and should not encounter significant resistance within individual service cultures.

Another opportunity for convergence exists in our method of submission, review and disposition of aeromedical evaluations. Each service retains (and should retain) its own authoritative body on disposition. Traditionally, physical exams were submitted on paper to the corresponding administrative body (AAMA, Code 42, ACS, etc) for review. Modern world-wide-web technology has presented the possibility for a new model for review and disposition which may potentially bring us closer together. A common internet application shared by the service authorities would better facilitate cross-communications between aeromedical specialists and provide for a common process which would better facilitate joint aeromedical communications and research.

| |
|---|
| **Initial Steps** |
| • Individual services move toward common "best-practices" as aeromedical policies (waiver guides) come up for review; informal collaboration across services (information sharing) with goal as unified approach to a given aeromedical condition.<br>• Basic physical exam requirements (exam, labs, forms, etc) are unified (see above).<br>• Aviator Classification system is unified (see above).<br>• Cross-pollination in training (joint residencies) and joint assignments at aeromedical centers, leading to better information sharing and opportunities for collaboration. |
| **Periodic "Aeromedical Council" (e.g. quarterly, semi-annual)** |
| • Joint forum in which representatives from all the services and aviation communities are able to share ideas and information in a unified effort to develop congruent "best practices" in waiver policies across service boundaries.<br>• Strategic long-term plan to review all aeromedical waiver policies in systematic manner over time.<br>• Barriers to commonality in waiver policy, administrative requirements, etc are explored and ultimately problems are solved. |
| **Consolidated Joint Waiver Guide** |
| • Policies are unified through an evidence-based risk management model, which accounts for all mission/service needs under a unified classification model.<br>• Resources are pooled, yielding an improved product without unnecessary duplication of effort.<br>• All Flight Surgeons have a single tool that allows for improved management of aviators in an increasingly joint environment. |

**Table 4:** Policy Development and Implementation of Process

**THE AEROMEDICAL ELECTRONIC RESOURCE OFFICE (AERO) AND CURRENT JOINT INITIATIVES AS AN EXAMPLE OF CONVERGENCE**

Opportunities to converge towards common systems, policies, and practices abound and do not necessarily require a monumental overhaul of what is currently in place. While compromise is important, the service-specific aeromedical authorities do not need compromise on their standards or requirements in order to find common ground. One example of such endeavors can be found in recent developments in the integration of the Aeromedical Electronic Resource Office (AERO) at Fort Rucker, Alabama.

In 2002, the U.S. Army Aeromedical Activity (USAAMA) adopted AERO as an internet-based solution to aeromedical review and disposition, replacing a cumbersome paper-based submission process in the Army. This government owned and developed system was fielded, and over a short period of time, resulted in significant improvements in the disposition of Army flight physicals. In addition to improving the submission process, internal processing times at USAAMA were reduced from 150 days to 1-2 days on average, while also making provisions for immediate review when necessary. AERO provided for data checking and was easily integrated into the Flight Surgeon's office, both CONUS and OCONUS in the deployed setting. Administrative errors on submitted physicals were reduced from 40% on the paper-based system to <1% on AERO, and immediate feedback was provided to the Flight Surgeon on the disposition of aircrew physicals. Backlogs were cleared and overall efficiency was dramatically improved.

In 2008, with problems similar to those experienced using the Army's paper-based systems, steps were taken independently in the U.S. Navy and U.S. Coast Guard to implement AERO as their system for aeromedical disposition and review. While still undergoing testing and implementation in both services, it is already clear that this system has the potential to make significant improvements in the process of disposition and allows for commonality on an entirely different level than ever before.

There are several points about this AERO migration which must be emphasized. Firstly, the Army, Coast Guard, and Navy all shared a similar pathway for review and disposition within their own organizational structures (e.g. all three use a centralized review authority). Secondly, the Coast Guard and Army share a common footing in aeromedical culture as a result of the sharing of a common training base for Flight Surgeons, and a common migration of Army Flight Surgeons into the Coast Guard medical service. Thirdly, in the case of the Coast Guard, the aeromedical physical exam parameters (items required for physical exams) were already very similar. To cement these similarities, the Coast Guard agreed to adopt the same standards utilized by the Army, and Code 42 in the Navy has worked diligently to more closely align physical exam parameters with the Army and Coast guard in order to facilitate AERO integration.

The opportunity presented by Navy and Coast Guard AERO integration allowed AAMA to make some minor modifications to AERO to account for differences in requirements within the Navy's aeromedical policy. Without modification, the process of review within AERO very easily accommodated differences in the waiver process in both services. Because AERO utilizes a role-based system, the actual waiver authority could be retained in the service and allow for service-specific review while allowing all three services to utilize a common system and begin to migrate specific physical exam parameters, beginning to overcome one of the previously mentioned hurdles to commonality.

While AERO is only one system and one example, it serves the purpose of this article, as a vivid example of the capacity for convergence towards the authors' vision of a single common aeromedical system, while simultaneously raising the program standards within each individual service.

**CONCLUSION**

The prospect of developing a joint Aeromedical System and Waiver Guide is clearly daunting and is not without its challenges. Service culture, existing systems, policies, and service specific regulatory landscape all play important roles in keeping aeromedical systems separate. It is clear with the continuing evolution of the military operational environment that each of the services must work to migrate towards commonality while time permits, before higher authorities mandate such a move. In the meantime, the benefits of increased jointness include increased efficiency, increased interperability, and the facilitation of aeromedical epidemiological research. Despite aeromedical divergence over the course of the last 100 years since the beginning of military aviation medicine, we are beginning to see a convergence towards a common system. As we continue to explore and overcome hurdles to joint aeromedical systems, we will see that the authors' vision of a single common system of Aeromedical Administration for the U.S. Military is indeed within reach.



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