Davis Hyperbaric Laboratory

USAF HYPERBARIC NEWSLETTER

January 1998

TABLE OF CONTENTS

RESEARCH & DEVELOPMENT

BASIC SCIENCE RESEARCH

This past year has been a busy one for cellular hyperbaric research at Brooks AFB. In the area of infectious disease we are exploring the feasibility of using hyperbaric oxygen as a means of treating problem lung infections. The scientific basis for this study is the well known phenomenon that prolonged exposure to pure oxygen can cause severe inflammation in the lungs and that short exposures to hyperbaric oxygen have systemic immune effects. Taken together this suggests that hyperbaric oxygen may increase the immune response in susceptible individuals giving them an edge in defeating difficult infections. We are studying this question in mice that are susceptible to a nasty, incurable fungal infection caused by the organism *Coccidiodes immites* which is found in soil in the southwestern US. While the study is not yet complete, preliminary indications are that HBO does produce changes in infected lungs that are consistent with an improved response. The preliminary results of the study, in collaboration with scientists at the Texas Center for Infectious Disease, are to be reported at the AsMA annual meeting in Seattle ("Hyperbaric oxygen treatment of mice with disseminated *Coccidiodes immites* infection") with the manuscript to follow in the first quarter of 1998.

Hyperbaric oxygen has long been recognized as a limb saving treatment for non-healing foot wounds in the diabetic. Why do antibiotics fail in these patients and why is HBO so effective? If the bacteria isolated from these wounds are sensitive to the antibiotics given then why do the wounds persist? Could it be that organisms that cannot be cultured in vitro are the cause of some of the problems? In collaboration with researchers at the University of Scranton (PA) and the AF Epidemiology lab at Brooks, we identified bacterial species in a wound using standard clinical microbiology and molecular biology techniques that do not require in vitro culture isolation. Both techniques found a problem bacteria*: Bacteroides fragilis*. However, the molecular biology approach also found *Proteobacterium*, an unusual pathogenic organism that is difficult to grow in vitro. This finding tends to support the idea that previously unidentified bacteria may play a role in diabetic wounds and that appropriate treatments (including HBO) must be used to defeat them. This ground breaking work is being submitted to the journal **Diabetes Care** ("Bacterial species identification in a non-healing diabetic foot wound: identification by 16s ribosomal DNA sequence"). We plan to use this preliminary work as a springboard to funding a more extensive study in the coming year.

Hyperbaric oxygen has been known to lessen the damage produced during ischemia-reperfusion, mainly through reduced sequestration of neutrophils (the cells that cause the most tissue damage during a stroke or heart attack). Neutrophils do their damage by producing small highly reactive molecules that damage essential components of the living cell, especially DNA and membranes. One of the most important of these dangerous molecules, peroxynitrite, has been the subject of our investigations. We have found that in activated immune cells that have plenty of oxygen available, exposure to HBO reduces production of peroxynitrite by about 40%. Activated immune cells maintained under hypoxic conditions produce only about 25% as much peroxynitrite as cells grown under normal oxygen conditions. HBO exposure does not have any effect on peroxynitrite production in hypoxic cells. Taken together these observations suggest that HBO serves to attenuate an active immune response in normal tissues thereby preventing unwanted damage, while having little effect in hypoxic tissues.

This investigation along with another related paper are being submitted to the **Journal of Cellular Physiology** for publication. In collaboration with Dr. Bowden at the Brooke Army Medical Center, Clinical Investigations Branch, we are developing some new studies to examine the role of hyperbarics in limiting cellular adhesion. Much needed in vitro dose response studies (i.e., pressure-time relationships) of HBO's effect on adhesion are planned, as well as, a clinical trial to examine in detail the effects of HBO on various adhesion molecules.

What effect does hyperbaric oxygen have on tumor growth? Based on current epidemiology the answer is none at all. Could hyperbarics be used as an adjuvant to cancer chemotherapy or radiation treatment? We have examined this issue in one of the most problematic of all human cancers: advanced prostate cancer. In a manuscript accepted for publication in the journal **Anticancer Research** ("The effect of hyperbaric oxygen on growth and chemosensitivity of metastatic prostate cancer") we showed that there was a slight benefit when hyperbarics was given along with doxorubicin and taxol, two front-line anticancer drugs. In a follow-up paper we examined in detail the pressure dependent effect of HBO on tumor growth ("Exposure to hyperbaric oxygen induces cell cycle perturbation in prostrate cancer cells", submitted to the journal **Prostate** and presented at 1997 UHMS annual meeting) and found that pressures of 3 ATA and greater can synchronize a tumor cell population, setting the tumor up for greater damage during chemotherapy and slowing growth.

John Kalns, PhD
Research Scientist

CHAMBERS: THE NEXT GENERATION!

Most of us in Hyperbaric Medicine (HBO) are aware that up to now an operational limitation of our discipline has been the lack of in-theater/field support for the requirement of combat casualty care and management. The size, cost and fabrication time of steel pressure vessels made forward deployment prohibitive. We acknowledge that the efficacy of hyperbaric oxygen is significantly enhanced if treatment is initiated quickly (within 4 - 6 hours) following injury. Therefore, to get HBO as close to the point of wounding as tactically possible, thus advancing our wartime readiness mission, and addressing the Joint Health Service Support Plan: Vision 2010, we are pursing alternate chamber materials technologies. These technologies include, for multiplace chambers: concrete/resin composite materials for placement at contingency hospital locations, and modular steel section (panels) chambers that can be transported for far forward deployment or contingency hospital placement. For monoplace emergency transport/evacuation use we entered into a collaborative evaluation of existing technologies with the US Navy. We are convinced these technologies will bring clinical hyperbaric treatment to the combatant in-theater, meeting CONOPS requirements for low-cost, cube, modularity and flexibility for deployment of far forward support of the warfighter.

Pursuant to that goal of developing an alternate material multiplace chamber, the USAF constructed a prototype concrete contingency hospital room (CCHR) using post-tensioned concrete construction materials. The project demonstrated several advantages including: 1) large, rectangular, floor-flush doors facilitating rapid and easy causality ingress/egress, 2) significant cost reduction over steel vessels -- approximately 30%, 3) variable room size and configurations (square, rectangular or irregular) offering flexibility to accommodate existing building designs, 4) sliding doors that do not encroach floor space, and with vertical walls significantly improving space efficiency, and 5) modular support systems for easy transport and installation. A significant advantage of this technology is that the CCHR can be constructed by military or contractor civil engineers instead of mechanical engineer pressure vessel specialists. Furthermore, the CCHR can be rapidly constructed, in-theater, in a minimum of 36 days (steel vessels average more than a year). The prototype chamber completed pressure cycling tests with over 25,000 cycles (simulating a service life of more than 25 years) and peak pressure successfully tested to 85 psig (> 6 ATA), far surpassing the designed pressure level of 29.4 psig (3 ATA). The code case to certify the technology is before the American Society of Mechanical Engineers (ASME) Committee for Pressure Vessels for Human Occupancy (PVHO). Once this approval cycle is completed, the technology will be available for implementation.

An alternative to the CCHR is a modular, expandable hyperbaric chamber system (MEHCS). Although this chamber is composed of traditional steel materials, the MECHS has many advantages over welded steel chamber technology including: 1) modular design for optimizing deployability configuration--meeting the requirements for reduced medical assemblage, 2) large doors facilitating rapid and easy causality ingress/egress, 3) flexibility to extend treatment room size depending upon patient load requirements, 4) sliding doors that do not encroach floor space, 5) optimized interior illumination, and 6) vertical walls maximizing interior space efficiency. This chamber is designed as a 3 ATA system and has the nominal configuration of approximately 8 feet by almost 11 feet, and weighs about 14,000 pounds. This chamber meets all safety codes prescribed by ASME-PVHO. Cost of the MECHS is less than $500,000, for a six-place chamber. This innovative modular system can be warehoused, completely palletized (in sections) ready for rapid forward deployment, thus attending to factors required by air transportable medical facilities. Modularity of the design allows bolted parts to be readily moved into medical treatment facilities through existing doors or passageways before assemblage, thus requiring little or no structural modifications. Furthermore, the system allows rapid configuration changes to adapt to increased causality loads, or alternative relocation of the system with minor downtime. MECHS is available, but will require integration into the inventory before it is deployable.

Operational hyperbarics recognized a need for a portable chamber to support deployed operations, providing safe aeromedical evacuation of theater casualties to a definitive medical hyperbaric treatment facility. A joint service (USN/USAF) collaborative effort was funded by the Department of Defense, Foreign Comparative Testing Program, to evaluate two candidate systems. The emergency hyperbaric treatment/evacuation system (EHTES) is a collapsible chamber constructed of composite materials, and is approximately 30 inches in diameter, and about seven feet long, when inflated. The chamber weighs less than 150 pounds and is self-contained, easily transportable, and capable of withstanding at least 3 ATA. Current chamber pressurization employs available air sources (compressed gas cylinders), but we are pursuing reduced logistic requirements through use of a support cart with molecular sieve oxygen generating capabilities. EHTES is easily pressurized in minutes with minimal training and has a built-in breathing system for oxygen administration with overboard dumping capability during air transport. Stabilized patients can be transported safely, while pressurized, by gurney, ambulance, or aircraft. As I mentioned above, the USAF entered into a collaborative venture with the US Navy on this project. The Navy will evaluate chamber compliance to ASME-PVHO standards, and test operational requirements on two candidate systems—one from the UK and another from Italy. The AF component of this joint endeavor is to evaluate the aeromedical worthiness of the candidate system. Tests conducted will extend the evaluation to determine compatibility with the airborne environment for system use with patients during aeromedical evacuation flights. Currently, we are working with the aeromedical research engineers to define test requirements for this system. Evaluation will commence later this year.

Finally, I mentioned we are pursuing technology to combine forward deployed chambers, perhaps CONUS chambers as well, with a system to generate greater than 99% pure oxygen. This system has been under development in a sister function at Brooks AFB for several years. It is now reaching maturity and ready for implementation. The system is small and has the ability to generate 30 liters of "pure" oxygen per minute. The current configuration can also liquefy and store large quantities of oxygen for later use. It is quite rugged and has a 500 hour service (filter change) interval. More about this technology in a subsequent newsletter as we get closer to our objective.

Historically, during contingency operations Hyperbaric Medicine relied upon CONUS, or at best host, hospital facilities for administration of this important modality. This will no longer be the case, as we bring these technologies to maturity. Since we will be able to initiate treatment for the combatant, in-theater, we will *preserve the combatant's optimal mission capability* by reducing the magnitude of the injury, and shortening the duration of recovery from battlefield injuries.

Larry Krock, PhD
Director, Applied Research

CLINICAL HYPERBARICS

CRUSH INJURY, HBO AND YOU

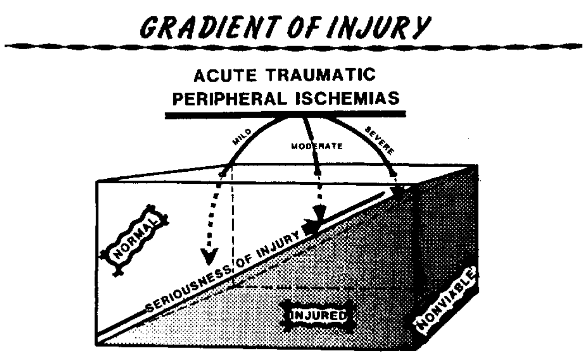
This clinical article is geared at improving our understanding of the application of Hyperbaric Oxygen (HBO) to the Acute Traumatic Peripheral Ischemias (ATPIs) and how the various mechanisms of injury and injury prevention may be better understood.

Primary	Hypoxia & Ischemia	Edema	Gradient	Reperfusion Injury
Crush Injury	4+	4+	3+	2+
Compart-ment Syndrome	4+	4+	4+	3+

Second-ary	Micro-Circulation Stasis	Contracture Formation	Infec-tion	Compro-mised Wound Healing
Crush Injury	4+	1+	1+	3+
Compart-ment Syndrome	4+	3+	1+	1+

Crush injuries and compartment syndrome are commonly recognized as belonging to the family of injury known as ATPIs, along with such notable others as: burns; frostbite; threatened flaps; and replantations. The common pathway in all of these conditions is traumatic hypoxia! Some of the primary characteristics of the ATPIs include Hypoxia, Ischemia, Edema, Gradient Injury, and Reperfusion Injury. Secondary characteristics include Microcirculation Stasis, Contracture Formation, Infection, and Compromised Wound Healing.

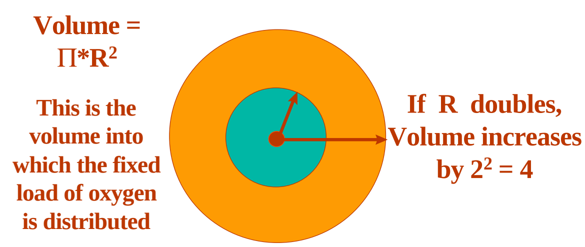
The concept of Gradient Injury can be visualized in the following graph, where there is a spectrum of tissue viability in and around the immediately damaged area. This spectrum ranges from minimal injury to total tissue non-viability, with all of the possibilities between. It is the tissues in the middle of the spectrum that are of great interest to us, because those are the ones that are at greatest risk, and will derive the most benefit from hyperbarics. In the end, being able to salvage a sufficient quantity of otherwise marginal tissue may be the difference between saving and losing a limb!



So just what is this reperfusion injury brough-haa-haa all about? It seems that these little leukocytes can sense that there's trouble in "River City", but don't have enough oxygen to do anything about it. So they just stick themselves to the blood vessel walls, waiting for some oxygen to come along so they can unleash their peroxidases and other "disolvazymes." Unfortunately, in these circumstances, the fairly indiscriminate nature of these oxidative materials, and the quantities in which they are released, seems to add to the damage, rather than help. In this hypoxic milieu, just a little additional cell wall damage from peroxidases becomes irreparable due to the lack of oxygen; intracellular fluids leak out and cannot be recovered as there is no oxygen to power the osmotic pumps. This extra fluid contributes to the local edema, which, in turn, worsens the existent hypoxia. Hyperbaric oxygen, applied early in the injury scenario, seems to prevent the WBCs from becoming "sticky", so that once perfusion is restored (reperfusion) this cascade of oxidative enzyme release is greatly reduced. Just a single HBO treatment delivered before, or within one hour of, re-establishment of the microvascular circulation, appears to be effective in limiting this reperfusion scenario.

As alluded to above, the edema and hypoxia processes exacerbate each other, since as one worsens, it feeds the other. As the edema increases, the extravascular compartment pressures increase which squeezes off the microvascular circulation (stasis), preventing the delivery of oxygen and nutrients. As this progresses, cellular damage worsens, permitting additional fluid leakage, and worsening the edema. This vicious circle continues, eventually resulting in cell death. Edema also exacerbates hypoxia by increasing the distance between capillaries, thus increasing the distance through which the delivered oxygen must diffuse before reaching the affected cells. The following diagram illustrates how the concentration

Diffusion Distance



Thus, the Diffusion Distance, "R" is related to the square root of the delivered oxygen load (P_aO_2)

of oxygen available for cellular use is related to the square of the diffusion distance. Thus, if the intercapillary distance doubles, the oxygen load available at the tissue level will decrease by a factor of four, exacerbating the existent hypoxic conditions.

A scale for evaluating traumatic injury has been advanced as the "Mangled Extremity Severity Scale", or MESS. The MESS score is calculated as shown below.

Skeletal Soft Tissue	Points
Low Energy Stab, Simple Fx	1
Medium Energy Open & Mult Fx	2
Hi Energy/Crush Shotgun, Hi-V GSW	3
Crush + Contam	4

Limb Ischemia	Points
Pulse decreased/absent Perfusion present/WNL	1
Pulseless, Paresthesias Diminished Cap Refill	2
Cool, Insensate Numb, Paralyzed	3
*Double Score > 6 Hr *	

Shock Score	Points
BP > 90	0
Transient Hypotension	1
Persistent Hypotension	2

Age Factor	Points
< 30 YO	1
30 - 50 YO	2
> 50 YO	3

Since a MESS of 7 or more is a 100% predictor of eventual amputation in an untreated individual, the application of HBO in such cases provides a valuable therapeutic treatment option in reducing limb loss. Therefore, HBO is recommended with a MESS score of 6 - 7 in all individuals, and should be considered in the compromised host (i.e., diabetes, PVD, collagen vascular disease) if the MESS score reaches 5 - 6; and at a MESS of 3 - 4 in severely compromised patients.

Application of HBO decreases the effects of the various mechanisms that lead to cell damage by several paths. First, HBO can increase the oxygen concentration 15 - 20 fold, providing a four-fold increase in the diffusion distance prior to the re-emergence of hypoxic conditions. In addition, hyperbaric conditions permit the blood plasma to carry 5 - 6 volume percent of oxygen over and above the 20 volume percent carried by hemoglobin. This level of oxygen, if present in the plasma, is capable of sustaining the basal metabolic functions of cells at risk---thus, the cells may be able to re-establish their intracellular environment and prevent the critical loss of additional fluids. Understanding this provides the explanation for why topical oxygen simply cannot work: the oxygen must be dissolved in the plasma to reach the affected cells at the cellular level. Topically applied oxygen simply cannot diffuse past the surface layers of the tissue, providing inadequate PO_2 internally! HBO is also known to produce a 15 - 20% vasoconstriction, decreasing the amount of fluid entering the area, and, thus, limiting additional edema formation. HBO also is capable of increasing the PO_2 above the 30 mmHg threshold essential for fibroblast function, collagen synthesis, and other healing functions. Increased oxygen tensions also serve to facilitate “fast mode” oxidative bacterial killing mechanisms in those leukocytes which are present, as well as, inhibiting the growth of any anaerobic pathogens which may have been introduced. Recommendations for HBO treatment following a crush injury are:

- ◆Initiate Primary Interventions (Surgery, etc)
  - If unavoidable delay, consider HBO early!
- ◆Begin HBO ASAP Following Definitive Treatment
  - HBO TID for 1 (2-3) day(s) after the injury
    - BID/TID & duration are controversial
  - If improved, decrease HBO to BID over next 4 - 6 days
  - If threatened flaps, continue HBO BID for up to 14 days
  - If osteomyelitis, continue HBO for up to 60 treatments

With the basics under our belts, we may now examine compartment syndrome in order to gain an appreciation of how HBO can help in the treatment of this disorder. Compartment syndrome may develop following any traumatic injury to a tissue compartment which is surrounded by relatively inelastic fascia. As fluid extravasates into the injured tissue. The pressure builds up within the fascial compartment until the capillary bed perfusion pressures are exceeded. At this point, the microcirculation shuts down creating an ischemic, hypoxic environment, and the process is now self-sustaining. As with crush injury, surgery is the primary treatment modality to decompress the tissue compartment. HBO plays an important role as adjunctive therapy for all of the reasons previously discussed.

Factors seen in compartment syndrome include:

- ◆Clinical Findings
  - Severe pain in muscle compartment
  - Marked increase in pain with passive muscle stretch
  - Marked swelling in muscle compartment
  - Marked tenseness in muscle compartment
  - Neuropathy, myelopathy, and/or encephalopathy
- ◆Skeletal Muscle Compartment Pressures
  - > 40 mmHg in uncompromised host
  - Serial pressures rising toward 35 mmHg
  - 30 - 40 mmHg in mildly compromised host (DM, PVD, CVD)
  - 20 - 30 mmHg in hypotensive patients with BP 33 - 50% below normal

The diagnosis of compartment syndrome may be made when any three of the clinical findings are present, or any ONE of the pressure findings exists! Primary surgical treatment should be initiated as quickly as possible; however, if surgical delays are unavoidable, an initial HBO treatment should be considered. Once surgery has been completed, follow-up HBO may help salvage marginal tissue, or even a limb!

Benton P. Zwart, MD, MPH
Fellow, Hyperbaric Medicine

CHRONIC REFRACTORY OSTEOMYELITIS (CRO)

Introduction

Non-hematogenous osteomyelitis is a surgical disease which customarily responds to aggressive debridements of sequestered (dead) bone and appropriate intravenous antibiotics. Only after antibiotics fail or the disease process is complicated by local factors such as crushed tissue or systemic host factors such as severe peripheral vascular disease, does Hyperbaric Oxygen

(HBO) become an adjunctive therapeutic modality. Coupled with attentive daily wound care, HBO achieves lasting healing rates of 80 - 90 % in chronic refractory cases.

This article will highlight the cost impact of conventional chronic osteomyelitis treatment and definitive treatment of refractory cases including HBO. A brief review of applicable bone physiology provides a framework for describing the epidemiological and pathophysiological basis of this disease. Consideration will also be given regarding the microorganisms involved in the etiology and clinical presentation and management of CRO. The Cierny-Mader classification will be introduced identifying the impact of local and systemic host factors. The adjunctive use of HBO treatment regimen is described and the desired treatment outcome is identified. A case presentation is given which highlights several important decision points in the management of this disease that can favorably determine outcome.

Healthcare Impact

A triad of overlapping clinical, economic and social costs must be accounted for to arrive at the total healthcare dollar impact of CRO. The highest clinical costs are found among these three settings: diabetes mellitus, work-related injuries and motor vehicle accidents (MVA), where the severity of the disease or the trauma coupled with a setting of a compromised environment (host or ambient) is the common denominator. Given a crush injury from a fall at a remote construction site or as a result of an MVA, in a person who is delayed in receiving definitive surgical attention or happens to be a diabetic, sets the stage for osteomyelitis. These infections often result in multiple treatment failures, ending in amputation. A quarter of the 11 million diabetics in the US will develop a foot infection, representing 15% of all hospital admissions. In 1988 dollars, foot infections cost > $200 million and limb amputations cost > $350 million. The economic costs of repeated hospitalizations, retraining for new job or expense of accommodation, disability compensation, and years of productive life lost adds up to a sizeable burden on the taxpayers. In 1989, 200,000 US work injuries accounted for $17 billion. The cost to society for the suffering of those so afflicted is difficult to quantify, but involves the loss of independence, chronic pain, maladjustment disorders, (e.g., depression, divorce, alcoholism, drug dependency, and suicide).

A sample case illustrates many of the cost aspects of chronic osteomyelitis. During the seven years prior to HBO therapy, a 36 year old female began with open fractures of the distal tibia and fibula stemming from an MVA. Following open reduction, internal fixation she developed osteomyelitis. Repeated admissions for bone debridements, bone grafts, musculocutaneous flaps, and IV antibiotics, accrued > $250,000 (direct medical costs, 1978-85 dollars). A distal pretibial wound continued to drain from exposed bone and she still could not work. An HBO consult was obtained and she was hospitalized for definitive care involving a repeat bone debridement, IV antibiotics and a course of HBO. If this failed she would have a below the knee amputation and go on to prosthetic rehabilitation. Her HBO therapy was begun as an inpatient then continued as an outpatient; wherein, she made slow, but continued, progress ultimately receiving 77 exposures. HBO and associated daily wound care added $18,000 to treatment costs. Loss of income over the 7 year period was at least $238,000. HBO led to a shortened hospital stay, reduced morbidity (a healed wound, no amputation) and a return to productive life. Review of several studies of chronic osteomyelitis in patients treated with either HBO or amputation revealed an average cost of HBO and wound care of $20-30,000 versus the cost of amputation and rehabilitation of $50-70,000.

Normal Bone Structure and Physiology

Bone is cellular and well vascularized; approximately 300 cc of blood passes through the skeletal system per minute. Osteoblasts actively lay down collagen and secrete bone concentrically around themselves, becoming resident osteocytes. Osteoclasts are bone-eaters, phagocytosing bone and placing calcium ions back into circulation in the blood in response to calcitonin. Bone is the site of the body store of calcium and phosphate. This Ca-P homeostasis also involves a complex interplay of enzyme systems which are modulated by circulating hormones processed in various metabolic centers in the endocrine glands, lungs, gut, and kidneys. Bone is of two types: trabecular/spongy (T) bone and compact (C) bone with a marrow cavity (Fig A). The differences in morphology dictate differences in mobilization of substances from the blood to the cells and back. T-bone is fed via the extracellular fluid (plasma) portion of the blood in a low pressure diffusional method in the peripheral marrow portions and ends of long bones. An important portal of entry into a bone is the nutrient artery. C-bone is nutri-

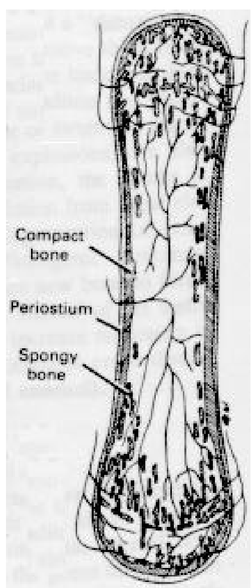
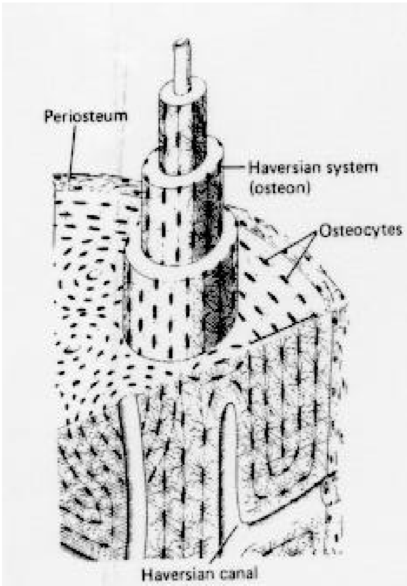


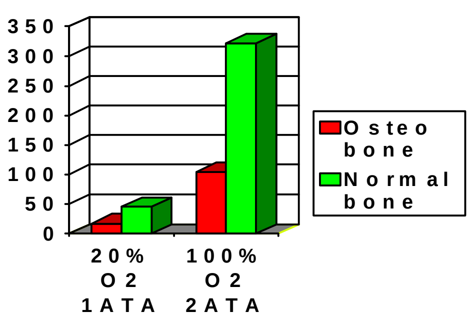
Figure A

Figure B



fied by collagen lined Haversian canals which have little canals (canaliculi) which imply two way diffusional gradients. These canals lead to individual cells which have interdigitating tight junctions which require a greater expenditure of ATP for active carriers/protein co-factors to pass substances back and forth between cells and blood (Fig B). The whole process depends upon aerobic metabolism (oxygen) for maximum efficiency.

Normal bone has a PO_2 of > 40 mmHg and > 300 mmHg with HBO; there is no change in blood flow during hyperbaric oxygen administration (Fig C). Perfusion in infected bone is lessened due to local edema and resultant increased intramedullary pressures; however, perfusion is not changed by HBO therapy acutely.



Epidemiology

Closed fractures have a < 1% incidence of osteomyelitis, rising to 5% with open fractures and > 30% with crush injuries. Less than 1% of elective orthopedic surgery cases become infected. This climbs to > 30% for emergent cases. Sites of predilection are the lower extremity followed by the mandible.

Pathophysiology

Infected bone is hypoxic with PO_2 in the range of 15 - 23 mm Hg. Oxygen consumption is elevated by the activity of the bacterial burden and inflammatory cells. Ischemia from crush injuries, for example, compounds hypoxia due to traumatic disruption of vessels and associated increased immune response activation. Hypoxia contributes to the favorable environment for bacteria by reducing leukocyte killing capacity (loss of "oxidative burst"). Additionally, hypoxia lowers fibroblast and osteoblast/osteoclast activity, retarding healing. Chronic osteomyelitis originates as non-hematogenous spread from a contiguous focus of infection due to a traumatic break in the skin. Clinically, it may first appear as a cellulitis with bullae on the skin overlying the bone infection. It becomes a persistently open, draining, painful wound, often with exposed dead bone. Infected bone is non-healing in the case of fractures and leads to non-union. This disease is often complicated by host factors (e.g., diabetes mellitus). Chronic refractory osteomyelitis (CRO) is characterized by duration longer than 6 months, unresponsive to antibiotics and surgery, with or without compromising host factors.

Cierny-Mader Classification

This clinical classification was devised to incorporate anatomical and physiological aspects of the disease process. This classification is further divided among systemic and local compromising factors. These are found in the groupings below.

Anatomical Stage

- Stage 1: Medullary Osteomyelitis
- Stage 2: Superficial Osteomyelitis
- Stage 3: Localized Osteomyelitis
- Stage 4: Diffuse Osteomyelitis

Physiologic Stage

- A Host: Normal
- B Host:
  - Systemic Compromise(Bs)
  - Local Compromise (Bl)
- C Host: Definitive Treatment Worse Than Present Disease

Local Compromise

- Venous Stasis
- Vessel Compromise
- Arteritis
- Radiation
- Lymphedema
- Scarring
- Loss of Sensation

Systemic Compromise

- Malnutrition
- Renal, Liver Failure
- Immune Deficiency
- Diabetes
- Malignancy
- Tobacco & ETOH
- Age Extremes
- Chronic Hypoxia

Clinical Management

The pillars of clinical management is surgical debridement of devitalized tissue and appropriate systemic antibiotics. Irrigation and suction arrays can be used to quiet a wound in preparation for more definitive treatment. Various methods of dead space obliteration (to fill surgical defects) involve fasciocutaneous or muscle flaps, autogenous bone grafts, and skin grafts. It is preferable to have as little foreign inert material in the wound area as possible; therefore, in the case of fracture, external fixation is desired.

Staphylococcus aureus accounts for 40 - 60% of cases of osteomyelitis, however, other aerobic gram positive (e.g., *Staph. epidermidis*) and gram negative (e.g., *E. coli*) bacteria, as well as anaerobic gram positive (e.g., *Clostridia*) and gram negative (e.g., *Pseudomonas*) organisms can be the triggers for osteomyelitis. In fact, mixed infections are found in 10 - 20% of cases.

Some antibiotics used in an anaerobic (hypoxic) environment are noted to have far less efficacy, namely, aminoglycosides, quinolones, trimethoprim/sulfamethoxisole (TMP/SMX), and vancomycin. Conversely, high oxygen tensions have shown in vitro and vivo augmentation of the action of several antimicrobials, e.g. tobramycin, TMP/SMX and nitrofurantoin.

Effects of Adjunctive HBO

HBO is considered as an adjunctive therapy in CRO to reverse the effects of hypoxia in the wound tissue environment. It aids in the elimination of the microbial burden by restoring the "oxidative burst" of the killing leukocyte. Fibroblasts become more migratory and efficient at laying down more mature collagen cross-linkages which provide a better foundation for angiogenic buds to invade. Osteoblast and osteoclast activity normalizes to restructure the healing bone. Activity of some antibiotics is augmented by HBO, as noted above.

HBO Treatment Regimen

Pure oxygen at 2.4 ATA for 90 minutes is given daily Monday through Friday. Each treatment session involves three oxygen periods (30 minutes each) interspersed with 10 minute air breaks. A total of 30 treatments are scheduled, followed by reassessment. Wound care includes daily debridement of accessible dead tissue and sequestra. Twice daily (BID) dressing changes consist of packing wounds with 2% boric acid soaked gauze until no clinical indications of infection are present. Treatment goal is to achieve total coverage of all exposed bone with granulation tissue, without drainage, erythema, swelling, or pain. This wound will then be aerobically stable enough to support a graft or flap and allow the patient to return to productive life. Clinical case reports and animal studies have shown 60 - 90% healing rates in CRO treated adjunctively with HBO.

Robert N Bertoldo, DO, MPH
Fellow, Hyperbaric Medicine

CASE REPORTS

A 25 year old gentleman ignited his heater when the evenings became cold. At approximately 0100-0200 hours he awakened. He felt very "dry" with an accompanying headache, nausea, vomiting, and mild shortness of breath. In addition, he felt mentally "slowed." At the Emergency Room his COHgb was 31%. After 3 hours of 100% oxygen the COHgb was 6.

There was no significant past medical history and review of systems proved unremarkable. Physical exam showed subtle neurological abnormalities. Coordination showed mild impairment of heel-shin test, mild impairment of tandem/heel/toe walking, and a "wobbly" Rhomberg. Mental status revealed difficulty with serial 7's and a feeling of only 80% mental function.

He was treated with a standard USAF CO Treatment Table. At depth, his wits were noted to be sharper and he seemed to have more energy. Upon completion of the treatment table, there were no abnormalities on physical exam. In fact, he felt his mental function to have returned to 100%. Follow-up over the ensuing 48 hours revealed no residua.

This case demonstrates the value of quickly removing the toxin, carbon monoxide, from the biologic system. His scenario, his COHgb, and his symptoms all suggest a serious exposure. Natural history for this sort of exposure suggests that Delayed Neurologic Sequelae (DNS) must be anticipated. Its published incidence is between 10 - 25%. This problem can range from mild IQ decrements to loss of bowel/bladder control. And, there is a significant potential for permanent residua.

Recent literature suggests DNS may well be a form of the ischemia-reperfusion injury. Here, an ischemic period causes local injury (i.e., endothelium). This is followed by oxygenated reperfusion. Because of the injury leukocytes arrive, attach, and activate. In essence, the leukocytes now become factories of oxygen radicals causing significant local damage. This injury with its accompanying edema results in neurologic dysfunction. HBO seems to mitigate this process by inhibiting the leukocyte attachment, thus short-circuiting the attack and minimizing the damage. In fact, Steve Thom's work at the University of Pennsylvania would suggest the mechanism is an inhibition of the leukocyte beta-2 integrin. As future investigations further clarify this mechanism, I think we can be fairly certain there will be an expansion of HBO indications.

WPB

LITERATURE REVIEW

Hyperbaric Oxygen Therapy in the Management of Crush Injuries: A Randomized Double-Blind Placebo-Controlled Clinical Trial. G. Bouachour, P. Cronier, J.P. Gouello, et al.

Journal of Trauma: Injury, Infection, and Critical Care 41(2): 333-339, 1996.

Abstract: HBO is advocated for the treatment of severe trauma of the limbs in association with surgery because of its effects on peripheral oxygen transport, muscular ischemic necrosis, compartment syndrome, and infection prevention. However, no controlled human trial had been performed until now to specify the role of HBO in the management of crush injuries. Thirty-six patients with crush injuries were assigned in a blinded randomized fashion, within 24 hours after surgery, to treatment with HBO (session of 100% oxygen at 2.5 ATA for 90 minutes, twice daily, over 6 days) or placebo (session of 21% oxygen at 1.1 ATA for 90 minutes, twice daily, over 6 days). All the patients received the same standard therapies (anticoagulant, antibiotics, wound dressings). Transcutaneous oxygen pressure measurements ($PtCO_2$) were done before (patient breathing normal air) and during treatment (HBO or placebo) at the first, fourth, eighth, and twelfth sessions. The two groups (HBO group, n=18; placebo group, n=18) were similar in terms of age; risk factors; number, type or location of vascular injuries, neurologic injuries, or fractures; and type, location, or timing of surgical procedures. Complete healing was obtained for 17 patients in the HBO group vs. 10 patients in the placebo group ($p < 0.01$). New surgical procedures (such as skin flaps and grafts, vascular surgery, or even amputation) were performed on one patient in the HBO group vs. six patients in the placebo group ($p < 0.05$). Analysis of groups of patients matched for age and severity of injury showed that in the subgroup of patients older than 40 with grade III soft-tissue injury, wound healing was obtained for seven patients (87.5%) in the HBO group vs. three patients (30%) in the placebo group ($p < 0.05$). No significant differences were found in the length of hospital stay and number of wound dressings between groups. For the patients with complete healing, the $PtCO_2$ values of the traumatized limb, measured in normal air, rose significantly between the first and twelfth sessions ($p < 0.001$). No significant change in $PtCO^2$ value was found for the patients whose healing failed. The Bilateral Perfusion Index (BPI = $PtCO^2$ of the injured limb/$PtCO_2$ of the uninjured limb) at the first session increased significantly from 1 ATA air to 2.5 ATA oxygen ($p < 0.05$). In patients with complete healing, the BPI was constantly greater than 0.9 at 2.5 ATA oxygen during the following sessions, whereas the BPI in air progressively rose between the first and the twelfth sessions ($p < 0.05$), reaching normal values at the end of the treatment. In conclusion, this study shows the effectiveness of HBO in Improving wound healing and reducing repetitive surgery. We believe that HBO is a useful adjunct in the management of severe (grade III) crush injuries of the limbs in patients more than 40 years old.

Commentary: This is the first controlled and randomized clinical trial looking at HBO treatment of major crush injuries. These injuries were grade III (from Gustillo)---extensive soft-tissue injury with or without bony involvement, with or without adequate soft-tissue coverage. The damage originated from blunt trauma. No penetrating trauma was included.

There was no difference between HBO and non-HBO groups under 40 years of age. **However, for patients greater than 40 years old there was a significant benefit using HBO.** The HBO group displayed markedly better healing, not to mention less secondary surgical procedures. And, transcutaneous oxygen measurements ($PtCO_2$) proved to be an excellent marker for healing. In fact, treatment successes showed an average change from the first day to the twelfth day of 21 mmHg to 90 mmHg oxygen tension.

In the military, blunt trauma is certainly prevalent; however, equally important is high energy penetrating trauma. As yet, there are no similar trials. There are only retrospective anecdotal series in which HBO is used regularly, but mentioned only in passing (i.e., Bosnian conflict). It would be very interesting to look at this data more closely and compare it to data obtained in those regions of the conflict without HBO facilities.

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OPERATIONAL HYPERBARICS

AN UPDATE ON THE NEW MASK

In the January 1997 issue of the USAF Hyperbaric newsletter, SSgt Massa, discussed his work on the new hyperbaric mask. To refresh your memory, the modified MBU-5/P aviators breathing mask had been in use since the 1970's. The mask is still a depot item, but the modified adapter is not available. The expense to re-mill the adapter was not cost effective. Recent technological developments in oxygen masks has greatly increased wearing comfort and reduced USAF maintenance costs.

The Davis Hyperbaric laboratory in conjunction with the Gentex Corporation finished testing a modified aviator's MBU-20/P derivative oxygen mask. The mask was tested with the assistance of TSgt Rogelio Cano, SSgt Dave R. Case and Mr. Ron Holden of the Research Chamber Operations Section. The mask was tested at 3.0, 2.5, 2.0 ATA and ground level using a pressure demand regulator (A-14) and pressure transducers. A mass spectrometer was used to analyze oxygen levels, carbon dioxide, and other exhaled gases. Tests confirmed that the mask could physiologically maintain levels of inspired oxygen while also exhausting expired carbon dioxide and other exhaled gases to a lesser ambient pressure.

The mask has been approved and is available from the Gentex Corporation. Gentex has made a few additional changes that have improved the performance and durability of the mask. The hardshell's diameter has been increased to reinforce against cracks. The strap assembly has been changed slightly. The new mask now comes in a blue transparent color . The transparent color is essential for monitoring patients inside the chamber. Best of all, Gentex has made significant cost reductions. The mask has reportedly dropped in price to between $350 and $400. Gentex is open to all suggestions that improve the mask's performance. I for one am glad to see the mask and overboard hoses are now available up to 120 inches. An adapter with longer hoses could be one option. The mask comes in four sizes; Small Narrow, Medium narrow, Medium Wide, Large Wide. Mr. Robert McKay is the point of contact for Gentex (909) 481-7667 or suggestions can be sent directly to me.

The new hyperbaric mask requires less pressure than the old MBU 5/P mask. If using the A-14 regulator, set the pressure dial to the letter "S" in the word SAFETY. The "S" setting delivers approximately 1 in H_2O. If using a different oxygen delivery system, calibrate your delivery system to deliver 1 in H_2O. Gentex has developed a compatible oxygen regulator that can replace the A-14 regulator inside the hyperbaric chamber. Gentex is also looking at developing a compatible overboard dump system.

NOTE: The HyperMed Patient Mask cannot be used with the current overboard dump system on Air Force 99/S hyperbaric chambers. Modifications to the overboard dump system and a Venturi system is required.

The new HyperMed mask and the older modified MBU 5/P mask are both available inside our chamber. The HyperMed mask is preferred and used exclusively by all of our personnel. The fit and comfort is considerably better.

Many thanks to all the volunteer divers who assisted with the test and evaluation of this mask.

John Kettinger, SMSgt USAF
Superintendent, Operations and Development

We at the Davis Hyperbaric Laboratory are also proud to announce the promotion of SSgt Tom Massa to Second Lieutenant Tom Massa.

HYPERBARIC TRAINING AND EDUCATION

LECTURES

The Staff/Fellow Conferences at Davis Hyperbaric Laboratory are alive and extremely well. We have had the pleasure and privilege to host numerous formal lectures/discussions. All of them have been CME accredited by the Office of the USAF Surgeon General. Each has been videotaped to facilitate continuing proficiency training in Hyperbaric Medicine.

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HBO LECTURE/SAFETY VIDEOS

The Davis Hyperbaric Laboratory Video Library, has had a growth spurt! The monthly Staff/Fellow Lecture Series held at Brooks AFB, is now being videotaped.

Lectures by scientists, foreign visitors, nurses, technical experts and physicians are available, and can be borrowed. All you have to do is ask! Plans are in the works to have these filmed lectures accredited for CHT, CME, and nursing.

To borrow a film---

Call: DSN: 240-3281
COM: (210) 535-3281
Write: DET 1, HSC/AOH
2509 Kennedy Circle, Suite 309
Brooks AFB, TX 78235-5304
E-mail: dolores.larkin@platinum.brooks.af.mil.

Capt Barbara Susen
Chief, Clinical Education & Equipment Development

A Partial Listing

Long Term Health Effects of Diving
Aircraft Mishap Investigation---Australian Style
Fire Review/Operational Safety (2 hours)
Pharmacology of HBO & Biochemistry of Healing
Monoplace Protocols
Crush Injury/Compartment Syndrome
The Historical Basis and Use of TcPO2 (2 hours)
Basic Science and HBO
Cardiopulmonary Effects of Pressure
Osteomyelitis and HBO
HBO---Delivery and Extraction in Human Tissues
Diabetes Mellitus and ABI
Wound Healing and Oral-Maxillofacial Surgery
Croatia Experience with HBO (4 hours)
Nicaraguan Indigenous Diving Experiences (2 hours)
Brown Recluse Spider Bites
Carbon Monoxide Poisoning
Nitrogen Narcosis
HBO and Frostbite
Altitude DCS---Current Concepts
Women's Health in Hyperbaric/Hypobaric Arenas
Environmental Medicine---The Russian Experience
Forensic Aspects of Diving Accidents

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HYPERBARIC NURSING COURSE

The Hyperbaric Nursing Course has been revised. The course is 7 weeks long, it requires the 1 week HTHCO course as pre-requisite, and four weeks OJT on the job site. The focus of the course changed from book learning and demonstrations, to hands on in the chamber. A total of eleven scheduled dives are now in the course plan; more emphasis has been placed on the specialized nursing skills needed in the hyperbaric environment. The nurses' critical care backgrounds are put to the test during the training dives with drips, ventilators and critical management.

The course continues as before, listed in the AFCAT 36-2223, as a TDY to school at BAFB, enroute to the new base. The number of nursing contact hours has not yet been determined. Questions? Call, Capt Barbara Susen COM: (210) 536-3281, DSN: 240-3281 or E-mail: barbara.susen@platinum.brooks.af.mil.

Capt Barbara Susen
Chief, Clinical Education & Equipment Development

ENLISTED HYPERBARICS

There is a Clinical Hyperbaric Training Course for Technicians (B3AZY4X0X1-005) tentatively scheduled for April 1998. This three-week course is mandatory for 4NOX1s and 4MOX1s who are stationed at or have an assignment to a clinical hyperbaric treatment facility. Let us know ASAP if you have individuals who require training. Our POC for the course is TSgt Robert Johnston; he can be contacted at DSN: 240-3281.

Clinical Hyperbaric Medicine is losing physicians, nurses and technicians from all three clinical treatment facilities within the next year due to separations, retirements and PCS. We are looking for a few folks who are interested in broadening their horizons and would like a challenging job in the exciting field of Clinical Hyperbaric Medicine. If you're up to the challenge, contact one of the POC's listed:

Brooks AFB, Texas: MSgt Dave Pridgen or SMS John Kettinger at DSN: 240-3281.

Wright-Patterson AFB, Ohio: MSgt Hector Chavez at DSN: 787-8603

Travis AFB, California: MSgt John Gorum at DSN: 799-3988

MSgt David Pridgen
Manager, Hyperbaric Medicine (DHL)

FELLOWSHIP TRAINING FOR PHYSICIANS

The USAF School of Aerospace Medicine trains two physicians annually in a Clinical Hyperbaric Medicine Fellowship at the Davis Hyperbaric Laboratory. The primary emphasis of the program is clinical (i.e., wound care and adjunctive use of hyperbaric oxygen for wound healing). However, fellows also treat decompression sickness (DCS) cases that are referred from the mid-south and are consultants for USAF operational DCS cases occurring worldwide. The USAF has been treating aviator's DCS in hyperbaric chambers since 1959.

In 1974 the Surgeon General established a hyperbaric center (later named the Davis Hyperbaric Laboratory) at Brooks AFB to direct the development of operational and clinical hyperbaric medicine throughout the Air Force. Davis Hyperbaric Laboratory is the lead agent for all DoD Clinical Hyperbaric Medicine programs.

The physician fellowship was established in 1978. It was the first Clinical Hyperbaric Medicine Fellowship in the United States, and remains the only military hyperbaric fellowship.

In the year of training, fellows learn the latest techniques in the management of chronic nonhealing wounds. In addition, they learn the nuances of the other thirteen accepted indications for hyperbaric oxygen therapy. Included in that list is the operationally relevant altitude-induced DCS. Fellows become singularly qualified in dealing with this malady. The current program achieves an exceptionally broad-based experience with multiple outside rotations (i.e., diving medicine, monoplace chamber operations, international conference attendance).

Fellows actively participate in hyperbaric medicine education by teaching classes to physicians, nurses, and technicians at the School of Aerospace Medicine. Opportunities for basic science and clinical research are available and encouraged.

Fellowship training incurs a two-year pay-back commitment. At the completion of training, fellowship trained physicians are assigned to one of the USAF's clinical hyperbaric medicine facilities located at Brooks AFB, Travis AFB, or Wright-Patterson AFB.

Physicians interested in fellowship training should contact **Lt Col William P. Butler**, Director, Hyperbaric Medicine Fellowship, Davis Hyperbaric Laboratory, Brooks AFB at **DSN 240-3281**.

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Fellow Profiles

Dr Robert N. Bertoldo attended medical school at the University of Health Sciences, Kansas City, Missouri, followed by a flexible internship at the Rocky Mountain Hospital in Denver, Colorado. After Aerospace Medicine Primary Course, he became a squadron medical element leader for the 428th Tactical Fighter Squadron (F-16B) at Nellis AFB. Next, he flew with the 390th Electronic Tactical Squadron (EF-111A) at Mountain Home AFB. From there he entered and successfully completed a Family Practice Residency at Creighton University. Elmendorf AFB was the next stop. He next matriculated to the twin residencies of Aerospace and Occupational Medicine at the School of Aerospace Medicine on Brooks AFB. He completed his MPH degree at the University of Texas in San Antonio.

As commander of the 9th Aerospace Medicine Squadron at Beale AFB (supporting high-altitude U-2 operations based in Cyprus, Saudi Arabia, France, England, and Korea) he logged both diving and flying time. In fact, he accumulated over 500 hours of flying in more than 30 different US and Allied military aircraft. In addition, he served as medical group commander during Operation Southern Watch.

Dr Bertoldo is currently certified by the American Board of Family Practice and the American Board of Preventive Medicine.

He and his wife, Barbara, are the parents of two children, Nathan and Emily.

Dr. Benton P. Zwart completes our Hyperbaric Medicine Fellowship team. Dr. Zwart came to the USAF after receiving his Bachelor's Degree (summa cum laude) and Master's Degree in Electrical Engineering at Lehigh University. During his first tour of duty he made major contributions to the development of a satellite navigation program known today as the Global Positioning System.

Col (S) Zwart then obtained his medical degree at the University of Connecticut School of Medicine in Farmington, CT, and underwent Family Practice training at Oakwood Hospital in Dearborn, Michigan. Subsequently, he was chosen to be the OIC of Flight Medicine at Scott AFB, followed by an assignment as Chief, Aerospace Medicine at Zweibrucken AB, Germany. During those years he flew in aircraft such as the UH-1 Huey, C-9 Nightingale, F-4 Phantom, and the C-23 Sherpa and has now logged over 950 career flight hours.

He then entered the Residency in Aerospace Medicine, earning his MPH from the Harvard School of Public Health. After completing his RAM program, he earned board certification in Aerospace Medicine and recently passed his Occupational Medicine Boards. Dr. Zwart spent a year traveling worldwide as a member of the Inspector General team. Subsequently, his aeromedical expertise was acknowledged when he was selected Chief, Flight Medicine Branch, Aeromedical

Consultation Service here on Brooks AFB. Just prior to beginning his Fellowship, he was the Director, Base Medical Services at San Vito Air Station, Italy, supporting the Bosnian peacekeeping efforts. He was directly involved in the humanitarian efforts of Joint Task Force Silver Wake during the evacuation of Albania.

He and his wife, Kay, are the parents of three daughters, Lauren, Kara, and Rebecca.

We welcome both of these highly qualified physicians to the realm of Hyperbaric Medicine. They are certain to make many contributions to the field during the upcoming years.

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MEDICAL SUPPLEMENTAL TEAM MEMBERS

There have been a lot of Supplemental Dive team members, both MC and NC trained. We always need more!!! The HTHCO course has now been reduced to 4 days, being offered only four times a year. Class slots need to be requested from your MAJCOM by your training action officer. The AFCAT has full prerequisite information. Plan now for the future.

The function and services our supplemental divers perform for their specific clinical HBO units are so important. They enhance our staff by knowledge, energy and numbers. I know you join me in thanking them for their willingness to volunteer their time to our units.

Capt Barbara Susen
Chief, Clinical Education & Equipment Development

PARALLEL UNIVERSES

US NAVY

Clinical Hyperbaric Medicine

James Chimiak, who is the Head of the Navy Operational Medicine Institute's Hyperbaric Medicine Division, was recently selected to co-chair a joint papers session on the cross-over day of the AsMA and UHMS annual meetings. He will represent the Aerospace Medical Association. Dr. Chimiak is a Fellowship trained Hyperbaricist (Duke University), in addition to being an active Flight Surgeon.

Diving Medicine Training for Uniformed Physicians, Physician Assistants, and Physiologists

The Naval Diving and Salvage Training Center (NDSTC), Panama City, Florida offers five graduate level diving medicine courses for interested DoD physicians, PA's, and physiologists. Quotas for training slots are offered based on operational need and order of application. This training is required for Navy Undersea Medical Officers and Navy residents in Aerospace Medicine and highly encouraged for all Flight Surgeons, Army Special Operations Medical Officers, and Aviation Physiologists.

The Recognition and Treatment of Diving Casualties courses (R & T) are 10 days long. Graduates receive 63 hours of CME credit and are certified to initiate hyperbaric treatment of dysbaric illnesses, to review diving duty physical exams, and to serve as inside tenders during recompression therapy. This course provides training necessary to safely and effectively perform as a medical advisor for diving operations. Students learn each job as part of the chamber team during diving accident scenarios and do several chamber dives, the deepest being 165 FSW. Applicants must have a current diving physical exam. There are no extra physical fitness requirements.

The Diving Medical Officer courses (DMO), a pipeline course for Navy Undersea Medical Officers, are 9 weeks in length. The course consists of one week of diving physics, 2 weeks of diving medicine which is almost identical to the R & T course, 5 weeks of dive training, and a final week of advanced diving medicine topics. Unlike the R & T students, DMO students must complete the rigors of Navy diver training which include daily strenuous physical training, one stressful week of SCUBA confidence training and certification dives to 190 FSW. DMO's become *bona fide* Navy divers qualified in open-circuit SCUBA and all Navy surface supplied rigs. They get a closed-circuit SCUBA familiarization which culminates in pool dives with the Draeger LAR-V. In addition to a current diving physical, applicants must pass a diver physical readiness test and a 1000 yard timed surface swim with fins. Graduates receive 95 hours of CME credits.

NDSTC, a tenant command on the Naval Coastal Systems Station, is considered to be one of the best diver training facilities in the world. These courses provide uniformed medical providers excellent continuing medical education opportunities and current, professional instruction in diving medicine. The are **no** course costs. Government messing and berthing are available. For more information and the 1998 course dates, contact **LT Jackson**, at DSN **436-5216/5** or COMM (904) 235-5216/5.

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US ARMY

The Army has decided to close the chamber complex at Ft. Rucker, Alabama. However, this was not the end of Army Hyperbaric Medicine. LTC Daniel Fitzpatrick, one of the Army's few fellowship trained hyperbaricists, moved to Eisenhower Regional Hospital on Ft. Gordon, Georgia. There, he began a Hyperbaric Medicine program. To accomplish this task, Davis Hyperbaric Laboratory loaned their Sechrist monoplace unit to the Army. Presently, there is talk of establishing a multiplace chamber there.

The Army's Institute of Surgical Research (ISR a.k.a. Burn Unit) has shown a new interest in Hyperbaric Medicine. Colonel Cleon Goodwin, Commander, has been discussing the possible use of HBO for his patients with the staff of Davis Hyperbaric Laboratory. Needless to say, this is an exciting future. *WPB*

CROATIAN PHYSICIANS VISIT

From 27 - 31 October 1997, DHL was pleased and privileged to host a delegation of five Croatian physicians. During the visit they were exposed to a wide variety of USAF missions both medical and the line. In addition, they were able to see the civilian multiplace and monoplace units in the San Antonio area. Each tour was noted to be an excellent experience and many in-depth discussions ensued. Needless to say, a number of friendships were forged.

During the lecture series, much information was exchanged. Certainly, the clinical material was interesting; however, it was the data regarding the war that was riveting.

Hyperbaric Medicine has been alive in Croatia for over 30 years. The unit at Split, Croatia (the sole Hyperbaric Medicine unit in the country) is a part of the Navy Medical Institute which provides Undersea & Hyperbaric Medicine, Occupational Medicine, Medical Selection Process, Epidemiology & Tropical Medicine, Microbiology & Medical Oceanography, and Sanitary Chemistry & Toxicology. The Undersea & Hyperbaric Medicine division supports Navy diving and submarine activities (1 submarine), in addition to clinical Hyperbaric Medicine.

Two 2-lock walk-in hyperbaric chambers that can treat eight patients plus two inside observers make up the unit's hardware. Also, there is a "wetpot" dive simulator sphere that has a 15 ATA capability. Current staffing include 3 specialists in Occupational Medicine (one with Undersea training specialty), 4 Hyperbaric nurses (2 RN's and 2 corpsmen) 1 engineer of Chemistry, 1 Chemistry lab technician, and 4 chamber operators. Up to 250 patients are treated annually.

A Draeger mask with a demand regulator has been used for the past 25 years without serious accident. Pressurized oxygen is used, rather than LOX. Although the overboard dump system was characterized as "ancient," it obviously functions well. A research/experimental chamber was shown that was created from a cut-out British torpedo tube. The chemistry lab shown appeared rudimentary; but, it apparently functioned without major difficulties.

Treatment of diving accidents did not include the use of USN TT5 or USN TT6A. The Catalina Table or the USN TT6 was the treatment of choice. In addition, clinical treatments were almost uniformly performed at 2.2 bar for 60 minutes of oxygen. Gas gangrene was treated at 3 ATA. Several patient examples were given. A patient with macular degeneration had his progressive blindness halted. A University mathematics professor suffering a bilateral amputation from a grenade blast was successfully treated to halt an infection.

War casualties were regularly treated. These included "Croatian soldiers, Muslim deserters, Serbian prisoners, and Croatian civilians." During this "passionate war," only two physicians manned the unit. There were 200 casualties treated. Many of these patients had external fixators. One patient exceeded 300 pounds. Generally, only three casualties were treated simultaneously. In order to enter and remove the patients, "slides" had to be used. The chamber room was frequently very hot (no air conditioning) with little in the way of breezes.

Of the 200 casualties, 172 (86%) were secondary to explosives or projectiles. Primarily injured were lower extremities. There were 103 explosive injuries, 51 rifle injuries, and 18 major lacerations. In addition, there were 28 (14%) other injuries. These included acoustic injuries (i.e., blast-related hearing loss---10), frostbite ("7 Muslim deserters and 6 Croatian soldiers"---13), Sudeck's reflex dystrophy (2), osteomyelitis (2), anaerobic hand infection (1). No burns were treated; the critical nature of the injury was cited as the main mitigating factor. Average number of treatments was 7; average hospitalization was 20 days. No comparison to non-HBO treated casualties has yet to be accomplished. These data were provided in hard copy; however, it is in Croatian.

The biggest problem facing the casualties was transportation/evacuation. A distance that could be "overflown in less than 4 hours" frequently required "up to 17 days" to traverse. The average transport time was 4 days.

This prompted the placement of "small teams of surgeons to the front lines to prepare the casualties for transport." Preventive fasciotomies were the rule, often preventing compartment syndrome. Although osteomyelitis was seldom treated during the war, much of the present patient population suffers osteomyelitis. Its pathogenesis is felt secondary to this front line surgery. However, it was pointed out that many extremities and lives were saved by this practice.

Hyperbaric oxygen therapy (HBO) was used to reverse "hypoxia/ischemia." Only 8% of the total casualties generated received HBO. Although this was felt to be "too little," it was recognized that "more (casualties) probably could not have been handled." Treatments continued seven days a week without breaks.

Another wartime triumph of the Navy Medical Institute was its Preventive Medicine program. With over 300,000 soldiers in the field, there was less than a 1% mortality. Of considerable concern was tetanus. Although 90% of the population is felt to be immunized, about 15 tetanus cases are encountered annually. These cases are primarily seen in older peasants and newborn gypsies (questionable umbilical cord cutting practices). Grenade, shrapnel, and gun shot wounds are high risk injuries. Preventive measures were felt necessary. During several months bridging 1990-1991 over 2,000,000 citizens were vaccinated. No cases of tetanus occurred in soldiers and the overall populace incident rate fell. With over 20,000 severe injuries and over 20,000 less severe injuries, this was a remarkable accomplishment.

In late 1992, there were thousands of refugees. Fifteen cases of *Typhus abdominalis* were encountered. This was the only "imported epidemic." Hemorrhagic fever with renal involvement (from animals) was found in just over 50 soldiers. Only 3 perished. Water and food supplies were well controlled---there were "no true outbreaks" of food/water borne illness.

Needless to say, this sort of informational interchange not only forged collegial respect, but also demonstrated the need for future such exchanges. The data obtained (not yet published, and, perhaps, never to be published) is uniquely valuable to military medicine.

WPB

NICARAGUAN VISITOR PLEADS FOR HELP

Dr. Humberto Olayo, Chief Physician at the Regional Hospital Knave Amanecer on the eastern coast of Nicaragua, visited DHL on 5 December 1997. He was accompanied by Drs. Diana Barratt and Keith Van Meter from the Jo Ellen Smith Medical Center Hyperbaric Medicine Department. These two physicians have been working with Dr. Olayo intermittently in Nicaragua for some time now.

Dr. Olayo runs the sole Nicaraguan hyperbaric chamber along the Central American Miskito Coast. Here, the primary industry of the indigenous Miskito Indians is sea-harvesting. These Indians scuba dive for the spiny lobster. There are about 150,000 Miskito Indians. They form the largest ethnic group in a country with only 4.3 million population. With an unemployment rate of 65% and a poverty rate of 85%, any consistent income in Nicaragua is rigorously sought.

Prior to 1958, there was no scuba diving. Despite its introduction, only about 120 Miskito Indians used scuba to collect the lobsters. The depths were usually 40 fsw or less and lobster traps seemed more efficient.

During the 11 year civil war, most industry was shut down including the lobster fishery. In 1990, it reopened and scuba became the preferred collection method. Now, over 2,500 Miskito divers are actively diving for lobster. The depth of harvest has deepened to 90 - 120 fsw. And, many daily dives are made. An average of 7.5 tanks per day are used for 4.7 consecutive days (range is 1 - 12 days). As a result, there has been a surge of decompression illness. Over 100 cases are seen annually.

When these divers present, it is almost invariably for a significant neurological "hit." The divers do not seek help for "minor" symptoms (i.e., limb pain, rash, paresthesias, etc.). Among the more serious presentations are motor deficits (78%), urinary problems (52%), dizziness and/or vertigo (39%), loss of consciousness (17%), cranial nerve deficits (7%), blindness and other visual abnormalities (2%), and aphasia (2%). Treatments included HBO (75%), steroids (72%), vitamins (22%), aspirin (20%), heparin (17%), and NSAIDs (11%). USN TT6 (74%) and USN TT5 (92%) were the primary HBO treatment regimens. Multiple HBO treatments were not infrequent as hospitalization averaged 11 days (range was 0 - 120 days).

Of interest, Dr. Olayo performs the HBO treatments in a 2-person multiplace chamber that is outside under an awning. He performs all the manual valve-turning that is necessary for pressurization, depressurization, and venting. Communication is by hand-signals and tapping on the chamber itself. There are no "inside observers." Needless to say, Dr. Olayo is often overtasked and overly tired. He is looking for some help.

The USAF was approached because of its long interest in DCS research. It was felt by Drs. Barratt and Van Meter that we would be interested in prospective, randomized studies using steroids in conjunction with HBO for these unfortunate victims.

Another, more important, reason the USAF should be interested in supporting Dr. Olayo with intermittent personnel is operational readiness. It is my contention that this setting is analogous to being operationally deployed. It is remote with only a modicum of resources available. Teams would, of necessity, have to bring much of their own equipment including the transportable hyperbaric chamber. In addition, they would probably need to bring much of their own habitat. This would be a grand environment to train the teams for forward HBO placement and operation. Such a team-training would directly support the UTC concept that Colonel E. George Wolf, DoD Lead Agent for Clinical Hyperbaric Medicine, has presented to the USAF Surgeon General for approval. These teams would not just be limited to Brooks AFB. I would envision each clinical center with at least two teams. Each team would deploy for 1 - 2 weeks annually for training.

As a result, some incredible clinical DCS studies could be accomplished. In addition, Dr. Olayo would obtain some much needed assistance. Observing and treating severe neurological DCS (both spinal and cerebral) would be a tremendous asset for both Staff Hyperbaricists and Fellows. The experience would indirectly benefit our "customers." Indeed, these "customers" are active duty line soldiers. This would also be an incredibly positive humanitarian project in a country where we have not always been viewed as a positive influence. And, finally, this would be a wonderful test ground for the UTC concept and training to implement this concept.

Needless to say, Dr. Olayo is pursing this vigorously through his Ministry of Health and the US Embassy and the State Department. With a little luck and USAF/SG support, this could well become a reality.

WPB

PERSONALS

USAF Hyperbaric Medicine is losing a number of valuable individuals:

Senior Airman Kelly Byrd, who was a medical technician at Davis Hyperbaric Laboratory, married Dr. (Lt Commander—Canada) Aaron Kahn, separated from the USAF, and is now working for DCIEM in Toronto.

SSgt Jennifer Middendorf, who was a medical technician at Davis Hyperbaric Laboratory, recently completed cross-training into Occupational Therapy at Wilford Hall Medical Center. She is now stationed at WHMC.

SSgt Jerry Querido, who was a medical technician at Davis Hyperbaric Laboratory, is now in training to become a military Physician's Assistant.

2 Lt Tom Massa, who was an operations physiology technician, was accepted to OTS and is now a physiologist at Columbus AFB, Mississippi.

Major Monica Skarban, chief nurse at Travis AFB, will leave in March 1998 for Grand Forks, North Dakota.

Captain Allison Bowden will be leaving Wright-Patterson AFB this summer. As yet, her new assignment is unknown.

Although it is tough for us to lose such quality people, we wish them great luck in their new endeavors and look forward to their return to Hyperbaric Medicine.

And, speaking of folks in Hyperbarics:

Captain Sue Ann Bradbury is now stationed at Travis AFB following her successful completion of the Hyperbaric Nursing Course.

Captain Charlene Sylvestre will be taking the Hyperbaric Nursing Course in March/April to fill Major Skarban's position at Travis AFB. She is currently a supplemental diver at Wright-Patterson AFB.

Captain Perry Carlson has settled into the Wright-Patterson AFB routine along with his family. Incidentally, he is a Navy-trained diver.

Captain Jack Smith has just returned from Germany successfully completing the Hyperbaric Nursing Course. He formally joined the Brooks AFB team in June.

USAF Hyperbaric Medicine is also suffering through the upheavals of retirement.

Colonel John Bishop, who heads Hyperbaric Medicine at Wright-Patterson AFB, will retire in January 1998.

Colonel Ben Slade, who lead Hyperbaric Medicine at Travis AFB, retired this past summer. He is now in civilian Hyperbaric Medicine practice with Dr. Paul Cianci in California.

TSgt Geno Sekinger, who is an operations physiology technician at Davis Hyperbaric Laboratory, is planning to retire this upcoming summer.

TSgt Rich Welch, who is an operations physiology technician at Davis Hyperbaric Laboratory, is planning to retire this upcoming summer.

Congratulations to these friends on their retirements. We wish them the best in their civilian pursuits. We look forward to future visits at any variety of conferences.

WPB

EDITOR'S NOTES

This newsletter is a bunch of work; however, it is a load of fun! I am sincerely grateful to all who contributed to its final face.

Comments and suggestions are welcome! Articles, case reports, informational letters, etc. are welcome!

Please send it all to:

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