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**A LARGE CASE SERIES OF AEROMEDICALLY
EVACUATED MILITARY WORKING DOGS WITH A
RESULTANT VALIDATION ALGORITHM FOR THE
THEATER VALIDATING FLIGHT SURGEON**

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14. ABSTRACT Military working dogs (MWD) are force multipliers. Their aeromedical evacuation (AE) and clinical validation by the Theater Validating Flight Surgeon (TVFS) remain essentially unexplored. This is a first-look observational study. All 161 missions from 2001-2015 were extracted from the Transportation Command Regulating and Command and Control Evacuation System. The stereotypic MWD was a middle-aged, male German Shepherd serving as an Army E-6, usually suffering from Disease, Non-Battle Injury (DNBI). DNBI dogs (72%) dominated, mainly with musculoskeletal/gastrointestinal issues. Battle Injury (BI) dogs commonly suffered gunshot wounds to the extremity. DNBI dogs were flown primarily for Diagnosis & Treatment; BI dogs for Rehabilitation. DNBI dog final dispositions included adoption and death; BI only adoption. TVFS validation employed aircraft and canine prescriptions. Few aircraft interventions were prescribed. Of the canine interventions, muzzles, kennels, attendants, and medications dominated. There were no differences in prescribing, excepting a significantly greater number of veterinary attendants assigned to BI dogs. Notably, 29 dogs flew with either a veterinary technician (11%) or a veterinarian (8%). Dogs routinely flew with handlers. These findings suggested a six-step clinical validation algorithm: <i>Step 1</i> - physiologic considerations and countermeasures; <i>Step 2</i> - tissue oxygen delivery (DO ₂); <i>Step 3</i> - veterinarian consultation; <i>Step 4</i> - flight safety; <i>Step 5</i> - medical attendant assignment; <i>Step 6</i> – communication. A toolkit was developed (Appendix C). Future research should target potential AE-related morbidity and mortality.				
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1.0 EXECUTIVE SUMMARY

Millions of dollars are rightfully invested each year in the training and veterinary care of military working dogs (MWDs). These dogs are ready force multipliers, not easily replaced. Evidence the career vignettes of some of the more famous MWDs (Appendix A). Despite the MWD's well documented value, to date, there has been little to no attention directed at the Aeromedical Evacuation (AE) of these valuable dogs. Likewise, the clinical validation of the ill/injured MWD by the Theater Validating Flight Surgeon (TVFS) remains essentially unexplored. This study began the examination of these relatively unnoticed arenas.

There was about one MWD evacuated for every 1,000 human evacuations, making such transports uncommon, but not at all rare; making it unlikely any TVFS has serious experience validating MWDs for AE; and, making this report and future MWD studies that much more important.

All 161 AE missions were extracted from the United States Transportation Command (TRANSCOM) Regulating and Command and Control Evacuation System (TRAC²ES) database. Despite data limitations, certain observations could be made. The stereotypic MWD was a middle-aged, male German Shepherd serving as an Army E-6, usually suffering from Disease, Non-Battle Injury (DNBI); evacuated Routine precedence out of United States Central Command for United States European Command aboard a C-17 for a 6⁺-hour flight; generally considered ambulatory and Not Seriously Ill; and, arriving most commonly for Diagnosis & Treatment or Surgery.

The DNBI dogs made up 72% of recorded missions with musculoskeletal (mostly hip/spine and limb/joint) and gastrointestinal (mostly liver/spleen and colon/stomach) issues predominating. Battle injured (BI) dogs most commonly suffered gunshot wounds to the extremity requiring preflight surgery. The DNBI dogs were flown primarily for Diagnosis & Treatment; the BI dogs flew for Rehabilitation. Twenty-six dogs flew two successive AE missions. The DNBI dogs' ultimate final disposition included both adoption and death; the BI dogs' ultimate final disposition included only adoption.

In order to minimize inflight risk from physiological stressors, the TVFS employed both aircraft and canine prescriptions. Few aircraft interventions were prescribed (mostly "no remain overnights"). Of the canine interventions, muzzles, kennels, attendants, and medications dominated. There were no differences in prescribing for the DNBI and BI dogs, excepting a significantly greater number of veterinary medical attendants assigned to BI dogs. Notably, 29 dogs flew with either a veterinary technician (11%) or a veterinarian (8%); handlers routinely flew with the dogs.

These observations coupled with the TVFS prescription profiles suggested a six-step clinical validation algorithm the TVFS might employ to systematically and coherently approach a MWD requiring AE. *Step 1* involves physiologic considerations and countermeasures. *Step 2* looks at tissue oxygen delivery (DO₂). Interestingly, given several reasonable assumptions, a well-conditioned MWD will probably not drop below the critical DO₂ (~9.8 ml O₂/kg/min), short of exsanguination and/or cabin decompression. *Step 3* consists of theater veterinarian consultation. *Step 4* mandates flight safety. *Step 5* considers medical attendant assignment. And, *Step 6* assures all parties communicate. A toolkit to facilitate this 6-step validation process was developed and is provided in Appendix C.

In conclusion, this study was the initial examination of the AE of MWDs. As such, it should be foundational for future MWD research targeted specifically at potential AE-related

morbidity and mortality. In addition, looking at AE outcomes with and without veterinary care training for AE and CCATT crews is vital. Furthermore, MWDs should be included in AE planning for any given mission. For instance, the long haul AE mission out of AFRICOM. Moreover, as long as the MWD is integral to the ground mission, technological advances in human AE should always include the MWD. Good examples here would be the employment of veterinary telemedicine, autonomous inflight care, and remotely piloted vehicle AE. Lastly, at a more basic level, future research might well include determining the specific critical tissue oxygen delivery (DO_{2crit}) for MWDs. The extant DO_{2crit} of 9.8 ml O_2 /kg/min was determined in mongrel dogs (14-17 kg). (Cain, 1965; Cain, 1977) The MWD is a highly trained German Shepherd or Belgian Malinois (~32 kg) whose DO_{2crit} may not be altogether extrapolated from mongrel dogs.

2.0 INTRODUCTION/BACKGROUND

“The capability that military working dogs bring to the fight cannot be replicated by man or machine. By all measures of performance, their yield outperforms any asset we have in our inventory. Our Army would be remiss if we failed to invest more in this incredibly valuable resource.”

--- General David H. Petraeus (8 February 2008)
(Crippen, 2012)

Dogs have been with humans almost from the beginning. The dog is the first and oldest domestic animal dating back some 12,000 years. Indeed, dogs have been subjects of sculptors, poets, and writers since ancient times. (von Stephanitz, 1923) Consequently, it is of no surprise that dogs would accompany humans into battle.

At any given time, there are over 500 military working dogs (MWDs) deployed worldwide and during the years in Iraq and Afghanistan upwards of 2,700⁺ dogs were deployed (Goodavage, 2012; Paterniti, 2014; Dufour, 2015). These dogs, on occasion, require veterinary care as well as aeromedical evacuation (AE). This report describes the AE of MWDs.

Up until relatively recently, MWDs have been referred to as war dogs. War dogs have been part of military conflict dating back to the ancient days of Persia, Babylonia, and Assyria. Additionally, both the ancient Greeks and Romans fielded specially trained attack dogs. (English, 2000; Lemish, 2008) In fact, the Romans organized the very first Army field units of attack dogs. (Downey, 1955) This practice continued throughout the Middle Ages and into the New World. While the Spanish conquistadors found greyhound attack dogs a formidable force multiplier in South America, the British colonists of North America found dogs much less useful. (Mastromarino, 1984; Lemish, 2008) Back in Europe, Napoleon Bonaparte recognized and was the first to take advantage of the dogs’ special senses, especially the superior hearing and olfaction of sentry dogs. Since that time, European countries have embraced the military dog (English, 2000).

In America, Native Americans widely employed dogs for sentry and pack duty (e.g., travois pullers), not to mention tracking game. In addition, dogs served as pets, ceremonial/religious sacrifices, and foodstuffs. (Fact Sheet, 1948; Mastromarino, 1984; Lemish, 2008) However, dogs were not regularly welcomed into the colonial military ranks. This, despite the exhortations of Benjamin Franklin, “Dogs should be used against the Indians. They should be large, strong and fierce; and every dog led in a slip string, to prevent their tiring themselves by running out and in...In case of meeting a party of the enemy, the dogs are all then to be turned loose and set on...This was the Spanish method of guarding their marches.” (Downey, 1955; Mastromarino, 1984) In fact, prior to World War I, war dogs were only sporadically employed, the best documented instance being the Civil War where prison attack dogs, the occasional messenger dogs, and sentry dogs saw action. (Downey, 1955; Lemish, 2008)

When the United States entered World War I, war dogs were well entrenched throughout Europe, valued assets by all combatants. There were around 30,000 German and around 15,000 French war dogs, most as sentry, messenger, ambulance, or draft dogs. Interestingly, Jack Russell terriers were particularly effective in ridding trenches of rats. (von Stephanitz, 1923; Fact Sheet, 1948; Waller, 1958; Lemish, 2008) Although, there was a rapid call for American war dogs, hostilities ceased well before a serious organized effort materialized. With the war’s end, the interest in war dogs waned and all but disappeared until 1942 and World War II.

At that time, a singular visionary, Mrs. Milton (Alene) Erlanger was instrumental in bringing the American dog into war. Shortly after Pearl Harbor, she telephoned noted veteran newspaperman, Roland Kilbon, who wrote a very popular canine column for the *New York Sun*. She said, "The dog game must play its part in this thing. Other countries have used dogs in their Armies for years and ours has not. We've got to do it. Just think what dogs can do guarding forts, munition plants, and other such places." (**Downey, 1955, p. 16**) Kilbon arranged several meetings with prominent dog enthusiasts, leading to the formation of Dogs for Defense with Mrs. Erlanger its temporary Chairman. Harry I. Caesar, Director of the American Kennel Club, with his high-profile influence, was persuaded to become its President. Mrs. Erlanger then became its Director of Finance. The challenge they had accepted flew in the face of a decided lack of American war dog military tradition. (**Downey, 1955**)

Concurrently, the American Theater Wing (Wing) aspired to contribute to the war effort, perhaps by way of purchase and donation of an airplane. Helen Mencken, star of stage and radio, was recruited to broker the offer to the Quartermaster General, Major General Edmund B. Gregory. Since Army regulations prohibited such a gift and no other project was readily available, General Gregory declined the offer. (**Downey, 1955**)

Enter Lieutenant Colonel Clifford G. Smith of the Quartermaster Corps' Plant Protection Division, who, impressed with a few well-placed sentry dog demonstrations, recommended a sentry dog trial. General Gregory recalled Helen Mencken, offering to the Wing the task of recruiting 200 dogs. She accepted. Recognizing the Wing's lack of expertise, its public relations counsel, Sidney Wain, suggested Dogs for Defense for the job. The Wing leadership agreed, giving the dog recruitment to Dogs for Defense and turning their attention to other highly successful war time ventures such as the Stage Door Canteen. (**Downey, 1955; Waller, 1958**)

In March 1942, Colonel Russell A. Osmun, Chief of the Plant Protection Division, tasked Dogs for Defense to supply the 200 dogs. By December 1942, the Quartermaster General declared his initial needs estimate for the Army, Marine Corps, and Coast Guard to be 125,000 dogs which, it turned out, was a gross overestimate. Dogs for Defense took to the challenge and, throughout the war, was the prime vendor of dogs. These dogs were donated, for the most part, by civilian individuals and families. All told, some 17,000-20,000 dogs were donated. Of those, just over 10,000 were trained. (**Fact Sheet, 1948; Downey, 1955; Galer, 2009; Short History, 2015**)

American war dogs served as casualty dogs, draft dogs, messenger dogs, pack dogs, scout dogs, sentry dogs, sledge dogs, and trail dogs (**Livestock, 1945**). The vast majority were sentry dogs (9,000⁺) with well over 3,000 dogs on coastal watch with the Coast Guard, followed in order of frequency by scout dogs (~600), sledge/pack dogs (~270), messenger dogs (~150), and mine dogs (~140). (**Fact Sheet, 1948; Rogak, 2011**) Scout dogs proved spectacularly effective in the Pacific, while mine dogs proved just as spectacularly ineffective. (**Lemish, 2008**)

Thirty-two different breeds were accepted for duty.¹ (**War Dogs, 1943; Lemish, 2008**) Eventually, several preferred breeds emerged: German Shepherd Dogs, Belgian Sheep Dogs, Doberman Pinschers, Collies, Siberian Huskies, Malamutes, and Eskimos. (**Waller, 1958;**

¹ *Airedale Terrier, Alaskan Malamute, Belgian Sheep Dog, Bouvier de Flandres, Boxer, Briard, Bull Mastiff, Chesapeake Bay Dog, Collie, Curley-coated Retriever, Dalmatian, Doberman-Pinscher, English Springer Spaniel, Eskimo, Flat-coated Retriever, German Shepherd Dog, German Short-haired Pointer, Giant Schnauzer, Great Dane, Great Pyrenees, Irish Setter, Irish Water Spaniel, Labrador Retriever, Newfoundland, Norwegian Elkhound, Pointer, Rottweiler, St. Bernard, Samoyede, Siberian Husky, Standard Poodle, and Wire-haired Pointing Griffon.* (**War Dogs, 1943**)

Lemish, 2008) Nevertheless, it took until the Korean War to hone in on one specific breed, the German Shepherd. Today, the German Shepherd remains a mainstay of the MWD world, though the Belgian Malinois has joined the mix and has well proven its worth. **(English, 2000; Lemish, 2008)**

During the Korean War, war dogs, transitioning to the MWD moniker, numbered around 1,500. Before the Korean War, MWDs were mainly sentry dogs. By war's end, they were mostly scout dogs. In Vietnam, some 4,000 MWDs served, acting not only as sentries, but also scouts, trackers, tunnel detectors, and mine detectors. Over the 84,000⁺ missions, they were directly responsible for 4,000⁺ enemy killed, 1,000⁺ enemy captured, 1,000,000⁺ pounds of rice and corn seized, 3,000⁺ mortars and munitions discovered, and 2,000⁺ tunnels and bunkers detected. Needless to say, the MWD cemented its role as a well proven and exceedingly valuable military commodity. **(Waller, 1958; Lemish, 2008; Rogak, 2011; Short History, 2015)**

In contrast to the Quartermaster Corps' initially humble training site in Front Royal, Virginia back in World War II, today's training site at Lackland AFB, Texas, under the United States Air Force's (USAF) 341st Training Squadron, is a sophisticated and well-honed operation responsible for training all Department of Defense (DoD) MWDs, as well as many other government dogs. Spread over 7,000 acres, it is the temporary training home for 340⁺ dogs and 460⁺ handlers annually. Unlike earlier times, today's training focuses on only four separate jobs – patrol/explosives detection, patrol/narcotics detection, patrol only, and detection only – with the expectation the MWD will have a 10-year career. And, during that career, a MWD could well save up to 150-200 lives. Indeed, it has been estimated explosive detecting dogs saved well over 10,000 lives in Vietnam. **(English, 2000; Mott, 2003; Toffoli, 2006; Baker, 2009; Galer, 2009; Goodavage, 2012; Quinn, 2014)**

Today's MWD most commonly comes from Europe, costing between \$3,000-\$4,500 each. From 2001-2014, approximately \$941,000 was spent acquiring MWDs. Defraying some of the initial outlay is Lackland's internal Belgian Malinois breeding program, begun in 1998, which produces upwards of 100⁺ puppies each year; unfortunately, only about half are suitable for training. Once trained, however, the MWD is valued at \$11,000-\$40,000 and an explosive detection dog may command as high as \$80,000. **(Mott, 2003; Roughton, 2011; Rogak, 2011; Goodavage, 2012; Newcomer, 2012; Quinn, 2014; Dufour, 2015)**

A typical MWD begins training at 12-36 months of age, is in good health without chronic conditions, of good temperament and behavior, environmentally stable, and trainable. These highly selected dogs, unlike their World War II counterparts, currently washout from training only about 10% of the time. Single purpose training, either patrol or detection, lasts around 90 days, while dual purpose training, patrol and detection, lasts around 120 days. **(Goodavage, 2012)**

Detection training depends primarily on the MWD's superior sense of smell. Within the dog's snout is an area called the olfactory recess consisting of a labyrinth of paper-thin bones lined with millions of scent receptors. Estimates suggest 125-250 million receptors as opposed to the human's 5-15 million receptors. In addition, the MWD's olfactory region of the brain is four-times larger than the human's. As a result, the MWD is anywhere from 10,000-100,000 times better at detecting scents. In fact, a good explosive detection dog is said to smell as little as 0.025 grams of explosive. **(Mott, 2003; Lemish, 2008; Rogak, 2011; Paterniti, 2014)**

Patrol training depends not only on the MWD's superior sense of smell, but also on its superior hearing and eyesight. The MWD can hear sounds up to 35,000 Hz while the human's upper limit is 20,000 Hz. In addition, the MWD can shut down its inner ear, thus seriously

damping out background noise. And, with seventeen ear muscles, the MWD can focus its ears for the best sound reception. As for its eyesight, the MWD has many more rods than cones making for superb night vision. Also, within its eye is the tapetum, a membrane around the retina that reflects light back onto the retina; this offers up a second sighting chance, proffering exceptional motion detection. **(Lemish, 2008; Goodavage, 2012)**

During a MWD's long career, its medical needs are met by Army veterinarians. These dogs, while generally in excellent health, are subject to a number of maladies. Most prevalent are trauma, heat stress, and gastric dilatation and volvulus. In addition, they infrequently suffer other medical conditions such as cystitis, lymphoma, pheochromocytoma, and fibrocartilagenous embolism. **(Toffoli, 2006)** And, increasingly, post-traumatic stress disorder is seen. **(Perry, 2012; Kershaw, 2015)** Any of these entities require prompt veterinary care.

With the extent of MWD deployments and the relative dearth of Army veterinarians, it is not unusual when one of these disorders presents, a veterinarian is not readily available. Consequently, the animal must be either transported to the nearest veterinarian or the human medical personnel must engage care. This happened not too long ago when a 5.5-year-old German Shepherd developed excessive drooling, tachycardia, lethargy, and a firm distended abdomen. No veterinarian was nearby, and the dog was too ill to transport; it would most likely have died during transport. The human surgical team, in communication with a veterinarian, emergently detorsed a 360-degree volvulus and performed a gastropexy. Six hours later, the animal was flown to Bagram (approximately 225 miles) for follow-up veterinary care; the dog fully recovered **(Beitler, 2011)**.

Even with a day-long Army veterinarian-shadowing program and studying a number of published articles, human medical personnel cannot and should not function as veterinarians, mandating the evacuation of an ailing or emergently treated MWD to a veterinarian. **(Vogelsang, 2007; Taylor, 2008; Taylor, 2009; Taylor, 2010; Beitler, 2011)** And, should the dog be unable to early return to its deployment, further evacuation back to the United States is inevitable.

Such major illness or injury that might require AE does happen. Baker et al have described 29 MWDs that suffered gunshot wounds (2003-2009) during Operations Iraqi Freedom and Enduring Freedom. The most common injury sites were the thorax (50%) and the extremity (46%). Of the 18 deaths, a full 17 had catastrophic non-survivable injuries (thoracic and head wounds predominating). Of the 11 survivors, all returned to full duty. **(Baker, 2013)** In another review, Takara and Harrell looked at the noncombat-related problems encountered in deployed MWDs from January 2009 through August 2010. The bulk of visits fell into four categories: dermatologic issues – 25% (e.g., otitis externa), soft tissue trauma - 21% (e.g., foot pad/paw injuries), alimentary system illness - 17% (e.g., diarrhea), and musculoskeletal system conditions - 14% (e.g., hind limb disease). **(Takara, 2014)** Both reports described MWD illnesses and injuries expected within the deployed veterinarian's clinical practice. Neither report addressed the AE of MWDs. Within these narratives, the only aerial evacuation mentioned was that by helicopter; no regulated, fixed-wing AE was discussed. Indeed, no serious literature focused on AE for MWDs, either tactical or strategic, could be found. In fact, there was just one serious reference to MWD evacuation identified, concentrating only on the requisite use of physical and chemical restraints in the "evacuation process." **(Jennings, 1983)**

Furthermore, in the original 2012 Joint Theater Trauma System MWD Clinical Practice Guideline (CPG), there were 18 appendices and 106 pages of material focused on the care of the MWD as provided by non-veterinary human healthcare providers. It definitively stated "HCPs [Health Care Providers] should only perform medical or surgical procedures necessary to

manage problems that immediately threaten life, limb, or eyesight, and to prepare the dog for evacuation to definitive veterinary care.” (CPG, 2012, p. 2) However, throughout the entire document the topic of clinical validation for AE by the Theater Validating Flight Surgeon (TVFS) remained unaddressed. (CPG, 2012) Likewise, in the most recent 2018 iteration of the MWD CPG, the emphasis rightfully retained human healthcare provider treatment of MWDs. In this iteration, evacuation was mentioned 41 times with nine instances of Urgent precedence (i.e., abdominal trauma, gastric dilatation and volvulus, heat stroke, hypothermia with an associated hypocoagulopathy, scorpion sting, spider bite, snake envenomation, intraocular foreign body, and acute spinal cord injury) and one instance of Routine precedence (i.e., canine post-traumatic stress disorder) discussed. Again, clinical validation of the MWD by the TVFS remained unaddressed. (CPG, 2018)

Clearly, the MWD is a valued member of the US military and is frequently going into very dangerous settings where its human partner is poorly outfitted to contribute (witness the dog’s superior senses of smell, hearing, and eyesight). Examples include explosive detection, drug detection, and adversary detection. Its training is resource intense including personnel, equipment, and supplies. Its welfare is an extremely high priority of our Army veterinary colleagues, such a high priority that human medical officers are expected to participate in their care when necessary. In addition, the MWD regularly undergoes regulated AE. In a preliminary inquiry, from 2004 through 2011, 58 instances of MWD transport were discovered. This finding prompted the present study where all instances of MWD regulated-AE from 2001 through 2015 were collected, the injuries/illnesses characterized, AE missions described, battle-injured dogs compared to disease, non-battle injured dogs, ultimate dispositions discussed, and the actions of the TVFS considered. From these data and analyses, a systematic approach to the clinical validation of a MWD for fixed-wing, regulated AE was formulated and is offered.

3.0 METHODS

This research consisted of a retrospective record review, descriptive analysis, and Battle Injury (BI) versus Disease, Non-Battle Injury (DNBI) comparisons of all regulated MWD evacuations. The *retrospective record review* extracted all canine AE transports as contained within the Transportation Command (TRANSCOM) Regulating and Command and Control Evacuation System (TRAC²ES) between January 2001 through December 2015 (15 years). Search terms included MWD, military working dog, canine, and K-9. Primary data fields included cite number, name, tattoo, age, gender, weight, rank, service, duty station, unit home, originating ICAO (International Civil Aviation Organization) code, originating facility, origin theater, destination ICAO code, destination theater, actual departure date, actual arrival date, aircraft type, injury type, criticality status, primary diagnosis, secondary diagnosis, remarks, primary medical specialty, secondary medical specialty, history, precedence, classification code, classification, reason regulated, altitude restriction, RON (remain overnight), stops, number of attendants, number of medical attendants, number of non-medical attendants, heart rate, respiratory rate, temperature, white blood cell count, blood pressure, SpO₂ (percent oxygen saturation of hemoglobin by pulse oximetry), FiO₂ (oxygen fraction of inspired air), oxygen, ventilator, medical equipment, consciousness status, and medications and dosing (up to 8 different medications for a single dog). Extracted from “history” and “remarks” were the secondary, or derived, data fields of breed, gender, tattoo, problem (trauma, non-trauma), trauma (blunt, penetrating), trauma etiology, trauma location, non-trauma system affected, non-trauma specialty, diagnoses, symptoms, laboratory exams, radiological exams, surgery, drain insertion, transfusion, transfusion characteristics, supplemental oxygen, activity level, attendants, kennel, muzzle, reason for AE, and any extra pertinent information. Nationality, veterinary record availability, and final disposition of the MWDs were obtained from the veterinary staff and records found at the 341st Training Squadron, Department of Defense Military Working Dog Veterinary Service, Lackland Air Force Base, Texas.

Based on a cursory search several years prior to the study (time frame → 2004-2011) that turned up 58 transports, well over 100 cases were expected. Descriptive analysis of the entire evacuated population of MWDs was deemed appropriate as no previous studies were discovered to base power and sample size calculations. However, notional power estimates (using percentages from the 161 transported canines in the TRAC²ES database) looking at Battle Injury versus Disease, Non-Battle Injury suggested adequate power (~98%) to detect a difference, if one existed, between the two groups (alpha error = 0.05; beta error = 0.20). Effect size, based on the weighted difference between the two groups, was estimated to be moderate at 0.54 (Hedge’s g). Again, since there was no precedent in this research arena, these estimates, though somewhat speculative, were considered acceptable.

The *descriptive analysis* was used to characterize the data with particular emphasis on the nature of injuries/illnesses requiring transport, flight stressors pertinent to those injuries, transport specifics (e.g., cabin altitude, duration), and TVFS prescriptions --- for continuous variables, mean and standard deviation were recorded; for categorical variables, number and percent.

In addition, the dichotomy between *BI versus DNBI* was explored. The two groups were characterized: for continuous variables, mean and standard deviation were reported; for categorical variables, number and percent. Comparisons between the two groups employed the independent means t-statistic for continuous variables and chi-square statistic for categorical

variables. Statistical significance was set *a priori* at $p < 0.05$. Throughout the study, data were cleaned, merged, and analyzed using IBM SPSS Statistics for Windows, Version 20.0 (Armonk, NY: IBM Corp).

As an aside, during prep for this study, several Flight Nurses and a Flight Technician were questioned about their experiences with the AE of MWDs. Their anecdotal stories were summarized in the Results to provide an introductory qualitative, non-systematic foil for this study. It is assumed that the dogs discussed were among the 135 in this study, as the study was all-inclusive. (*personal communications*, see **Acknowledgements**)

Importantly, this research was thoroughly reviewed and determined exempt from oversight by both the Air Force Research Laboratory (Wright-Patterson Air Force Base, Ohio) and the Department of Defense Military Working Dog Veterinary Service (Lackland Air Force Base, Texas) Institutional Animal Care and Use Committees.

4.0 RESULTS

4.1 Introduction

Anecdotally, MWDs appear to have been evacuated under the care of both Critical Care Air Transport Teams (CCATT) and AE crews. Of 11 verbally re-counted transports, five flew via CCATT-crewed (gunshot wounds = 2; post-traumatic stress disorder = 1; unknown = 2) and six flew via AE-crewed (improvised explosive wounds = 1; closed skull fracture = 1; dental issue = 1; unknown = 3) missions. Only one dog flew muzzled; six flew inside a kennel; two were on a litter; and, one flew within the lower half of a kennel. All flew with handlers; none flew with either a veterinarian or veterinary technician. But for one flight, all were intertheater. The sole intratheater flight was from Kandahar to Bagram flying the famed MWD Lucca. (see **Appendix A**) (*personal communications*, see **Acknowledgements**)

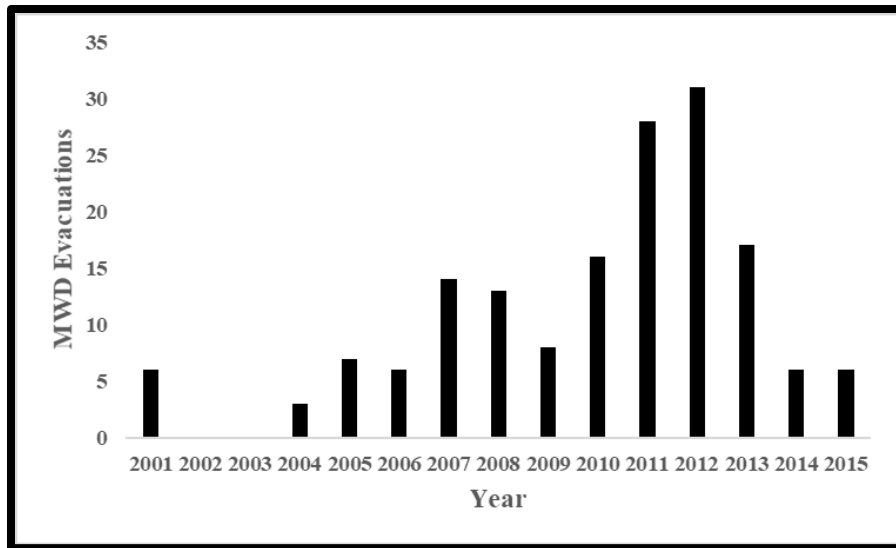
Three dogs required IVs for the administration of pain and sedation medications. One dog's handler was administering hydromorphone as needed while, at the same time, a continuous infusion mix of ketamine and benzodiazepine was delivered. The dog became non-responsive. The handler notified the AE crew who requested CCATT assistance. Evaluation revealed shallow breathing and > 4-seconds gum-based capillary refill. The infusion was stopped and "blow by" oxygen initiated. Intubation, though considered, proved unnecessary. After about an 8-hour flight, this same dog underwent a postflight hind leg amputation. No other inflight issues were described though one dog did attempt, unsuccessfully, to "nip" a CCATT nurse while she was attaching a power adapter to an infusion pump. These two incidents prompted two recommendations: assign a veterinary technician to any AE mission manifesting a critically ill/injured MWD and direct hand-off communication between the MWD treatment team and the AE and/or CCATT crew(s). (*personal communications*, see **Acknowledgements**)

Interestingly, the MWDs were routinely described as the "star of the show." Indeed, they appeared to have a "calming effect" on their fellow human passengers. (*personal communications*, see **Acknowledgements**)

These anecdotes emphasize the need for a more systematic accounting of the AE experience of MWDs. This report is the initial systematic examination of that AE experience.

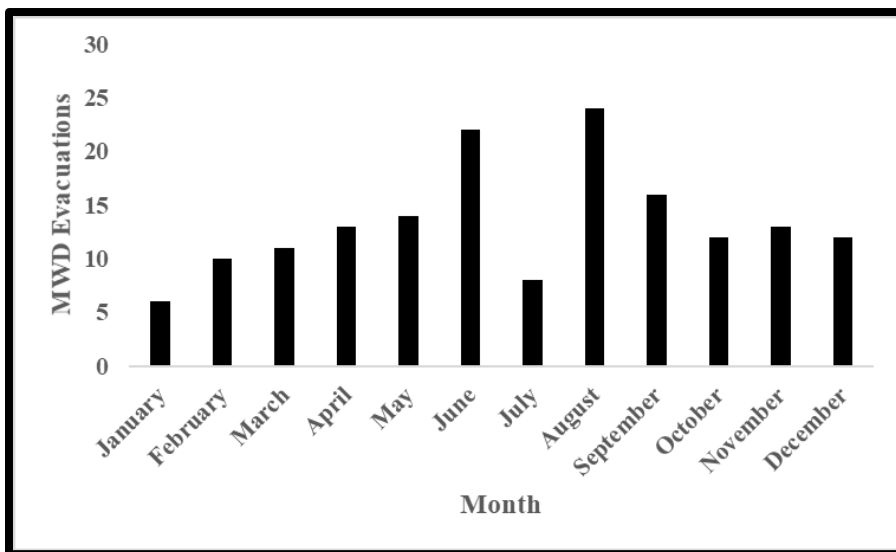
Aeromedical evacuations of MWDs from 2001-2015 were extracted from the TRAC²ES database. A total of 135 MWDs were evacuated. Of these, 26 underwent two separate and successive transports, making for a total of 161 transports. Seven dogs were not US military: Australian (2), British (2), Czech (1), coalition (1), US contractor (1); four were Battle Injury and three were Disease, Non-Battle Injury; and, three of the seven dogs underwent two separate and successive transports (Australian – 2; British – 1), all secondary to gunshot wounds. Although these seven dogs were non-US, their ten transports were USAF-regulated. It was felt that their experience added to the overall MWD AE picture and was, thusly, included in the overall analysis.

Over this 15-year period, around 11 MWDs were evacuated per annum (mean = 10.7, SD = 9.2) with the fewest transports during 2002 and 2003 (0%) and the most transports during 2011 and 2012 (37%). See **Figure 1**. The busiest months were June and August (29% of transports), with an overall average of 13 in a month (mean = 13.4, SD = 5.2). See **Figure 2**. Notably, there was about one MWD evacuated for every 1,000 human evacuations, making such transports uncommon, but not at all rare.



Note: MWD (Military Working Dog).

Figure 1. MWD Evacuations per Annum from 2001-2015



Note: MWD (Military Working Dog).

Figure 2. MWD Evacuations by Month from 2001-2015

4.2 MWD Demographics

Although breed went unrecorded 84% of the time, when recorded, German Shepherds predominated (77%). The average age leaned towards 6 years (mean = 5.6 years, SD = 2.0 years) and there was an almost 5-fold number of male dogs evacuated over female dogs (most likely reflecting the overall military predilection for male MWDs). Practically half of the MWDs were from the Army with the Air Force and Navy each at around 16% and the Marines at 13%. Excepting 2 warrant officer dogs, all were enlisted, with the most favored rank being E-6

(34%) followed by E-5, then E-7, then E-4. A full 65% of the MWDs originated out of Central Command (CENTCOM), most from Operation Enduring Freedom in Afghanistan. Both European Command (EUCOM) and Pacific Command (PACOM) had a considerable number of MWD evacuations, with a smattering from Southern Command (SOUTHCOM), Africa Command (AFRICOM), and the Continental United States (CONUS). See **Table 1** and **Table 2** for details.

Table 1. MWD Demographics

MWD Demographics		
Characteristic	Number (%)	Mean (SD; range)
Breed		
German Shepherd	20 (12)	
Dutch Shepherd	3 (2)	
Belgian Malinois	1 (< 1)	
Labrador	2 (1)	
Not Recorded	135 (84)	
Age (years)		5.6 (2.0; 2-11)
Gender		
Male	131 (81)	
Female	27 (17)	
Not Recorded	3 (2)	
Service		
Army	79 (49)	
Navy	25 (16)	
Air Force	25 (16)	
Marine	21 (13)	
NATO	2 (1)	
Other	6 (4)	
Not Recorded	3 (2)	
Grade		
E-1	8 (5)	
E-3	1 (< 1)	
E-4	11 (7)	
E-5	32 (20)	
E-6	55 (34)	
E-7	18 (11)	
E-8	4 (3)	
W-3	2 (1)	
Other	2 (1)	
Not Recorded	28 (17)	

Note: The MWD is assigned rank, usually enlisted and generally one level above its handler. E refers to enlisted ranks; W refers to warrant officer ranks. NATO (North Atlantic Treaty Organization).

4.3 MWD AE Mission Dynamics

The vast majority of missions took place aboard a C-17, C-130, or KC-135, with 60⁺% of recorded missions aboard the C-17. At the same time, the average mission duration was just over 6 hours (mean = 6.2 hours, SD = 3.5 hours). This makes sense, as the principal theater of origin was CENTCOM and the main destination theater was EUROM. The major theater routings, as expected, were CENTCOM to EUROM, EUROM to CONUS, and PACOM to PACOM. Over half of the MWDs were ambulatory (58%) with the remainder being assigned a litter (41%). See **Table 2** and **Table 3** for details.

Table 2. MWD AE Mission Dynamics

MWD AE Mission Dynamics		
Characteristic	Number (%)	Mean (SD; range)
Aircraft		
C-17	72 (45)	
C-130	22 (14)	
KC-135	20 (12)	
Other	9 (6)	
Not Recorded	38 (24)	
Origin Theater		
CENTCOM	105 (65)	
-- OEF	67 (64)	
-- OIF	26 (25)	
-- Other	13 (12)	
EUROM	28 (17)	
PACOM	22 (14)	
SOUTHCAM	3 (2)	
AFRICOM	2 (1)	
CONUS	1 (< 1)	
Flight Time (hours)*		6.2 (3.5; 0.5-14.8)
Destination Theater		
EUROM	85 (53)	
CONUS	38 (24)	
PACOM	19 (12)	
CENTCOM	17 (11)	
Not Recorded	2 (1)	
Precedence		
Routine	116 (72)	
Priority	35 (22)	
Urgent	9 (6)	
Not Recorded	1 (< 1)	
Classification**		
Ambulatory	94 (58)	
Litter	65 (41)	
Other	2 (1)	

Note: * Flights exceeding 15 hours were considered outliers, most probably mis-recorded, and not considered in this analysis. ** The ten Classification Codes recorded were collapsed into the three categories as listed. % (percent), SD (standard deviation), CENTCOM (Central Command), OEF (Operation Enduring Freedom), OIF (Operation Iraqi Freedom), EUROM (European Command), PACOM (Pacific Command), SOUTHCAM (Southern Command), AFRICOM (Africa Command), CONUS (Continental United States).

Table 3. MWD AE Missions --- Origin Theater to Destination Theater

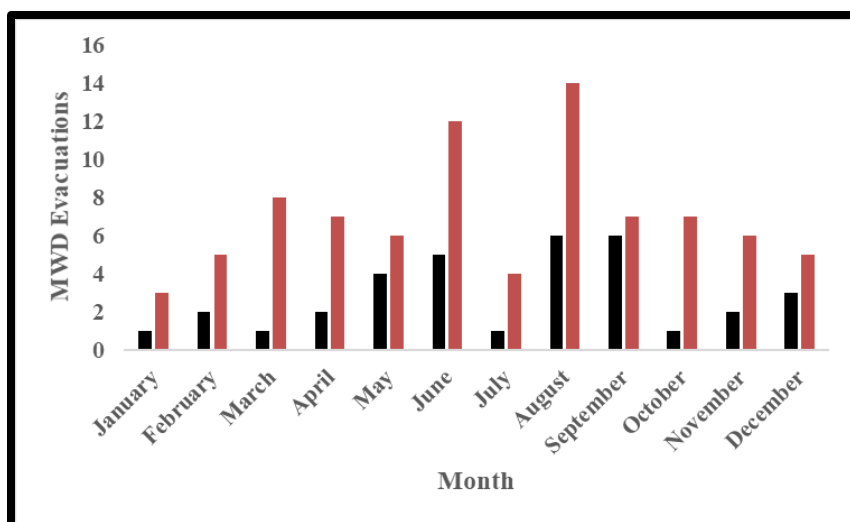
MWD Origin-Destination Theaters						
Origin Theater	Destination Theater					TOTALS
	CENTCOM	CONUS	EUCOM	PACOM	Not Recorded	
AFRICOM	---	---	2	---	---	2
CENTCOM	16	10	78	1	---	105
CONUS	---	1	---	---	---	1
EUCOM	1	21	5	---	1	28
PACOM	---	3	---	18	1	22
SOUTHCOM	---	3	---	---	---	3
TOTALS	17	38	85	19	2	161

Note: AFRICOM (Africa Command), CENTCOM (Central Command), CONUS (Continental United States), EUCOM (European Command), PACOM (Pacific Command), SOUTHCOM (Southern Command).

4.4 MWD Clinical Characteristics

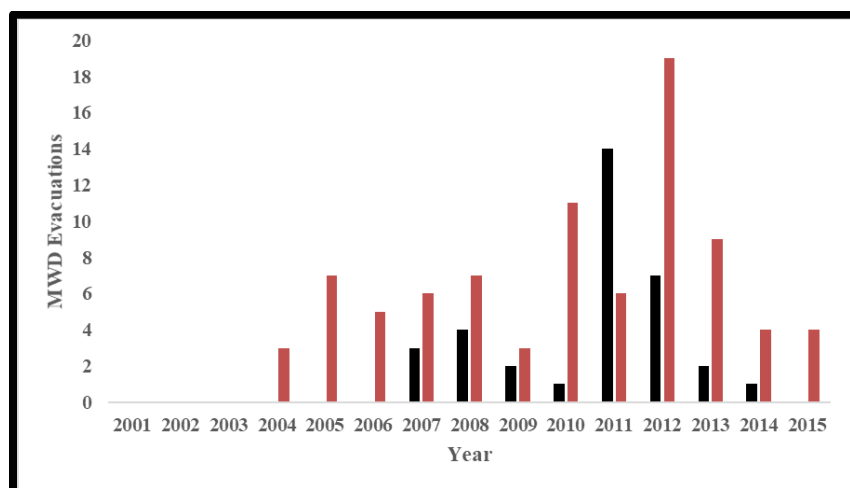
In looking at the clinical aspects of transported MWDs, it was reasonable to separate the dogs suffering Battle Injury (BI) and from those with Disease, Non-Battle Injury (DNBI). This permitted a ready comparison between the two groups. The Demographics (Section 4.2) and AE Mission Characteristics (Section 4.3) were very similar in both groups. The only significant differences between groups were Service and Classification, respectively. Army and Marine dogs suffered significantly more BI (chi-square = 12.99, df = 6, N = 118, p = 0.043), reflecting their combat mission, while the BI dogs travelled significantly more on litters than the DNBI dogs (chi-square = 6.70, df = 2, N = 118, p = 0.035), reflecting the more debilitating nature of gunshot and improvised explosive device (IED) injuries.

Not unexpectedly, BI dogs suffered significantly more trauma than DNBI dogs (chi-square = 37.9, df = 1, N = 115, p < 0.00001). In addition, the trauma suffered in BI dogs was significantly tilted towards penetrating while that of the DNBI dogs was blunt (chi-square = 26.4, df = 1, N = 53, p < 0.00001). Out of the 161 transports, 34 were for BI and 84 for DNBI; 27% went unrecorded. In no month did AE for BI exceed that for DNBI and only in 2011 did the transports for BI exceed those for DNBI. See **Figure 3** and **Figure 4**.



Note: Black bars denote BI. Red bars denote DNBI. MWD (Military Working Dog), BI (Battle Injury), DNBI (Disease, Non-Battle Injury).

Figure 3. BI & DNBI Evacuations by Month from 2001-2015



Note: Black bars denote BI. Red bars denote DNBI. MWD (Military Working Dog), BI (Battle Injury), DNBI (Disease, Non-Battle Injury).

Figure 4. BI & DNBI Evacuations per Annum from 2001-2015

Vital signs between the two groups proved essentially identical as the significant differences in heart rate and temperature were not clinically relevant. However, the number of symptoms recorded, laboratory measurements, radiological exams, surgeries performed, and transfusions were significantly different. Not unexpectedly, the non-trauma aspects of DNBI dominated in all these categories while the trauma aspects of BI dominated in all these categories. This was especially noticeable with laboratory measurements and radiological exams more pronounced with DNBI dogs, where diagnostic investigation was integral to the dog's care. On the other hand, surgeries were more pronounced with BI dogs, where immediate treatment of injuries from gunshot wounds and IEDs were requisite. See **Table 4** for details.

Table 4. MWD Clinical Characteristics --- Part 1

MWD Clinical Characteristics --- Part 1			
Characteristic	Battle Injury (n = 34)	Disease, Non-Battle Injury (n = 84)	
Vital Signs	Mean (SD; range; n)		
Heart Rate (beats/min)	82 (21; 45-130; 28)	97 (21; 56-160; 63)	0.002 ^b
Respiratory Rate (breaths/min)	27 (13; 12-60; 24)	31 (16; 12-100; 46)	0.241 ^b
Temperature (degrees F)	100.5 (1.2; 97-103; 28)	101.2 (1.1; 97.9-103.5; 48)	0.013 ^b
White Blood Cell Count (cells/ul)	12.6 (5.0; 10-19; 8)	13.3 (6.5; 6.9-29; 16)	0.805 ^b
Systolic Blood Pressure (mmHg)	131 (20; 114-173; 13)	140 (43; 95-272;16)	0.474 ^b
Diastolic Blood Pressure (mmHg)	80 (14; 62-109; 13)	80 (22; 51-136; 16)	0.967 ^b
	Number (%)		P-value
Symptoms (n = 96)			
Trauma	19 (95)	14 (18)	< 0.005 ^a
Non-Trauma	1 (5)	62 (82)	
Laboratory Exams (n = 18)			
Trauma	1 (100)	1 (6)	< 0.005 ^a
Non-Trauma	0 (0)	16 (94)	
Radiological Exams (n = 41)			
Trauma	10 (100)	3 (10)	< 0.005 ^a
Non-Trauma	0 (0)	28 (90)	
Surgeries (n = 55)			
Trauma	30 (94)	6 (26)	< 0.005 ^a
Non-Trauma	2 (6)	17 (74)	
Transfusions (n = 8)			
Trauma	5 (100)	0 (0)	0.005 ^a
Non-Trauma	0 (0)	3 (100)	

Note: **Bold** denotes statistical significance. ^a Statistical analyses employed the chi-square statistic. ^b Statistical analyses employed the independent means t-test statistic. min (minute), F (Fahrenheit), ul (microliter), mmHg (pressure in millimeters Mercury).

Whether BI or DNBI, most of the MWDs were conscious and not seriously ill. In fact, most traveled Routine precedence. Indeed, there was no clear statistical difference in clinical gravity between the BI and DNBI dogs. In short, it appeared that the MWD was evacuated in *stable*, rather than *stabilized* (aka clinically volatile) condition. And, the most common Reason for Transport was to place the dog in the closest facility with appropriate veterinary capability. See **Table 5** for details.

Table 5. MWD Clinical Characteristics --- Part 2

MWD Clinical Characteristics --- Part 2			
Characteristic	Battle Injury (n = 34)	Disease, Non-Battle Injury (n = 84)	P-value
	Number (%)		
Consciousness (n = 80)			
Conscious	24 (89)	47 (89)	0.999 ^a
Semi-conscious	2 (7)	4 (8)	
Unconscious	1 (4)	2 (4)	
Criticality (n = 78)			
Not Seriously Ill	17 (59)	33 (67)	0.437 ^a
Seriously Ill	12 (41)	13 (27)	
Very Seriously Ill	---	3 (6)	
Precedence (n = 118)			
Routine	22 (65)	61 (73)	0.402 ^a
Priority	11 (32)	18 (21)	
Urgent	1 (3)	5 (6)	
Reason for Transport (n = 118)			
Closest with Capability	31 (91)	70 (83)	0.875 ^a
Outpatient	2 (6)	5 (6)	
Continuity of Treatment	1 (3)	4 (5)	
Nearest MTF to Duty Station	---	2 (2)	
Recovered, Returning to Duty	---	2 (2)	
Other	---	1 (1)	

Note: ^a Statistical analyses employed the chi-square statistic. MTF (medical treatment facility) --- with MWDs, the facility was usually a veterinary hospital.

Further breaking down the Reason for Transport was enlightening. Diagnosis & Treatment predominated in DNBI dogs followed by Surgery; whereas, Rehabilitation was the primary transport reason in BI dogs. See **Table 6** for details.

Table 6. Detailed Reasons for Transporting MWDs

Detailed Reasons for Transporting MWDs		
	Battle Injury (n = 34)	Disease, Non-Battle Injury (n = 84)
	Number (%)	
Closest with Capability		
Diagnosis & Treatment	1 (6)	28 (50)
Surgery	4 (25)	14 (25)
Rehabilitation	8 (50)	7 (13)
Higher Level of Care	2 (13)	5 (9)
Chemotherapy	---	1 (2)
Consultation	1 (6)	---
Dental	---	1 (2)
Outpatient		
Rehabilitation	1 (50)	2 (50)
Diagnosis & Treatment	1 (50)	---
Higher Level of Care	---	1 (25)
Surgery	---	1 (25)
Continuity of Treatment		
Diagnosis & Treatment	---	4 (100)
Higher Level of Care	1 (100)	---
Nearest MTF to Duty Station		
Diagnosis & Treatment	---	1 (50)
Rehabilitation	---	1 (50)
Recovered, Returning to Duty		
Return to Duty	---	1 (100)
Other		
Surgery	---	1 (100)

Note: MTF (medical treatment facility) --- usually a veterinary hospital.

4.5 MWD Transport Diagnoses

Transport diagnoses fell into two categories --- trauma and non-trauma. Trauma was designated either BI or NBI (Non-Battle Injury). It was further characterized as either penetrating or blunt in origin. When it came to BI, penetrating bullets or shrapnel/fragments were most commonly at fault, usually resulted in wounds or fractures, and often affected the extremities with a goodly number to the head, chest, and pelvis. In contrast, NBI were almost exclusively blunt in origin, the result of falls or jumps, generally limited to the extremities, and mainly consisted of fractures. See **Table 7** for details.

Table 7. MWD Trauma Diagnoses

MWD Trauma				
	Battle Injury (n = 34)		Non-Battle Injury (DNBI: n = 84)	
	Penetrating	Blunt	Penetrating	Blunt
	Number (%)			
Location				
Extremity	10 (40)	1 (17)	1 (100)	17 (81)
Head	5 (20)	1 (17)	---	2 (10)
Chest	5 (20)	1 (17)	---	1 (5)
Pelvis	5 (20)	2 (34)	---	---
Abdomen	---	1 (17)	---	---
Back	---	---	---	1 (5)
Etiology				
Gunshot	19 (76)	---	---	---
Improvised Explosive Device	5 (20)	3 (50)	---	1 (6)
Fall	---	1 (17)	---	4 (25)
Jump	---	---	1 (50)	4 (25)
Repetitive Motion	---	---	---	3 (19)
Training	---	---	---	2 (13)
Stab	---	---	1 (50)	---
Shrapnel	1 (4)	---	---	---
Club	---	1 (17)	---	---
Burns	---	---	---	1 (6)
Dog Fight	---	---	---	1 (6)
Motor Vehicle Accident	---	1 (17)	---	---
Impact (Diagnosis)				
Fracture	15 (34)	8 (73)	---	14 (58)
Wound	23 (52)	---	1 (100)	---
Other	6 (14)	3 (27)	---	10 (42)

Note: DNBI (Disease, Non-Battle Injury)

Non-trauma disease was limited to DNBI dogs. Most of the non-trauma AE diagnoses stemmed from musculoskeletal system, specifically hip/spine and limb/joint disease. Though not as frequent, gastrointestinal issues often arose and necessitated AE. Most commonly seen were liver/spleen and colonic disease. Despite routine prophylactic gastropexy, gastric dilatation and volvulus was even seen. See **Table 8** for details.

Table 8. MWD Non-Trauma Diagnoses

MWD Non-Trauma		
System	Disease	
Number (%)		
Musculoskeletal	23 (31)	
	Hip/spine disease	10 (43)
	Limb/joint issue	7 (30)
	Heat injury/Rhabdomyolysis	4 (17)
	Muscle abscess	2 (9)
Gastrointestinal	19 (26)	
	Liver/spleen disease	6 (32)
	Colonic disease	5 (26)
	Gastric dilatation & volvulus	4 (21)
	Tumor mass	2 (11)
	Pancreas issue	1 (5)
	Foreign body ingestion	1 (5)
Genitourinary	8 (11)	
	Renal dysfunction/failure	3 (38)
	Hydronephrosis/hydroureter	2 (25)
	Tumor mass	1 (13)
	Prostamegaly	1 (13)
	Hematuria	1 (13)
Cardiac	6 (8)	
	Pericardial effusion	4 (67)
	Cardiomyopathy	1 (17)
	Ascites	1 (17)
Otolaryngologic	6 (8)	
	Mandibular mass	2 (33)
	Hemorrhage	2(33)
	Otitis media	1 (17)
	Epistaxis	1 (17)
Psychiatric	6 (8)	
	Post-Traumatic Stress Disorder	4 (67)
	Anxiety	2 (33)
Hematologic	2 (3)	
	Mast cell tumor	1 (50)
	Pancytopenia	1 (50)
Central Nervous	2 (3)	
	Ataxia	1 (50)
	Blindness	1 (50)
Dermatology	2 (3)	
	Abdominal wall tear	2 (100)

4.6 MWD Successive Transports

Successive transports took place in 26 MWDs. Time between transports proved not significant (t-statistic = -1.09, df = 10, 14, p = 0.285) between BI and DNBI dogs (mean = 4.0 days, SD = 3.2 days, range = 1-10 days versus mean = 5.4 days, SD = 3.2 days, range = 0-11 days, respectively). Routine-Routine made up 58% of the successive transports, Priority-Priority 19%, and split precedence 23%. There was no statistical difference between BI and DNBI precedence profiles (chi-square = 3.60, df = 2, N = 29, p = 0.165). See **Table 9** for details.

Table 9. Precedence for MWDs with Successive Transports

MWDs with Successive Evacuations				
Precedence	Battle Injury (n = 34)		Disease, Non-Battle Injury (n = 84)	
	Penetrating	Blunt	Trauma	Non-Trauma
	Number (%)			
Routine - Routine	4 (36)	1 (9)	6 (40)	4 (27)
Priority - Priority	4 (36)	---	---	1 (7)
Urgent - Urgent	---	---	---	---
Split				
Urgent to Routine	---	---	1 (7)	---
Priority to Routine	---	---	1 (7)	2 (13)
Routine to Urgent	1 (9)	---	---	---
Routine to Priority	1 (9)	---	---	---

Note: Chi-square analysis looked at BI versus DNBI comparing the relatively non-serious Routine-Routine group of dogs to the relatively serious, collapsed Priority-Priority/Urgent-Urgent group to the collapsed Split precedence group. BI (Battle Injury), DNBI (Disease, Non-Battle Injury).

The majority of successive transports came out of CENTCOM (88%). For all intents and purposes, there was no difference in the number of BI dogs (11) versus the number of DNBI dogs (12). Penetrating trauma dominated the BI dogs, while DNBI dogs were evenly divided between trauma and non-trauma. PACOM made up 12% of the successive transports; all 3 were DNBI. There was no difference in precedence profile between the two Commands (chi-square = 2.49, df = 1, N = 26, p = 0.115). See **Table 10** for details.

Table 10. Originating Theater for and Injury/Illness in MWDs with Successive Transports

MWDs with Successive Evacuations				
Theater (Illness/Injury)	Battle Injury (n = 34)		Disease, Non-Battle Injury (n = 84)	
	Penetrating	Blunt	Trauma	Non-Trauma
	Number (%)			
CENTCOM (n = 23)	10 (43)	1 (4)	6 (26)	6 (26)
Gunshot	7 (70)	---	---	---
Improvised Explosive Device	3 (30)	---	---	---
Fracture (fall)	---	1 (100)	---	---
Fracture (various)	---	---	5 (83)	---
Burn	---	---	1 (17)	---
Salivary Gland Bleeding	---	---	---	1 (17)
Pericardial Effusion	---	---	---	1 (17)
Megacolon	---	---	---	1 (17)
Renal Failure	---	---	---	1 (17)
Heat Injury	---	---	---	1 (17)
Abscess (unspecified)	---	---	---	1 (17)
PACOM (n = 3)	---	---	2 (67)	1 (33)
Cruciate Tear	---	---	1 (33)	---
Fracture (toe)	---	---	1 (33)	---
Lumbosacral Disease	---	---	---	1 (33)

Note: CENTCOM (Central Command), PACOM (Pacific Command).

4.7 MWD Transport Prescriptions

In order to fly these ill and injured MWDs, the TVFS employed both aircraft and canine prescriptions. Aircraft prescriptions were generally uncommon, documented in only 44 dogs, and were much more limited in scope than with humans, with only 3 specific prescriptions documented. The most frequent aircraft prescription was No RONS (remain overnights). The least frequent was cabin altitude restriction (CAR). In fact, only 3 dogs (2%) flew with a CAR -- a head-injured dog, a spinal cord compromised dog, and a dog with paralytic ileus.

Canine prescriptions were more varied. Here, the TVFS prescribed both the Precedence and Classification for each dog, dependent on the clinical situation. From there, the prescriptions fell into five categories: Equipment, Dog-Specific Equipment, Diet, Attendants, and Medications. Medications will be separately considered in the next section.

The most commonly seen Equipment with BI dogs were drains and infusion pumps; with DNBI dogs, blankets. Kennels and muzzles, Dog-Specific Equipment, were regular accompaniments to both BI and DNBI dogs. Diet for both BI and DNBI dogs was usually regular. And, both BI and DNBI dogs commonly traveled with one non-medical attendant, their handler (75%), this finding in direct contradistinction to the mandate “MWDs must never be transported without a handler.” (CPG, 2018) Interestingly, veterinary technicians (11%), veterinarians (7%), and even flight nurses (1%) occasionally attended the MWD, making multiple attendants (16%) not uncommon. No MWD had a CCATT team specifically prescribed for its care. See **Table 11** for details.

Table 11. TVFS Prescriptions – Aircraft & Canine Interventions

TVFS Prescriptions - Interventions				
	Overall Count (n = 161)	Battle Injury (n = 34)	Disease, Non-Battle Injury (n = 84)	
Aircraft Prescriptions	Number (%)			P-value
No RONs	30 (68)	13 (72)	11 (73)	0.982 ^a
No Stops	11 (25)	4 (22)	3 (20)	
Cabin Altitude Restriction	3 (7)	1 (6)	1 (7)	
- 5,000 feet	2 (67)	1 (100)	1 (50)	
- 6,000 feet	1 (33)	---	1 (50)	
Canine Prescriptions	Number (%)			P-value
Equipment				
- Drains	13 (32)	10 (37)	2 (18)	0.118 ^a
- Infusion Pump	12 (29)	10 (37)	1 (9)	
- Blanket	12 (29)	5 (19)	6 (55)	
- Monitor	2 (5)	1 (4)	1 (9)	
- Suction	2 (5)	1 (4)	1 (9)	
Dog-Specific Equipment				
- Kennel	78 (68)	13 (52)	49 (74)	0.121 ^a
- Muzzle	20 (17)	7 (28)	9 (14)	
- Both	17 (15)	5 (20)	8 (12)	
Diet				
- Regular	90 (74)	21 (70)	48 (76)	0.093 ^a
- NPO	12 (10)	4 (13)	5 (8)	
- Soft	5 (4)	4 (13)	1 (2)	
- Clear Liquid	1 (< 1)	---	1 (2)	
- Other	13 (11)	1 (3)	8 (13)	
Attendants				
	Medical [39 (20)]			
-- Veterinary Technician	17 (55)	11 (69)	4 (44)	0.238 ^a
-- Veterinarian	12 (39)	3 (19)	5 (56)	
-- Nurse	2 (7)	2 (13)	---	
	Non-Medical [121 (80)]			
-- Handler	121 (100)	26 (100)	67 (100)	0.0008 ^a *
Attendants per Dog				
- One (1)	102 (80)	15 (50)	62 (90)	0.00003 ^a
- Two (2)	25 (20)	14 (47)	7 (10)	
- Three (3)	1 (< 1)	1 (3)	---	

Note: **Bold** denotes statistical significance. ^a Statistical analyses employed the chi-square statistic. * This analysis compared the Attendant Profile (Medical versus Non-Medical Attendant) between the BI and DNBI dogs. In this case, BI dogs had significantly more Medical Attendants than the DNBI dogs. RON (remain overnight), NPO (*non per os* aka nothing by mouth).

4.8 MWD Medication Prescriptions

When it came to medications, nine different drug classes were prescribed, in order of frequency: Antimicrobials (32%), Opioids (25%), Non-Steroidal Anti-Inflammatory Agents (22%), Sedatives (8%), Gastrointestinal Agents (6%), Nutritional Supplements (3%),

Neuropsychiatric Agents (2%), and Steroids (1%), with an assortment of medications under Miscellaneous (3%). Within the database, each dog could potentially have eight different medications recorded. Interestingly, two of the BI dogs had seven medications and one even had eight, while none of the DNBI dogs had more than six medications. Overall, there was essentially no difference in the distribution of medication types between BI and DNBI dogs. See **Table 12** for details.

Table 12. TVFS Prescriptions --- Medication Classes

TVFS Prescriptions - Medication Classes			
	Battle Injury (n = 34)	Disease, Non-Battle Injury (n = 84)	
Class	Number (%)		P-value
Antimicrobials (n = 61)	31 (32)	30 (31)	0.265 ^a
Opioids (n = 48)	26 (27)	22 (22)	
Non-Steroidal Anti-Inflammatory Agents (n = 42)	17 (18)	25 (26)	
Sedatives (n = 16)	11 (11)	5 (5)	
Gastrointestinal Agents (n = 11)	6 (6)	5 (5)	
Other (n = 16)	5 (5)	11 (11)	
Nutritional Supplements (n = 6)	---	6 (6)	
Neuropsychiatric Agents (n = 4)	4 (4)	---	
Steroids (n = 1)	---	1 (1)	
Miscellaneous (n = 5)	1 (1)	4 (4)	

Note: ^a Statistical analyses employed the chi-square statistic.

Generally, any medication prescribed was administered by the attendant, in most cases the MWD's handler. Analgesics were routine whether Non-Steroidal Anti-Inflammatory Agents (NSAIDs), such as carprofen, or Opioids, like tramadol. By far, the most commonly prescribed medications were carprofen, in 53 dogs (33%), and tramadol, in 33 dogs (20%). Opioids and Sedatives were occasionally paired with their respective reversing agents, naloxone and atipamezole, in case the dog became unresponsive. In addition, Antimicrobials were frequently dosed. At least 15 different antibiotics were recorded with amoxicillin/clavulanate and enrofloxacin being the two most common, each prescribed in 16 dogs (10%). Four MWDs were evacuated with Post-Traumatic Stress Disorder which explains the use of Neuropsychiatric Agents. And, supplemental oxygen was prescribed in 8 dogs (5%). Two of those dogs (1%) flew intubated attended by the treating veterinarian, one with a ventilator and one with a face mask. Sadly, the ventilator-accompanied dog did not survive his severe non-traumatic intracranial hemorrhage, presumptive sequelae of a cobra envenomation. See **Table 13** for details.

Table 13. TVFS Prescriptions --- Entire Medication Listing

TVFS Prescriptions - Entire Medication Listing			
	Number (%)		Number (%)
Antimicrobials (n = 76)		Sedatives (n = 17)	
Amoxicillin/Clavulanate	16 (21)	Dexmedetomidine	6 (35)
Enrofloxacin	16 (21)	Alprazolam ^f	4 (24)
Cephalexin	13 (17)	Ketamine ^g	2 (12)
Cefazolin	7 (9)	Trazadone	2 (12)
Doxycycline	5 (7)	Diazepam	1 (6)
Ampicillin/Sulbactam	5 (7)	Midazolam	1 (6)
Ampicillin	3 (4)	Atipamezole*	1 (6)
Metronidazole	2 (3)	Nutritional Supplements (n = 7)	
Animax Ointment ^{a,c}	2 (3)	Dasuquin	1 (14)
BNP Ointment	2 (3)	Cosequin	1 (14)
Gentamicin	1 (1)	Duralactin	1 (14)
Clindamycin	1 (1)	Denosyl	1 (14)
Ciprofloxacin	1 (1)	Dermcaps	1 (14)
Amantadine ^b	1 (1)	Lactulose	1 (14)
Otomax ^c	1 (1)	V-capsules	1 (14)
Opioids (n = 60)		Neuropsychiatrics (n = 4)	
Tramadol ^d	33 (55)	Fluoxetine	2 (50)
Hydromorphone	13 (22)	Buspirone	1 (25)
Fentanyl	7 (12)	Gabapentin	1 (25)
Buprenorphine	3 (5)	Steroids (n = 4)	
Butorphanol	2 (3)	Prednisolone	2 (50)
Morphine	1 (2)	Prednisone	1 (25)
Naloxone*	1 (2)	Dexamethasone	1 (25)
NSAIDs (n = 55)		Miscellaneous (n = 6)	
Carprofen	53 (96)	Diphenhydramine	1 (17)
Ketoprofen ^e	1 (2)	Propranolol	1 (17)
Metacam	1 (2)	Benazepril	1 (17)
GI Medications (n = 18)		Furosemide	1 (17)
Famotidine	5 (28)	Lidocaine	1 (17)
Ranitidine	4 (22)	Heparin	1 (17)
Omeprazole	2 (11)	Oxygen (n = 8)	
Sulcralfate	2 (11)	Intubated**	2 (25)
Sulfasalazine	2 (11)	Not Intubated	6 (75)
Ondansetron	1 (6)	-- Face Mask	3 (50)
Ursodiol	1 (6)	-- Blow By Oxygen	2 (33)
Metoclopramide	1 (6)	-- Nasal Canula	1 (17)

Note: ^a Animax has antimicrobial and antifungal activity. ^b Amantadine is a human anti-viral agent, but in dogs it is an analgesic, particularly useful in preventing wind-up pain. ^c Animax and Otomax have steroid components; they are primarily employed for ear infections and dermatologic issues. ^d Tramadol is seldom used today due to its variable absorption. ^e Ketoprofen is seldom used today as carprofen, galliprant, meloxicam, and deracoxib are much more effective. ^f Alprazolam, though a sedative, is more of an anxiolytic (e.g., noise). ^g Ketamine is useful for anesthesia as well as pain control. (^{a-g} *personal communication*, Dr. Lauren Shaughnessy, DVM) * Denotes reversal agents: naloxone for opioids and atipamezole for dexmedetomidine. ** Two dogs were intubated, one with a ventilator. NSAID (non-steroidal anti-inflammatory drug), GI (gastrointestinal).

4.9 MWD Dispositions

Of the 135 MWDs transported, 69 (51%) were eventually adopted and 34 (25%) died. Twelve (9%) had other sorts of documented outcomes while 20 (15%) went unrecorded. Though

the relationship between the AE flight, evacuation diagnosis, and subsequent outcome cannot be ascertained from the data collected in this study, it is nonetheless valuable to look at the dogs' final dispositions.

It is interesting to note that the sole outcome recorded for BI dogs was Adoption, most commonly with IED-injured dogs. Death was not recorded in any of the transported BI dogs.

The DNBI dogs' disposition profile differed significantly from that of the BI dogs (chi-square = 7.4, df = 2, N = 79, p = 0.025). Better than half saw Adoption with musculoskeletal issues dominating. In contrast to the BI dogs, not only did Death occur, but it was also the ultimate outcome in just under a third of dogs, with the musculoskeletal and gastrointestinal systems making up a full 40% of the AE moves for these dogs. See **Table 14** for details.

Table 14. MWD Dispositions

MWD Dispositions		
	Battle Injury (n = 34)	Disease, Non-Battle Injury (n = 84)
Long Term Outcome	Number (%)	
Adoption	11 (100)	39 (57)
IED	6 (60)	---
GSW	2 (20)	---
Fall/Club	2 (20)	---
Musculoskeletal	---	14 (45)
Gastrointestinal	---	5 (16)
Otolaryngologic	---	3 (10)
Central Nervous System	---	3 (10)
Genitourinary	---	2 (6)
PTSD	---	2 (6)
Cardiac	---	1 (3)
Dermatologic	---	1 (3)
Death	---	22 (32)
Musculoskeletal	---	4 (20)
Gastrointestinal	---	4 (20)
Cardiac	---	3 (15)
Hematological	---	3 (15)
Genitourinary	---	2 (10)
Central Nervous System	---	1 (5)
PTSD	---	1 (5)
Otolaryngologic	---	1 (5)
Pulmonary	---	1 (5)
Other	---	7 (10)
Musculoskeletal	---	2 (40)
Gastrointestinal	---	1 (20)
Genitourinary	---	1 (20)
Otolaryngologic	---	1 (20)

Note: IED (improvised explosive device), GSW (gunshot wound), PTSD (Post-Traumatic Stress Disorder).

5.0 DISCUSSION

5.1 Review of Results

This study was the first systematic examination of AE in MWDs. It was a retrospective review of 161 MWD transports (2001-2015). From these transports, the stereotypic MWD undergoing AE was determined: a middle-aged, male German Shepherd serving as an Army E-6, usually suffering from DNBI; evacuated Routine precedence out of CENTCOM for EUCOM aboard a C-17 for a 6⁺-hour flight; generally considered ambulatory and Not Seriously Ill; and, arriving most commonly for Diagnosis & Treatment or Surgery.

Although this characterization is useful, it is incomplete. A more detailed look at the BI-DNBI dichotomy proved much more valuable. Like humans (**Harmon, 2005**), DNBI dogs made up the bulk of AE transports (71%). In fact, every month saw DNBI predominate and, excepting 2011, every year saw DNBI predominate. Notably, May 1st of 2011 saw a spectacular special forces operation where a MWD, a Belgian Malinois named Cairo, was instrumental to finding and killing Osama bin Laden. Indeed, Cairo became something of a celebrity. (**Rogak, 2011**) Prior to that date, during the year 2011, there had been only one DNBI dog evacuation. Subsequent to that date, there were 14 BI dog evacuations, 9 from gunshot wounds all between June and September. Gunshot wound evacuations in the years before and following 2011 were sporadic, at best. Most likely, MWDs were specifically targeted as part of a concerted response to bin Laden's death. Such targeting is not unheard of and was common during the Vietnam War. (**Lemish, 2008**)

When AE was accessed, both DNBI and BI dogs were evacuated needing the closest facility with veterinarian capability. However, DNBI dogs were transported mostly for Diagnosis & Treatment while BI dogs were mostly transported for Rehabilitation. Upon boarding the AE aircraft, both the DNBI and BI dogs had essentially the same precedence and criticality profile. Even those dogs with separate, successive AE flights had similar precedence and criticality profiles. Moreover, whether it be a DNBI or BI dog on a single or successive AE flight(s), there were no demonstrated clinical differences in vital signs, suggesting the dogs were mostly clinically stable. Indeed, the fact that almost 75% of the dogs were transported Routine precedence reinforced the notion that MWDs were mostly evacuated in stable clinical condition.

For DNBI dogs, preflight laboratory and radiological examinations were a regular component of the Patient Movement Request, most probably because the dog presented with a multi-symptomatic, not-so-obvious problem requiring preflight investigation. The most common DNBI issues evacuated were musculoskeletal and gastrointestinal. With the harsh working environment of the MWD, musculoskeletal issues are to be expected. (**Takara, 2014**) Likewise, as most MWDs are larger dogs --- German Shepherds and Belgian Malinois dominate the ranks --- age-related musculoskeletal issues are well known and expected. (**Evans, 2007**) At the same time, these larger dogs with deep chests are subject to gastrointestinal maladies, especially gastric dilatation and volvulus. (**Jennings, 1992**) Even with routine prophylactic gastropexy seriously reducing the number of MWDs with gastric dilatation and volvulus, gastric bloat, quite dangerous in and of itself, can still occur. (*personal communication*, Lauren Shaughnessy, DVM) At the same time, other serious gastrointestinal issues regularly surface. (**Rogak, 2011**) As many of the musculoskeletal, gastrointestinal, genitourinary, and cardiac issues are not necessarily remediable, prognosis is often poor. This may well reflect the high percent of final disposition deaths (32%) seen with evacuated DNBI dogs.

Interestingly, outside of AE, the DNBI picture is not dissimilar. Over a 20-month period, the 1,350 non-combat veterinary dog visits in a combat zone consisted of dermatologic illness (25%), soft tissue trauma (21%), alimentary issues (17%), and musculoskeletal problems (14%). Most common were otitis externa, paw injuries, diarrhea, and hind limb disease, respectively. (Takara, 2014) The main difference appeared to be the non-AE, relatively non-serious dermatologic illness and soft tissue trauma --- those dogs were not evacuated.

Outside of AE, discharge from the military resulted mainly from behavior (38%), spinal cord and/or degenerative joint disease (37%), geriatric (6%), and heat stroke (4%). (Evans, 2007) In the AE dogs, musculoskeletal (45%), gastrointestinal (16%), otolaryngologic (10%), and central nervous system (10%) issues were associated with the bulk of adoptive dispositions; behavior did not play a role.

When it came to death, outside of AE, degenerative joint disease (19%), neoplasia (18%), spinal cord disease (16%), and geriatric (14%) appear to be the chief causes. (Moore, 2001) In fact, musculoskeletal disease was the leading cause of euthanasia. (Takara, 2014) With the AE dogs, musculoskeletal (20%), gastrointestinal (20%), cardiac (15%), and hematological disease (15%) were associated with an eventual death disposition.

For BI dogs, preflight laboratory and radiological examinations were not routine. Here, most probably, the reason being the obvious injury --- a bleeding wound or fractured extremity, the result of an IED or gunshot. Surgery, on the other hand, was a common preflight event. As veterinarians were not widely distributed, BI dogs sometimes required damage control, stabilizing surgery performed by human physicians. Evacuation to a veterinarian was then mandatory. (CPG, 2018)

Over a 6-year period during Operations Iraqi Freedom and Enduring Freedom, Baker et al studied 29 dogs with gunshot wounds. Eighteen had catastrophic, non-survivable injuries primarily to the thorax (50%) and head (33%). Those that survived suffered mainly extremity (55%) and thorax (36%) wounds; each of the four dogs with thoracic injuries required a chest tube. All survivors eventually returned to duty; median return-to-duty time was 90 days. (Baker, 2013)

The AE dogs mirrored these survivors. Gunshot wounds (61%) dominated as did extremity injuries (32%). And, the fact that the Baker et al survivors all returned to duty was consistent with AE dogs' exclusive association with adoptive disposition.

5.2 Validating MWDs for AE --- Findings & Algorithm

To manifest the MWD upon an AE flight, the TVFS must clinically validate the dog is "fit to fly." This section not only discusses the validation parameters prescribed in the 161 AE missions, but also offers up a systematic approach for evaluating a MWD for AE validation.

The TVFS's job is to ensure the physiological safety of any patient that is manifest on an AE flight, whether that be human or canine. In the case of dogs, the TVFS employs both aircraft and canine prescriptions to make that happen. Only a few aircraft interventions were prescribed, most likely because the TVFSs did not consider such prescriptions requisite. Those that were prescribed --- no remain overnights, no stops, and CAR --- are frequently associated with the need for swift unimpeded transport of the very seriously ill or injured. In only a small number of dogs were these interventions prescribed, most likely because only a few dogs were considered Very Seriously Ill. In fact, only three dogs were so designated. In toto, no aircraft prescribing differences were detected between the DNBI and BI dogs.

Likewise, when it came to the canine prescriptions, there was little difference between the DNBI and BI dogs. The sole difference between groups was seen with attendants. The BI dogs saw a significantly greater number of veterinary attendants (veterinarian, veterinary technician) than the DNBI dogs. As a consequence, the BI dogs were more likely to have assigned ≥ 2 attendants than the DNBI dogs. On the other hand, there was no significant difference between the DNBI and BI dogs in medical equipment, diet, muzzles, or kennels. Interestingly, BI dogs trended toward more drains and infusion pumps, probably reflecting their significantly greater number of trauma surgeries.

A large number of MWDs travelled with a kennel, a muzzle, or both. This, for the safety of the AE crews. In addition, most of the dogs travelled with a handler; per guidelines, all should have travelled with a handler. This, for the care and comfort of the dog and for the safety of the AE and CCATT crews. For the most part, unlike human patients, MWDs pose a certain level of threat to the AE and CCATT crews. Despite the anecdotal “calming effect” of the dogs, the potential threat cannot be ignored and must remain a focus for the TVFS.

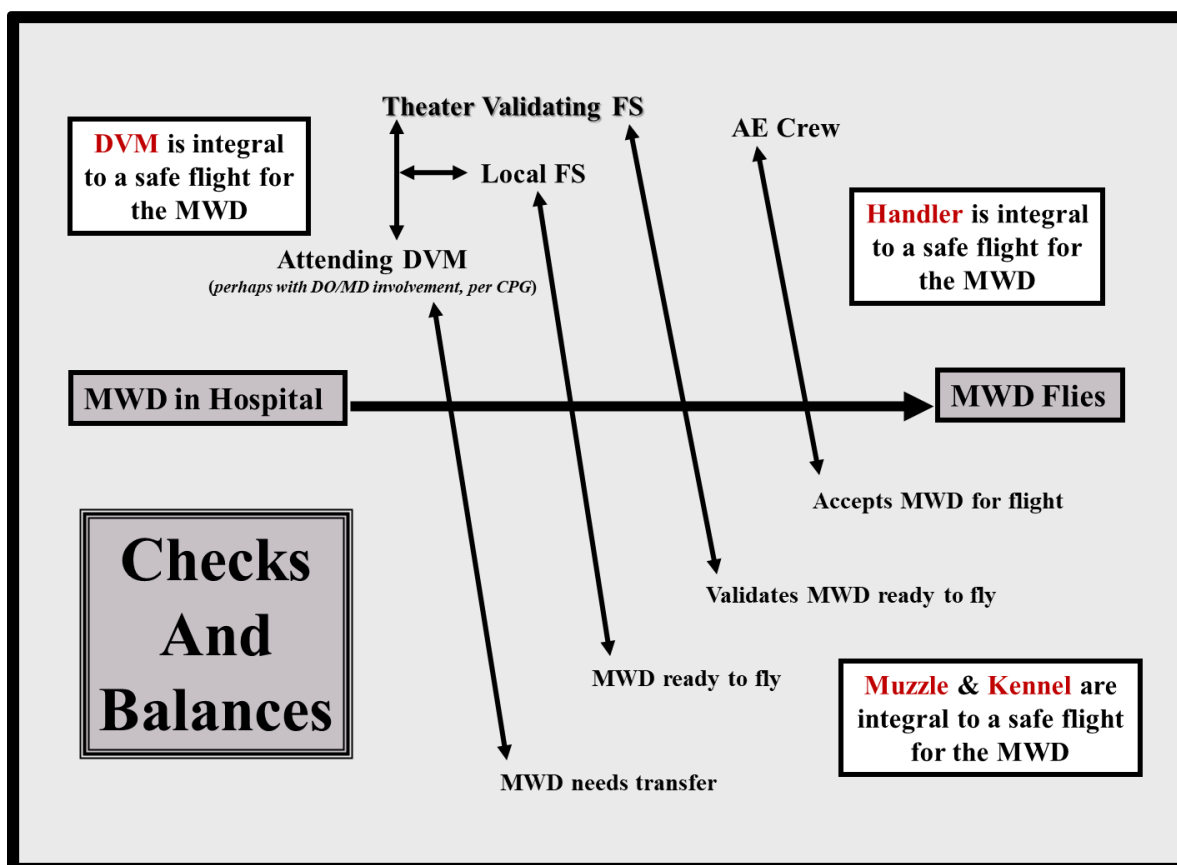
At the same time, the MWDs often travelled with medications, in most instances multiple medications. Antibiotics and analgesics (i.e., Opioids and NSAIDs) predominated. In addition, Gastrointestinal and Sedative agents were frequently seen.

It is important to note that medication dosing and use in dogs may be different from that in humans. Indeed, drugs are almost always dosed per kilogram in dogs. Additionally, bioavailability may be an issue. For instance, tramadol, the most frequently prescribed opioid for transported MWDs, sees little use in civilian veterinary practice due to its variable absorption. Moreover, side effects may be different in dogs. For instance, aspirin, a good analgesic, when dosed more than three consecutive days, almost invariably leads to gastric and/or duodenal ulcers. Similarly, steroids dosed in conjunction with NSAIDs must be avoided as the combination almost always guarantees a swift gastric ulcer. (*personal communication*, Lauren Shaughnessy, DVM;) Of all the dogs transported, no dog saw aspirin and only one dog took steroids and that uncombined with any NSAID.

Some medications employed have added effects not readily apparent to human clinicians. Gabapentin helps with nerve-based pain, but also has behavior control characteristics. Dexmedetomidine, while mostly a Sedative, has analgesic and behavior control properties. Ketamine, a sedative and anesthetic, is also an analgesic. Trazadone, a sedative, is also an anxiolytic. Diazepam and midazolam, both Sedatives, are also anesthetics. Amantadine, while a human anti-viral, often serves as a canine pain medicine, especially for neck and back pain. In addition, it also prevents the windup phenomenon blocking the development of both hyperalgesia and allodynia. (*personal communication*, Lauren Shaughnessy, DVM)

These examples bring into sharp focus the need for the TVFS to be in ready communication with the theater veterinarian. Consider this scenario. The attending physician and/or theater veterinarian decides that a MWD must be evacuated, whether it be for veterinary care, higher level care, and/or rehabilitation. (CPG, 2018) The local clearing flight surgeon then considers the dog’s ability to tolerate inflight stressors. If the dog is deemed a candidate for evacuation, a Patient Movement Request is submitted to TRAC²ES. The TVFS, generally a geographically separated Aerospace Medicine specialist, studies the request and assesses the dog’s readiness for flight. (Hurd, 2006) This is where ready communication with the theater veterinarian is imperative. Taking the theater veterinarian’s input, the attending’s input, the clearing flight surgeon’s input, the MWD Clinical CPG, and the MWD Transfusion CPG into consideration, the TVFS will tailor the flight to the dog in such a way as to mitigate/minimize the

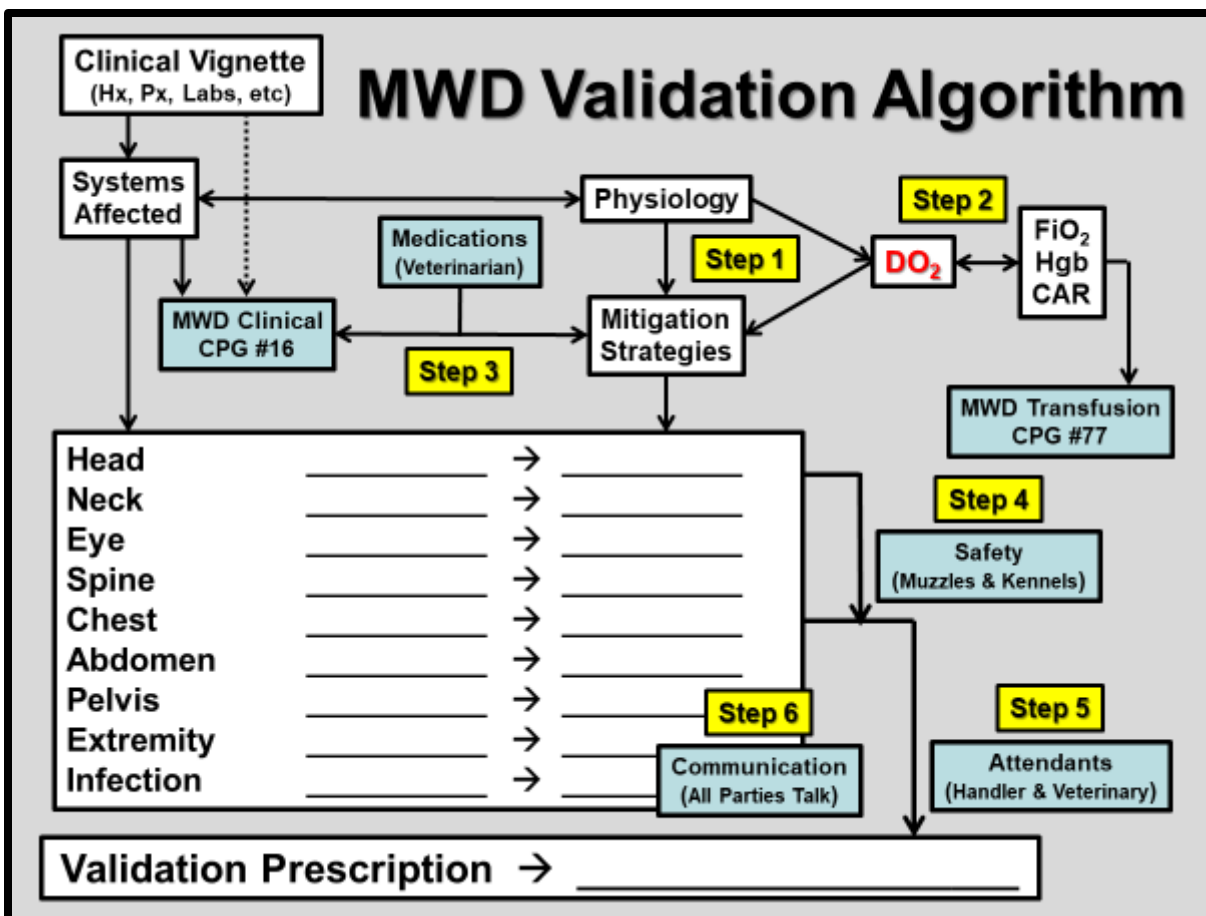
dog's vulnerability to flight-related risks. That is, the TVFS will ensure the MWD is "fit to fly." See **Figure 5**.



Note: DVM (Doctor of Veterinary Medicine), MWD (Military Working Dog), FS (Flight Surgeon), AE (aeromedical evacuation), CPG (clinical practice guideline), DO (Doctor of Osteopathy), MD (Doctor of Medicine).

Figure 5. Checks & Balances --- How the Physicians and Veterinarians Interact

In order to devise the best "fit to fly" scenario, the TVFS must approach clinical validation systematically. One methodology has been well described for human patients. (Butler, 2020a; Butler, 2020c) Taking this methodology and adapting it to the MWD produced the following six-step validation strategy. *Step 1* considers the clinical vignette, the dog's inflight physiology, and the various requisite countermeasures. *Step 2* evaluates the dog's tissue oxygen delivery (DO_2) in the face of the known canine critical DO_2 (DO_{2crit}). *Step 3* factors into the mix consultation with the theater veterinarian. *Step 4* deals with aircraft and crew safety in the face of a potentially dangerous dog. *Step 5* focuses on the dog's need for veterinary/medical attendants. *Step 6* assures all parties are communicating. Conjoining the results from each step permits a coherent and well-reasoned validation prescription for the MWD that should permit safe AE. This process can be diagrammed as an algorithm. See **Figure 6**.



Note: Hx (history), Px (physical exam), MWD (Military Working Dog), CPG (Clinical Practice Guideline), DO₂ (tissue oxygen delivery), FiO₂ (oxygen fraction of inspired air), Hgb (hemoglobin level), CAR (cabin altitude restriction).

Figure 6. MWD Validation Algorithm

Step 1 --- Physiologic Considerations and Countermeasures

The initial step in any clinical validation is an evaluation of the dog's clinical status. This begins with the clinical vignette entered into the Patient Movement Request. From the vignette, the TVFS determines clinical severity and potential threat to life, limb, or eyesight. Several articles and the latest MWD CPGs offer up extended discussions of veterinary treatment for a number of canine maladies subject to AE. (Vogelsang, 2007; Taylor, 2008; Taylor, 2009; Taylor, 2010; CPG, 2018; CPG, 2019) In addition, MWD veterinary care hands-on-training for human health care providers is extant and gradually becoming more routine for those providers that could encounter the ill/injured MWD without a local veterinarian. (Newcomer, 2012; Butcher, 2015; Dufour, 2015) In fact, there are even dog simulators available for such training. See Figure 7. Lacking that, shadowing a busy veterinarian prior to deployment is an option. (Beitler, 2011; *personal communication*, Michelle Bryce, DO and Lauren Shaughnessy,

DVM) Study of the CPGs and/or hands-on training better equip the TVFS in determining MWD clinical severity and potential threat to life, limb, and eyesight.



Note: This photograph is US government property and, as such, is not subject to copyright. It is a US Army photograph taken by Sgt. Daniel Butcher. (Butcher, 2012)

Figure 7. Training with MWD Simulator

With severity and threat in hand, Precedence, in this study most commonly Routine, and Classification, in this study most commonly ambulatory, are prescribed. The MWD CPG also offers up precedence guidance for the more seriously injured/ill dogs. Although the viewpoint is decidedly Army with tactical, rotary wing MEDEVAC (medical evacuation) either stated or implied, the precedence guidance remains valid for fixed wing, regulated AE and should be consulted. (CPG, 2018) For ease, the guidance has been extracted from the CPG and tabulated here. See **Table 15**.

Table 15. Precedence Guidance as Extracted from the MWD Clinical Practice Guideline

MWD Clinical Practice Guideline		
Clinical Situation	Recommended Precedence	CPG (page)
Abdominal Trauma --- AFAST score increasing	Urgent	50-51, 54
Gastric Dilatation and Volvulus --- emergent surgery in 2-4 hrs --- shock management	Urgent	59-60
Heat Stroke --- pending shock --- associated bleeding disorder	Urgent	67
Hypothermia --- pending shock --- associated bleeding disorder --- <i>afterdrop & rewarming shock</i>	Urgent	72
Envenomations* --- spiders (anti-venom) ---- diphenhydramine dosed	Urgent	78
--- scorpions (anti-venom) ---- diphenhydramine dosed	Urgent	78
--- snakes (anti-venom) ---- upper limb & torso bites ---- diphenhydramine/epinephrine dosed	Urgent	79
Eye Globe Foreign Body --- eye unbandaged	Urgent	101
Acute Spinal Cord Injury --- confined to kennel --- mild to moderate injury	Urgent	107
Blast Injury --- delayed onset signs & sxms	<i>asap</i>	83
Burns --- debridement needed	<i>evacuate</i> most likely Priority	86
Crush Injury/Crush Syndrome --- crush syndrome in 4-6 hrs ---- rhabdomyolysis & reperfusion injury	<i>evacuate</i> most likely Priority or Urgent	89
Open Fracture --- confined to kennel --- requires emergency surgery	<i>evacuate</i> most likely Priority or Urgent	91
Long Bone Fracture --- confined to kennel	<i>evacuate</i> most likely Priority or Urgent	93
Wounds --- wound vac equipment --- can wait until w/ Veterinarian	<i>evacuate</i> most likely Routine or Priority	96
Traumatic Brain Injury --- mild to moderate injury	<i>evacuate</i> most likely Priority or Urgent	111
Post-Traumatic Stress Disorder	Routine	115

Note: * In areas where envenomation is particularly high risk, antivenom, found at the Role II and/or Role III level of care, is highly regulated. When intravenously dosed, it can be life-saving. (CPG, 2018) AFAST (Abdominal Focused Assessment with Sonography for Trauma), hrs (hours), sxms (symptoms), asap (as soon as possible).

Also from the vignette, issues subject to the physiological stressors are identified. For instance, trapped thoracic air and the Boyle's Law effect of hypobaria. These stressors include acceleration/deceleration forces, excess noise, thermal instability, reduced humidity, unrelenting vibration, hypoxia, and hypobaria. (AFI 48-307 Vol 1, 2017) These stressors pose a *second hit* risk. The *first hit* being the initial injury/illness; the *second hit* being an added physiological insult. (Goodman, 2010; Goodman, 2011) The result, a potential for added canine morbidity and mortality. To counter *second hit* vulnerability, the TVFS intervenes with aircraft and/or canine prescriptions. An in-depth and detailed discussion of flight stressors' impact on human physiology can be found in the monograph *Physiological Foundation for Clinical Validation of Aeromedical Evacuation Patients*. (Butler, 2020c) Although it is specific to the human, the physiology discussed is not dissimilar to that of the dog and, in many instances, directly applicable. That monograph in conjunction with the following tables offer up guidance for prescribing both aircraft and canine interventions. See Table 16 and Table 17.

Table 16. TVFS Prescribing Considerations --- Inflight Physiological Stressor Counters

Prescribing Considerations for the TVFS with MWDs --- Inflight Physiological Stressors			
Inflight Stressors	Physiological Effects	Clinical Effects	Countermeasures
Gravity	acceleration-deceleration	hemodynamic flow	head-first load, tail-first load, head of bed elevation, long steady take-off, gentle climb out, long slow landing
Humidity	reduced humidity	dehydration	rehydration (oral, intravenous), humidified breathing gases
Temperature	thermal instability	hypothermia, hyperthermia	Hypothermia: upped aircraft heat , blankets (reflective, heated), warmed IV fluids; Hyperthermia: upped aircraft cooling, upped airflow , cool misting (ground)
Noise	temporary threshold shift	temporary hearing loss	earplugs, earmuffs
Vibration	vibration	increased pain intensified pressure points upped metabolic activity tissue edema	damping with cushions (preferably air bladder* or jelly/gel), seat/litter isolation (hammock-like), centered fuselage loading away from engines, aircraft routing
Barometric Pressure	pressure-volume-diameter changes -- <i>pneumocephalus</i>	trapped gas expansion -- agitation, confusion, vomiting (<i>tension pneumocephalus</i>)	supplemental O ₂ , head-first load, HOB elevation, long slow take-off & landing, CAR
	-- <i>pneumothorax</i>	-- dyspnea, no breath sounds, tympany (<i>tension pneumothorax</i>)	needle/chest tube, Heimlich valve/suction water seal, supplemental O ₂ , CAR
	-- <i>pneumomediastinum</i>	-- dyspnea, subcutaneous neck air (<i>"malignant" pneumomediastinum</i>)	bedrest, supplemental O ₂ , CAR
	-- <i>pneumopericardium</i>	-- shifting tympany, muffled heart sounds (<i>pericardial tamponade</i>)	bedrest, supplemental O ₂ , needle/tube drain suction water seal, CAR
	-- <i>pneumoperitoneum</i>	-- distention, tympany, oliguria (<i>abdominal compartment syndrome</i>)	gastric tube, supine, bedrest, supplemental O ₂ , CAR
	-- <i>pneumotaxis oculi</i>	-- peri-orbital/orbital emphysema	supplemental O ₂ , humidity, CAR
	-- <i>miscellaneous (equipment)</i>	ETT (or tracheostomy) cuffs: <i>tracheal pressure necrosis</i> bladder catheter balloon: <i>balloon rupture</i>	recline w/ HOB elevated, patching per veterinarian, supplemental O ₂ , slow take-off/landing, CAR
		closed system drains: <i>air and/or drain fluids into wound</i> ostomies: <i>ostomy dislodgement</i> air splints: <i>tourniquet-like effect</i>	air exchange with ascent/descent; air replacement w/ saline air replacement w/ saline (for balloon inflation, saline is generally preferred over air)
	venous gas emboli effect altered tissue dynamics -- <i>inflammatory upregulation</i> -- <i>Starling dysequilibrium</i>	evolved, infused (tissue edema effect)	venting drain on ascent/descent "burping" or "pinholing" appliance air exchange with ascent/descent; substitute plaster splint
	drop in DO₂	leaky vessels, tissue edema leaky vessels, tissue edema	CAR CAR
Oxygen	hypoxia	ischemia	CAR , transfusion, supplemental O ₂
	-- <i>injured bone & soft tissue</i>	tissue ischemia	supplemental O ₂ (at least ground level equivalent)
	-- <i>on supplemental oxygen</i>	hypoxia & ischemia	supplemental O ₂ (at least ground level equivalent)
	drop in DO₂	ischemia	CAR , transfusion, supplemental O ₂

Note: Red text denotes aircraft prescriptions. * Air bladder cushions provide better vibration damping, but are subject to asymmetric Boyle's Law expansion with hypobaria. Table is adapted from that in a US government publication and, as such, is not subject to copyright. (Butler, 2020c) IV (intravenous), CAR (cabin altitude restriction), O₂ (oxygen), ETT (endotracheal tube), DO₂ (tissue oxygen delivery).

Table 17. TVFS Prescribing Considerations --- Interventions

Prescribing Considerations for the TVFS with MWDs --- Interventions		
Prescriptive Category	Prescription	Clinical Setting
Medical Adjuncts	cardiac monitor; suction; pulse oximeter medical attendant (Veterinary tech, Veterinarian) CCATT (rarely ever)	Cardiac, Pulmonary, Critical Care Cardiac, Psychiatric Critical Care, Cardiac, Pulmonary
Medical Interventions	protect airway (orotracheal intubation) gastric tube supplemental O ₂ (blow-by, mask), ventilator (rarely ever) sedation/muzzle-kennel blood components (per CPG & direct consultation with Veterinarian) medications (direct consultation with Veterinarian) extended ground stabilizing (per CPG & direct consultation with Veterinarian) generally not an issue	Critical Care, Immediately Post-Operation Critical Care, Abdominal Surgery (GI, splenectomy) Critical Care, Pulmonary, Trauma, Burns Psychiatric Trauma, Anemia All Settings Trauma, Critical Care
Middle Ear Adjuncts	endotracheal (or tracheostomy) tube cuffs - cuff inflation w/ water chest tube - suction or Heimlich valve (no clamping of tubing) Jackson-Pratt™ drain - open on ascent and descent Hemovac™ drain - open on ascent and descent colostomy bag - decompress on ascent ("pinhole", "burp") bladder catheter - balloon inflation w/ water bivalve casts; control air splints cushions (litter, head, heel) blankets	All Settings Trauma, Pulmonary Trauma, Pulmonary Orthopedic, ENT, Thoracic, Abdominal Surgery Orthopedic, ENT, Thoracic, Abdominal Surgery Abdominal Surgery All Settings Orthopedic Neurologic, Orthopedic, Critical Care All Settings
Positioning Interventions	head first loading litter at aircraft airflow outlet valves head of bed elevation headrest to elevate and protect head	Neurologic, Ophthalmologic Infectious Neurologic, Ophthalmologic, ENT, Pulmonary, Cardiac Neurologic, Ophthalmologic, ENT
Safety	muzzle, kennel sedation handler	All Settings
Aircraft Manipulations	cabin altitude restriction full use of runway length modify rate of climb and descent (long, slow landings; long steady climbs) cabin airflow rates and patterns, control outlet airflow volumes aerial refueling no RONs (remain overnight); no stops	Trapped Gas, DO ₂ optimizing, Pulmonary, DCS Neurologic, Pulmonary, Cardiac Neurologic, Pulmonary, Cardiac Infectious Cabin Altitude Restriction, Extended AE Flight Critical Care, Cardiac, Pulmonary

Note: Peach highlights denote Safety Prescriptions. Gold highlights denote Aircraft Prescriptions. Table is adapted from that in a US government publication and, as such, is not subject to copyright. (Butler, 2020c) CCATT (Critical Care Air Transport Team), GI (gastrointestinal), O₂ (oxygen), CPG (Clinical Practice Guideline), ENT (Ears, Nose, Throat – Otolaryngology), DO₂ (tissue oxygen delivery), DCS (decompression sickness), RONs (remain overnights).

Step 2 --- Tissue Oxygen Delivery (DO₂)

The next step is to determine that inflight DO₂ will be well above the critical level requisite for tissue viability, the so-called DO_{2crit}. Unlike the human, where DO_{2crit} has not been fully defined, that is < 7.3 ml O₂/kg/min, the canine DO_{2crit} has been well defined at 9.8 ml O₂/kg/min. (Cain, 1965; Cain, 1977; Leiberian, 2000)

A number of physiological factors contribute to DO₂. Among them are the ambient barometric pressure (P_B), oxygen fraction of inspired air (FiO₂), hemoglobin oxygen content constant (HgbCC), hemoglobin level (Hgb), arterial hemoglobin oxygen saturation (SaO₂), plasma oxygen content, and cardiac output (CO). The HgbCC is an unchangeable constant (1.34 ml O₂/g Hgb in both dogs and humans). Plasma oxygen content is seldom of influence outside of the hyperbaric environment as it makes up only about 0.3 vol% of the overall 20 vol% arterial oxygen content. (Robinson, 2002; Stephenson, 2002; Poole, 2015; Reece, 2015; Butler, 2020c) Likewise, SaO₂ and CO seldom factor for the TVFS, as they have been optimized prior to flight by the attending clinicians. That leaves three factors within ready reach of the TVFS --- FiO₂ (via supplemental oxygen), hemoglobin level (via transfusion), and P_B (via CAR).

The impact from these three factors is well demonstrated within the following standard physiological equations. (Butler, 2020c) Definitional details for each equation can be found in **Appendix B**.

$$\text{Alveolar Gas Equation} \rightarrow P_{A\text{O}_2} = [(P_B - P_{\text{H}_2\text{O}}) * F_{\text{iO}_2}] - P_{\text{aCO}_2}/RQ$$

$$\text{Arterial Oxygen Content Equation} \rightarrow \text{CaO}_2 = (\text{SaO}_2 * \text{HgbCC} * \text{Hgb}) + (0.0031 * P_{\text{aO}_2})$$

$$\text{Tissue Oxygen Delivery Equation} \rightarrow \text{DO}_2 = (\text{CaO}_2 * \text{CO})/\text{Wt}$$

With these equations and the oxyhemoglobin dissociation curve, DO_2 can be calculated. At the same time, it is essential to know what normal is for the MWD. This is especially important for hemoglobin level, weight, blood gases, and cardiac output. See **Table 18**.

Table 18. Normal MWD Clinical Parameters

MWD Clinical Practice Parameters		
Parameter	Normal	Source
Vital Signs		
--- Temperature (F)	101-103	CPG, 2018
--- Heart Rate (beats/min)	60-80	
--- Respiratory Rate (breaths/min)	16-30	
--- Blood Pressure (mmHg)	Systolic = 120 Diastolic = 80	
--- Capillary Refill (seconds)	< 2	Vogelsang, 2007
--- Weight (kg)	15-46 (mean = 32)	present study
Laboratory Values		
--- WBC (cells/uL)	6-17	CPG, 2018
--- Hgb (g/dl)	12-18	
--- Hct (%)	35-45	
--- Glucose (mg/dl)	60-110	
Arterial Blood Gas Values		
--- pH	7.35-7.45	CPG, 2018
--- PaO ₂ (mmHg)	85-100	
--- PaCO ₂ (mmHg)	24-38	
--- HCO ₃ (mmol/L)	17-25	
--- Lactate (mmol/L)	1.5-2.0	
Tissue Oxygen Delivery Factors		
--- CO (conditioned greyhound) (L/min)	4.4-8.1	Poole, 2015
--- CO (large dog) (L/min)	2.4-9.6	Stephenson, 2002
--- CO (unconditioned mongrel) (L/min)	2.7	Poole, 2015
--- DO _{2crit} (ml O ₂ /kg/min)	9.8	Cain, 1965; Cain, 1977

Note: F (Fahrenheit), min (minute), mmHg (pressure in millimeters of Mercury), kg (kilogram), uL (microliter), g (gram), dl (deciliter), Hct (hematocrit), % (percent), mg (milligram), mmol (millimole), L (liter), pH (serum acid-base level), PaO_2 (partial pressure of arterial oxygen), PaCO_2 (partial pressure of arterial carbon dioxide), HCO_3 (serum bicarbonate level), CO (cardiac output), $\text{DO}_{2\text{crit}}$ (critical level of tissue oxygen delivery), O_2 (oxygen).

The TVFS can increase the DO₂ by upping the FiO₂ with supplemental oxygen, thus providing more oxygen to the dog. Eight dogs in this study were supplemented, mainly with face mask, nasal cannula, or blow by techniques. When needed, supplemental oxygen levels should achieve, at the very least, ground level equivalency. This can be calculated for each individual dog; however, tables are much more user-friendly. See **Table 19**.

Table 19. Table for Determining Sea Level Oxygen Equivalency at Altitude

Altitude (Ft)	Atmospheric Pressure (mmHg)	Oxygen 21% (mmHg)	Oxygen Requirements to Maintain Sea Level Equivalency**																							
10000	522	110		32	38	45	53	60	68	75	83	90	98													
9000	543	114		30	36	43	50	58	65	72	79	86	93													
8000	565	119		29	34	41	48	55	62	69	76	83	89	96												
7000	587	123		28	33	40	46	53	59	66	73	79	86	92	99											
6000	609	128		27	32	38	44	51	57	63	70	76	82	89	95	101										
5000	633	133		26	30	37	43	49	55	61	67	73	79	85	91	97										
4000	656	138		25	29	35	41	47	53	59	64	70	76	82	88	94	100									
3000	681	143		24	28	34	39	45	51	56	62	67	73	79	84	90	96									
2000	707	148		23	27	32	38	43	49	54	59	65	70	76	81	86	92	97								
1000	733	154		22	26	31	36	42	47	52	57	62	68	73	78	83	88	94	99							
0	760	160	PiO ₂	150	178	214	250	285	321	357	392	428	463	499	535	570	606	642	677	713						
			FiO ₂	0.21	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00						
			O ₂ Source	RA	Nasal Cannula (1-6 L/min)					Non-Rebreathing Mask (7-15 L/min)																
					Simple Mask (5-10 L/min)					Partial Rebreathing Mask with Bag (7-15 L/min)																
				**Pertinent Formula:																						
				$PiO_2 = FiO_2 \times (P_{sea\ level} - P_{H_2O})$																						
				$Required\ FiO_2 = [FiO_2 \times (P_{sea\ level} - 47\ mmHg)] / (P_{altitude} - 47\ mmHg)$																						

Note: Table employs formulae described by McLaughlin et al and oxygen delivery device capabilities described in the Air Force Instruction. (McLaughlin, 2003; AFI 48-307 Vol 1, 2017) It was taken from US government publication and, as such, is not subject to copyright. (Butler, 2020c) Although this table is determined for sea level equivalency, another could be easily created with any desired ground level equivalency. Rule of Thumb: Nasal Cannula (~4% per each added L O₂/min); Simple Mask (~6% per each added L O₂/min); Non-Rebreathing Mask (~4-6% per each added L O₂/min). Despite it being devised for the human, it is a good approximation for the dog. Ft (feet), mmHg (pressure in millimeters Mercury), % (percent), PiO₂ (oxygen partial pressure of inspired air), FiO₂ (oxygen fraction of inspired air), O₂ (oxygen), RA (room air), L (liter), min (minute), P (pressure).

The TVFS can augment hemoglobin levels through transfusion, thus providing more oxygen carrying capacity to the dog. A dog without a previous transfusion does not require crossmatching as there are no naturally circulating alloantibodies. However, a dog with an earlier transfusion, at or about 72 hours prior, must be crossmatched. (CPG, 2019) Well prior to AE, during initial resuscitation and treatment, the attending physician/veterinarian will have stabilized the dog, if needed, with transfusion. In this study, only six dogs required transfusion and all during the resuscitation and treatment. None were transfused at the behest of the TVFS. Importantly, the TVFS must realize that the dog has a hemoglobin reserve housed in the spleen that can be released with exercise or exercise-like activity (e.g., vibration, increased metabolism), the so-called splenic release response. A conditioned greyhound, with a normal hemoglobin level of 19-20 g/dl at rest, can see 23-24 g/dl with exercise. (Poole, 2015) Of note, should the hemoglobin level be low, the threat of continued bleeding be real, and/or inflight transfusion be not possible, the TVFS can augment inflight oxygen carrying capacity indirectly by prescribing a CAR.

Traditionally, the CAR is indicated for trapped gas, severe respiratory disease, and intravascular bubbles (i.e., decompression sickness, air gas embolism). (Borden, 2004) Additionally, by dropping the cabin altitude, FiO₂ rises and the Starling-described intravascular-extravascular fluid flux favoring tissue edema is moderated, the dog having a greater amount of oxygen available both directly and indirectly. (Butler, 2020c) In short, the CAR drops tissue edema and ups oxygen levels, thusly improving tissue oxygen delivery. (Butler, 2020b; Butler, 2020c) In this study only three dogs were prescribed a CAR: a head-injured dog (5,000 feet), a spinal cord compromised dog (5,000 feet), and a dog with paralytic ileus (6,000 feet). The CAR prescription most likely countered trapped gas and edema in the gunshot to the head; edema around the cord in the L₅-S₁ disc extrusion; and, trapped gas in the paralytic ileus. Interestingly, the degree of trapped gas relief can and should be estimated. (Butler, 2020c) See Table 20.

Table 20. Trapped Air Pressure-Volume-Diameter Relationships

Pressure-Volume-Diameter Relationships			
Altitude (feet)	Pressure (mmHg)	Volume Change (%)	Diameter Change (%)
10000	523	45.3	13.3
9000	543	40.0	11.8
8000	565	34.5	10.4
7000	587	29.5	9
6000	609	24.8	7.7
5000	632	20.3	6.3
4000	656	15.9	5
3000	681	11.6	3.7
2000	707	7.5	2.4
1000	733	3.7	1.2
500	746	1.9	0.6
Sea Level	760	0	0
33	1520	-50	-21
66	2280	-67	-31
99	3040	-75	-37
132	3800	-80	-41
165	4560	-83	-45

Note: The table was derived with the ideal application of Boyle's Law ($P_1 \cdot V_1 = P_2 \cdot V_2$) and the volume of a spherical bubble ($V = 4/3 \pi r^3$). The table was taken from US government publication and, as such, is not subject to copyright. (Butler, 2020c) mmHg (pressure in millimeters Mercury), % (percent), P_1 (initial pressure), V_1 (initial volume), P_2 (end pressure), V_2 (end volume), V (volume), π (pi, constant = 3.14), r (radius).

In this study, these prescriptions --- supplemental oxygen, transfusion, and CAR --- saw little use --- 5%, 0%, and 2%, respectively, of the 161 transports. Unlike humans (Butler, 2020c), there was no obvious adverse impact from this paucity of prescriptions. This is probably a consequence of the dog's greater cardiac output (CO) capacity and seriously reduced weight.

A conditioned greyhound, whose physiology arguably may well mimic that of a well-trained MWD, has a resting CO around 4.4 L/min with an average weight of about 32 kg, while a soldier's normal CO is around 5.0 L/min with an average weight of about 80 kg. All else equal ($\text{FiO}_2 = 21\%$ and $\text{Hgb} = 10 \text{ g/dl}$), DO_2 on the ground is 18.4 ml $\text{O}_2/\text{kg}/\text{min}$ in the MWD versus 8.4 $\text{O}_2/\text{kg}/\text{min}$ in the human; in an 8,000 foot cabin, the MWD sees 17.4 $\text{O}_2/\text{kg}/\text{min}$ while the human 7.9 $\text{O}_2/\text{kg}/\text{min}$. At altitude, the MWD is well above the $\text{DO}_{2\text{crit}}$ (9.8 $\text{O}_2/\text{kg}/\text{min}$) (Cain, 1965; Cain, 1977), but the human is seriously edging near the $\text{DO}_{2\text{crit}}$ (< 7.3 $\text{O}_2/\text{kg}/\text{min}$) (Lieberman, 2000). Short of exsanguination and/or a cabin decompression, it is unlikely that the MWD will experience a compromised DO_2 . That said, the TVFS still should consider DO_2 in the MWD. Though DO_2 can be calculated, tables for the MWD are available. See **Appendix B**.

Step 3 --- Consultation with the Veterinarian

Having considered the physiology, pathophysiology, and DO_2 , not to mention having developed a tentative prescribing schema for validation, the TVFS *must* consult the theater veterinarian. This, despite study of the CPGs and/or hands-on veterinary care training. Although important, such resources cannot substitute for veterinary consultation. Indeed, they serve only to familiarize the TVFS with canine care and facilitate intelligent veterinary consultation. And, though the MWD and the human have much in common physiologically, there are clinical nuances the TVFS will simply not know. This is particularly true regarding medications.

Most of the MWDs will be prescribed medications. It is incumbent upon the TVFS to have a feel for the medications employed and the dosing. See **Table 21**. *However, it is especially important to remember that the TVFS does not independently prescribe medications for the MWD. Such prescribing is performed only with the direct ongoing consultation of the theater veterinarian.* In this study, a full 95 dogs traveled with medications, mostly antibiotics and analgesics (whether Opioids or NSAIDs). Dosing may be quite different in dogs. For instance, to have a clinical effect, diphenhydramine generally is dosed much higher in dogs than humans. (*personal communication*, Lauren Shaughnessy, DVM) Many of the dogs (53%) carried multiple medications. Drug interactions may also be quite different in dogs. Though NSAIDs and steroids together are generally to be avoided in humans, in dogs the combination frequently yields dangerous gastric ulcers and is roundly contraindicated. (*personal communication*, Lauren Shaughnessy, DVM) Consultation with the veterinarian will avoid such medication blunders and ensure appropriate dosing. Consultation will also present the opportunity to discuss MWD sedation (see below, *Step 4*) and assignment of medical attendants (see below, *Step 5*).

Table 21. MWD Medication Dosing

MWD Medication Dosing (TVFS does <i>not</i> prescribe without theater veterinarian consultation)			
Drug	Dose	Route	Source
Antibiotics			
Amoxicillin	20-30 mg/kg q12h	PO	CPG,2018
Amoxicillin-Clavulanic Acid	13.75 mg/kg q12h	PO	Vogelsang, 2007
Ampicillin	20-30 mg/kg q8h	IV	CPG,2018
Ampicillin-Sulbactam	20-30 mg/kg q8h	IV	CPG,2018
Cefazolin	20-30 mg/kg q8h	IV	Vogelsang, 2007
Cefotaxime	22-25 mg/kg q8h	IV/IM/SQ	CPG, 2018; DD Form 3073, 2019
Ceftriaxone	25 mg/kg q8-12h	IV	Vogelsang, 2007
Cephalexin	20-30 mg/kg q8-12	PO	Vogelsang, 2007; CPG, 2018
Ciprofloxacin	35 mg/kg q12h	PO	CPG, 2018
Ertapenem	15 mg/kg	IV/SQ	DD Form 3073, 2019
Pain Medications			
Morphine	0.5-2.0 mg/kg q3-4h	IM/SQ	Vogelsang, 2007
Fentanyl	4-10 ug/kg		Vogelsang, 2007
Meloxicam	0.1-0.2 mg/kg	IV/SQ/PO	DD Form 3073, 2019
Propofol	3-6 mg/kg slow, then 0.1-0.6 mg/kg/min	IV	Vogelsang, 2007
Sedatives			
Diazapine	0.2-0.3 mg/kg	IV	Vogelsang, 2007
Ketamine	2-10 mg/kg	IV/IM	Vogelsang, 2007; DD Form 3073, 2019
Midazolam	0.1-0.3 mg/kg	IV/IM	DD Form 3073, 2019
Other Medications			
Diphenhydramine	2 mg/kg	IM	Vogelsang, 2007
Epinephrine	0.02 mg/kg	IV	Vogelsang, 2007
Methylprednisolone	30 mg/kg	IV	Vogelsang, 2007

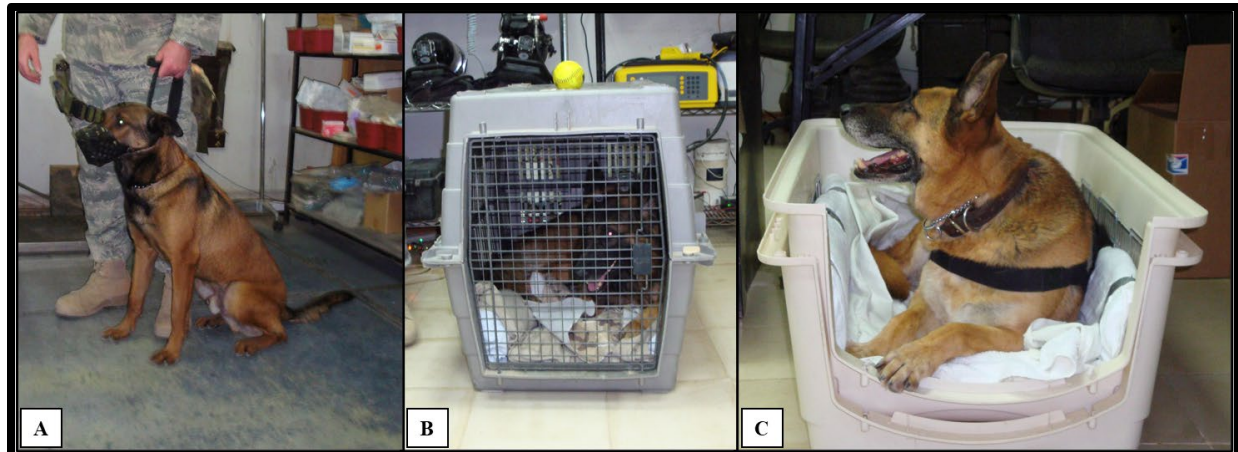
Note: The TVFS is not an independent veterinary prescriber. This dosing chart is provided to aid the TVFS while in direct consultation with the theater veterinarian. mg (milligram), kg (kilogram), h (hours), qXh (dosed at X hour intervals), PO (*per os* = oral), IV (intravenous), IM (intramuscular), SQ (subcutaneous), CPG (Clinical Practice Guideline), DD (Department of Defense).

Step 4 --- Flight Safety

Flight safety is mandatory. Non-medical attendants, specifically dog handlers, are key to flight safety. A MWD is often trained to be dangerous. A MWD is also trained to obey the handler. The handler is trained to effect the care and comfort of the dog, this to include the provision of meals, water, and medications. The handler calms the MWD and ensures the dog is not a hazard to human patients, AE crew, CCATT crew, or flight crew. (**Vogelsang, 2007**) In addition, kennels and muzzles offer further protection. Indeed, should the AE crew need to

directly interact with the dog, unless clinically contraindicated, a muzzle is imperative. (Taylor, 2008) As earlier mentioned, a CCATT nurse barely avoided a “nip” from an unmuzzled MWD, this incident serving only to emphasize that any dog, no matter how contained, when uncomfortable, sick, or injured may lash out at strangers.

In this study, 75% of the transports documented the inclusion of a handler and 12% a muzzle. As for a kennel, 50% of the transports documented its presence. These findings suggest a potential flight safety issue. In the future, these findings should not be replicated. See **Figure 8**.



Note: A → MWD safely restrained with a muzzle. B → MWD safely restrained with a kennel. C → MWD unmuzzled and reclining in a half kennel, not a safe flight situation. Photographs taken by and courtesy of Col (ret) Michelle Bryce, DO, MTM&H.

Figure 8. Making the MWD Safe for Flight

Another aspect of flight safety is dog placement. Keeping the dog distanced from other patients seems reasonable, either far forward or far aft. This may well be of particular relevance since, in this study, only one of ten litter-bound dogs had a muzzle and only two of 33 ambulatory dogs had both a kennel and muzzle.

Sometimes a dog may require sedatives and/or sedative-anxiolytics. The dog’s observed behavior should alert and guide the TVFS to consider these medications. The most commonly prescribed sedative was dexmedetomidine. But, it has a limited duration of action and can seriously drop the blood pressure (e.g., muddy gum color and heart rate in the 30s). Not the best sedative for AE. Better would be trazadone or gabapentin. (*personal communication*, Lauren Shaughnessy, DVM) In any event, no such medication should be prescribed without theater veterinarian consultation. In this study, 16 dogs flew with sedation.

Consequently, it seems imminently reasonable the TVFS prescribe, at the very least, a non-medical attendant handler and a muzzle for any dog transported. Whether the muzzle is applied throughout the flight can be the handler’s decision. A kennel, if available, should also be seriously considered. At the same time, independent of kennel/muzzle considerations, conscious distancing of the dog far forward or far aft of other patients is sound decision-making. And, lastly, dependent on the dog’s behavior and theater veterinarian recommendations, the TVFS must ponder sedation. A relatively low threshold for prescribing sedatives is mandatory. With these measures, flight safety is assured.

Step 5 --- Medical Attendant Assignment

Consulting the theater veterinarian affords the TVFS an opportunity to discuss whether specialized medical attendants are needed for the MWD, specifically veterinary technicians and veterinarians. In this study, 17 veterinary technicians and 12 veterinarians were assigned to dogs, about 18% of the transports. Veterinary technicians were assigned to dogs suffering serious extremity injuries (mostly fractures), pneumothorax, hemorrhagic diarrhea, and even Post-Traumatic Stress Disorder. Veterinarians were assigned dogs with serious extremity injuries (pelvic fractures), pelvic hemorrhage, abdominal infection, pancytopenia, and even pericardial effusion.

These exemplars suggest the veterinary technician be assigned should the dog have a malady with volatile potential while the veterinarian should be assigned should the dog have an issue that is definitely volatile. Of course, this recommendation assumes that either a veterinary technician and/or a veterinarian are available for assignment. Most likely, they will not be available. Importantly, appropriate emergency canine-specific equipment should accompany either veterinary attendant. All that said, always accompanying the MWD should be a handler. **(CPG, 2018)**

Other medical attendant options are available. In this study, two flight nurses were specifically assigned to dogs. Assigning additional AE crew for the MWD should probably be dedicated to those seriously ill or very seriously ill dogs. And, although certainly beyond the usual into the rare, the TVFS could even assign a CCATT if the dog requires specialized care (e.g., ventilator management, pressor management) and no veterinarian is available. However, prior to making such unusual medical attendant assignments, AE and CCATT crewmembers should be routinely trained in canine medical management, something, as yet, not widely available. **(Newcomer, 2012; Butcher, 2015; Dufour, 2015)** At present, the primary canine treatment guidance for human healthcare providers is the MWD CPG. **(CPG, 2018)**

Step 6 --- Communication

Prior to actually manifesting MWDs on an AE aircraft, it is essential that the TVFS assure all parties concerned --- TVFS, treatment team, consulting theater veterinarian, and AE and/or CCATT crew(s) --- are communicating. Though evacuated regularly, MWDs transports will never be routine events. Without good communication, things like veterinary attendant assignment, emergency canine-specific equipment prescription, and inflight medication management can go awry. Witness the anecdotal non-responsive and over-medicated MWD that required a halt to its ketamine/benzodiazepine infusion and initiation of blow by oxygen. In fact, intubation was considered. The standard MWD requires a 9-11 mm inner diameter endotracheal tube. **(CPG, 2018)** The standard-carried human endotracheal tube has an 8 mm inner diameter. Fortunately, intubation proved unnecessary. In this one case, attendant assignment, medication management, and emergency canine-specific equipment were all in abeyance. Prior all-party communication could have potentially prevented this near catastrophe and, maybe even, prevented the dog's later postflight amputation.

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Employing this six-step methodology should produce a logical, coherent, and individualized validation prescription for the MWD, ensuring the dog is “fit to fly” and best positioned for a safe flight. In this way, the MWD gets the very best from the TVFS.

6.0 LIMITATIONS

This study is retrospective research subject to the limitations any after-the-fact data collection is subject to, that is missing data, incomplete data, and/or inaccurate data. Great care was taken to optimize data quality through detailed review of the textual clinical vignettes and remarks entered into the database. However, missing data could not be abrogated. Though deemed not probable, it is possible that the missing data could alter some observations and/or conclusions taken from the available data.

This study is also a case series and, as such, has no comparable non-AE controls. In addition, though a rather large case series of MWDs, the overall population was relatively small. That said, it was felt that an internal comparison between BI and DNBI dogs was fitting. In fact, power analysis suggested adequate power (~98%) to detect statistically significant differences.

Regrettably, incomplete identification recording within the TRAC²ES database did not permit a complete matching to veterinary records. As a result, immediate postflight outcomes (e.g., complications, surgeries, hospital days) could not be determined and, thusly, flight-related morbidity and mortality could not be examined. At the same time, for the same reason, accounting of ultimate final disposition was incomplete. Despite this, disposition conclusions were rational, plausible and, thusly, felt to be valid.

Lastly, the MWD clinical validation algorithm was devised from a decidedly human perspective. As the human and canine physiologies are not too dissimilar, this approach was reasonable. Great care was taken, however, to minimize anthropomorphizing.

7.0 CONCLUSION

While millions of dollars are rightfully invested each year in the training and veterinary care of MWDs, to date, there has been little to no attention/research directed at the AE of these valuable dogs. Likewise, the clinical validation of the ill/injured MWD by the TVFS remains essentially unexplored. This study began the examination of these relatively unnoticed arenas and produced a number of findings.

First, this study demonstrated the force multiplying nature of the MWD with career vignettes of some of the more famous MWDs (**Appendix A**), their value being readily apparent. Consequently, it was not unusual for the MWD to undergo AE. In fact, there was about one MWD evacuated for every 1,000 human evacuations, making such transports uncommon but not at all rare, making it unlikely any TVFS has serious experience validating MWDs for AE, and making this report and future MWD studies that much more important.

Second, all 161 AE transports from 2001-2015 were extracted from the TRAC²ES database. Despite data limitations, certain observations could be made starting with the stereotypic dog: a middle-aged, male German Shepherd serving as an Army E-6, usually suffering from DNBI.

Third, DNBI dogs made up 72% of recorded missions with musculoskeletal and gastrointestinal issues predominating. Battle injured dogs most commonly suffered gunshot wounds to the extremity requiring preflight surgery. The DNBI dogs were flown primarily for Diagnosis & Treatment; the BI dogs flew for Rehabilitation. The DNBI dogs' final disposition included both adoption and death; the BI dogs' final disposition included only adoption.

Fourth, in order to minimize inflight risk from physiological stressors, the TVFS employed both aircraft and canine prescriptions. Few aircraft interventions were prescribed. Of the canine interventions, muzzles, kennels, attendants, and medications dominated. There were no differences in prescribing for the DNBI and BI dogs, excepting a significantly greater number of veterinary medical attendants assigned to BI dogs.

Fifth, these observations coupled with the TVFS prescription profiles suggested a six-step clinical validation algorithm the TVFS might employ to systematically and coherently approach a MWD requiring AE. The steps being: physiologic considerations and countermeasures; tissue oxygen delivery; theater veterinarian consultation; flight safety; medical attendant assignment; and, all-party communication.

Lastly, these findings suggested a validation toolkit for the TVFS had merit; it was created and is appended (**Appendix C**).

In conclusion, this study was the initial investigation into the AE of MWDs. As such, it should be foundational for future MWD research looking specifically at potential AE-related morbidity and mortality. Indeed, looking at AE outcomes with and without veterinary care training for AE and CCATT crews is vital. In addition, MWDs should be included in AE planning for any given mission. For instance, the long haul AE mission out of AFRICOM. Moreover, as long as the MWD is integral to the ground mission, technological advances in human AE should always include the MWD. Good examples here would be the employment of veterinary telemedicine, autonomous inflight care, and remotely piloted vehicle AE. Lastly, at a more basic level, future research might well include determining specific DO_{2crit} for the MWD. The DO_{2crit} of 9.8 ml O₂/kg/min was determined in mongrel dogs (14-17 kg). (**Cain, 1965; Cain, 1977**) The MWD is a highly trained German Shepherd or Belgian Malinois (~32 kg) whose DO_{2crit} may not be altogether extrapolatable from mongrel dogs.

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APPENDIX A --- Famous MWDs

In the last century, high-performing MWDs have reached super-star status. One of the more recent such animals is Cairo, a Belgian Malinois, who took part in and contributed mightily to the Osama bin Laden raid by Seal Team 6. (**Goodavage, 2012; Quinn, 2014**) This section describes four such heroic, perhaps even Homeric, MWDs: *Sergeant Stubby* from World War I, *Chips* from World War II, *Nemo* from the Vietnam War, and *Lucca* from the most recent Iraq-Afghanistan War.

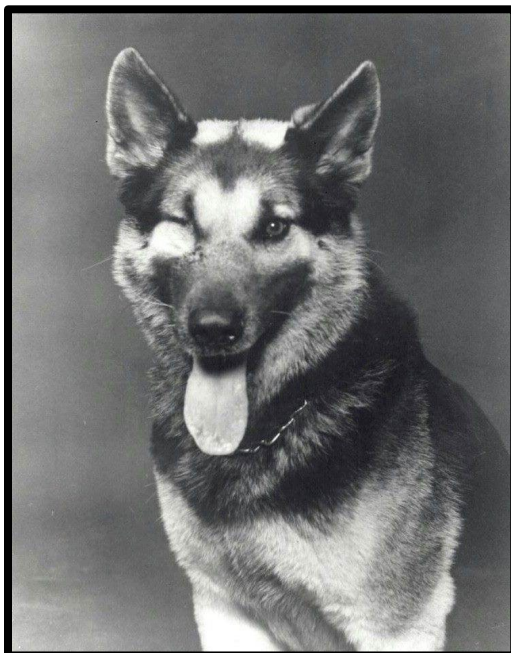
Sergeant Stubby



Chips



Nemo



Lucca



Note: Sources for the photographs follow in the accompanying vignettes.

Sergeant Stubby, World War I



Note: Sgt. Stubby is pictured here wearing the chamois blanket given him by a group of French women for display of all his medals. This photograph was discovered in Wikipedia and, according to Wikipedia, "...is a media file that is in the public domain in the United States." (Open access; accessed on 3 November 2020: https://commons.wikimedia.org/wiki/File:Sergeant_Stubby.jpg)

When the United States entered World War I, there was no Army tradition for war dogs. Despite the extensive employment of war dogs by the other combatants, the United States failed to field an organized war dog effort. This did not deter the American soldier from having dogs. These were mostly mascots and Sergeant Stubby was one of these mascots. **(Rogak, 2011; Goodavage, 2012; Kelly, 2015)**

In April 1917, shortly after the United States entered World War I, a diminutive stray wandered onto Camp Yale in New Haven, Connecticut and joined up with the 102nd Infantry Regiment. "Stubby," so named for his small stub of a tail, became the 102nd's mascot and Private Robert Conroy's pet. A smart animal, he rapidly endeared himself to everyone with such antics as saluting on-command with his right paw. **(Rogak, 2011; Goodavage, 2012; Kelly, 2015)**

Eventually, the 102nd was shipped to France aboard the USS Minnesota. There with Private Conroy, nicely smuggled aboard, was Stubby. **(Rogak, 2011; Goodavage, 2012; Kelly, 2015)**

The 102nd hit the front lines in early 1918. Stubby rapidly acclimated to the loud bangs of gunfire and the booms of artillery. Stubby even adjusted to poison gas. Following a brief hospitalization from such gas, he became the unit's early warning system, barking at the slightest hint of gas. Stubby also routinely assisted the field evacuation of wounded soldiers from no-man's land. But, his greatest feat was detecting and helping capture a stealthy German who crept too close. For this action, Stubby was given a field promotion, now "Sergeant Stubby." In due course, Sgt. Stubby caught shrapnel in his chest and foreleg. Again hospitalized, once able to amble about, Sgt. Stubby visited other patients, boosting morale throughout the facility. **(Rogak, 2011; Goodavage, 2012; Kelly, 2015)**

At war's end, Sgt. Stubby returned home with Corporal Conroy. Seventeen battles and numerous medals made him famous. He was awarded lifetime membership in the Red Cross, YMCA, and the American Legion. A nationwide celebrity, he hosted visits from Presidents Woodrow Wilson, Warren G. Harding, and Calvin Coolidge. It was widely reputed that President Coolidge shook Sgt. Stubby's right paw. Sadly, Sgt. Stubby, perhaps the most famous mascot-pet-turned-war dog ever, was laid to rest in 1926. **(Rogak, 2011; Goodavage, 2012; Kelly, 2015)**

Chips (11A), World War II



Note: This image was taken purportedly on Sicily. It is courtesy of the US Army Quartermaster Museum, Ft Lee, Virginia and is US government property not subject to copyright.

Chips, branded 11A, was a mixed breed German Shepherd (with German Shepherd, Husky and Collie bloodlines), donated to Dogs for Defense by Edward J. Wren of Pleasantville, New York. He arrived at the Front Royal, Virginia Army Dog Training Center in early 1942. **(Lemish, 2008)**

After sentry training, he was teamed with his handler, Private John P. Rowell of the 30th Infantry, 3rd Infantry Division. The pair was part of the October 1942 beach-landing invasion of French Morocco. This action was followed with the July 1943 invasion of Sicily; they were part of Patton's Seventh Army. **(Lemish, 2008)**

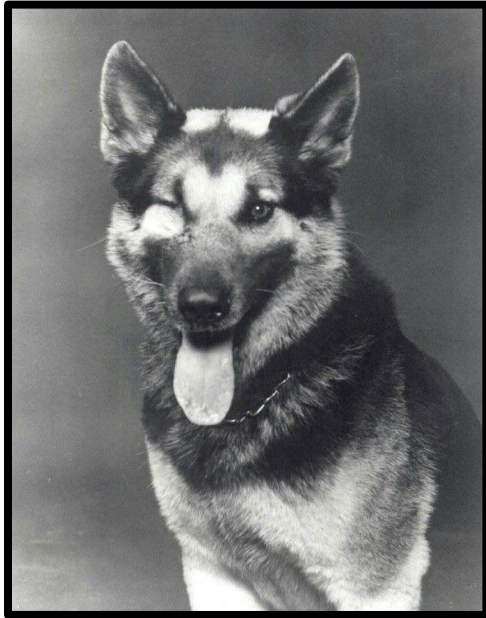
While patrolling, in the early morning hours, Private Rowell and Chips came upon a camouflaged pillbox that opened fire. Chips broke free and immediately charged the pillbox leaping through the gun-slot. In moments, the machine gun ceased firing and an Italian soldier appeared with Chips biting and slashing repeatedly at his arms and throat. Three other Italian soldiers emerged surrendering with hands raised high. Chips suffered a minor scalp wound with powder burns. Despite his injuries, Chips remained on duty. Later that same evening, Chips silently alerted Private Rowell to ten hidden Italian soldiers whom Rowell promptly took prisoner. **(Lemish, 2008)**

Needless to say, Chips' exploits came to press attention and the "hero dog" was born. In fact, Major General Lucian K. Truscott, Jr. waived the regulation prohibiting issuance of medals to animals. As a result, Chips was awarded the Distinguished Service Cross, the Silver Star, and the Purple Heart.¹ In addition, he was even the subject of two speeches in Congress. Perhaps more impressive, while in Italy, it is reputed that General Eisenhower met the now famous Chips. He innocently went to pet the war dog and was promptly nipped for his trouble. **(Lemish, 2008)**

After an assault landing and eight significant battles, Chips began to show some wear; he became skittish, forcing relegation to prisoner-of-war sentry duty. In October 1945, after three hard Army years, Chips found himself demilitarized at the Front Royal Dog Training Center. Shortly thereafter, in December 1945, he returned home to Pleasantville, New York. With failing kidneys, Chips took his final breath on 12 April 1946. **(Lemish, 2008)**

¹Eventually, the regulations surfaced and forced a revocation of the medals, making Chips the first and last dog officially decorated during World War II. **(Lemish, 2008)**

Nemo (A534), Vietnam War



Note: This is a United States Air Force photograph and, as such, is US government property not subject to copyright. It was discovered in an article by Gabriel H. Sanchez, BuzzFeed. (Sanchez, 2015) (Open access, accessed 3 November 2020: https://www.buzzfeed.com/gabrielsanchez/the-bravest-military-animals-to-ever-serve?sub=4010249_6767077)

Tan Son Nhut Air Base was huge, the largest air base in South Vietnam. Its eastern and southern border was metropolitan Saigon. The base was designed for 3,000 personnel, but had 25,000 and, during daylight, swelled to 50,000 with all the military and civilian workers. This sort of expanding and contracting population made infiltration by the Vietcong a real threat. (Lemish, 2008; Rogak, 2011)

On 4 December 1966, one handler and three sentry dogs were killed by Vietcong infiltrators. That evening, thinking the threat gone, Airman Second Class (E-3) Robert Thorneburg was walking sentry duty with his MWD, the 4-year old Nemo (A534). Patrolling along the runways, suddenly, Nemo alerted, his gaze frozen toward the adjacent graveyard. With the enemy's first shot, Thorneburg released Nemo who immediately attacked, charging the graveyard despite a fuselage of bullets. One bullet struck Nemo's right eye and another hit Thorneburg's shoulder. Both Nemo and Thorneburg continued their assault on the Vietcong, causing them to scatter leaving behind one dead. Medics worked Thorneburg's injuries while other troops rushed Nemo to the base veterinarian. Nemo lost his right eye, needed skin grafts, and required a temporary tracheostomy. Both Thorneburg and Nemo fully recovered despite their injuries. (Lemish, 2008; Rogak, 2011)

Nemo returned to Lackland Air Force Base in July 1967. Though no longer able to perform sentry duties, he proved an impressive canine recruiter. He made numerous public appearances across the country, not to mention a host of television appearances. A hero MWD and media personality, Nemo succumbed to a combination of war wounds and natural causes on 15 March 1973, at an elderly 11-years old. (Lemish, 2008; Rogak, 2011)

Lucca (K458), Iraq/Afghanistan War



Note: This is a United States Marine Corps photograph and, as such, is US government property not subject to copyright. It was sourced from Homeward Bound Lucca Retires (image 8 of 8), photograph by Cpl Jennifer Pirante. It was identified in the Defense Visual Information Distribution Service. (Open access, accessed on 18 December 2020: <https://www.dvidshub.net/image/617349/homeward-bound-lucca-retires>)

Lucca (K458) is a German Shepherd, Belgian Malinois mix born in the Netherlands. At two years of age, she and Marine Staff Sergeant (E-6) Chris Willingham met in Tel Aviv, Israel. There, they were paired for off-leash explosive detection training. From that time on, they were practically inseparable. **(Goodavage, 2014)**

Over the next six years, Lucca ran point for over 400 patrol missions, two deployments in Iraq and one in Afghanistan. At no time during any of these missions was any serviceman injured by an explosive. This, despite alerting to literally hundreds of IEDs. She was the quintessential poster-girl for MWDs. **(Goodavage, 2014)**

In Iraq, Lucca teamed with Staff Sergeant Willingham. That is, until he made rank. When promoted to Gunnery Sergeant (E-7), Gunny Willingham turned Lucca over to Marine Corporal (E-4) Juan Rodriguez. **(Goodavage, 2014)**

Corporal Rodriguez and Lucca then teamed for a deployment into Afghanistan, the Nahri Saraj District in the Helmand River Valley. In the middle of a hot afternoon on 23 March 2012, while running point for an Army Green Beret patrol through a fallowed poppy field, Lucca alerted to an IED. Rodriguez had her back away. While doing so, a second IED exploded shearing off her left paw at the mid-leg level. Rodriguez, quick reacting, ran to her, immediately applying two tourniquets. A Blackhawk swiftly medevac'd the pair to Camp Leatherneck where a 3-man veterinary team was waiting. Following damage control surgery, Lucca and Rodriguez were loaded aboard a C-130 for the short 180-mile AE flight to Kandahar. **(Goodavage, 2014)**

On the flight line, Lucca was met by veterinarians Lieutenant Colonel James Giles III and Captain Nathan Chumbler. She was then taken to the human NATO Role 3 Multinational Medical Unit. After a CT scan revealed no hidden injuries, she went to the operating room where Dr. Giles amputated her left foreleg without incident or complication. Come her third post-operative day, after a C-17 AE flight, Lucca and Rodriguez found themselves at the Dog Center Europe very near Ramstein Air Base, Germany. Lucca eventually made a full recovery. **(Goodavage, 2014)**

In early July 2012, Corporal Rodriguez and Lucca flew to Helsinki where the now-retired Lucca officially met her adoptive family, the Finland-stationed Willinghams. It was a joyous reunion. She continues to live a happy dog's life with her first "daddy," Chris Willingham (and his family), marked by occasional visits from her second "daddy," Juan Rodriguez. **(Goodavage, 2014)**

Since that time, Lucca has become quite the celebrity --- from riding in the 2013 Rose Parade to accepting the American Kennel Club Heroic Military Working Dog Award to earning the United Kingdom's People's Dispensary for Sick Animals (PDSA) 2016 Dickin Medal. Named after the PDSA's founder Maria Dickin and introduced in 1943, it recognizes outstanding acts of bravery or devotion to duty by military or civil defense animals in any theater of war. The Dickin Medal has gone to 32 messenger pigeons, 3 horses, 1 cat, and 31 dogs. Lucca is the first US Marine MWD to take home the honor. **(Goodavage, 2014; Fox News, 2016; Newton, 2016)**

APPENDIX B --- Tissue Oxygen Delivery Tables for MWDs

These tables were created using several standard physiological equations along with a standard oxyhemoglobin dissociation curve. The equations were taken from the monograph *Physiological Foundation for Clinical Validation of Aeromedical Evacuation Patients* by WP Butler and LW Steinkraus and the textbooks, *Textbook of Veterinary Physiology* (3rd Edition) edited by JG Cunningham and *Duke's Physiology of Domestic Animals* (13th Edition) edited by WO Reece along with HH Erickson, JP Goff, and EE Uemura. They are as follows:

Alveolar Gas Equation → $P_{AO_2} = [(P_B - P_{H_2O}) * FiO_2] - PaCO_2/RQ$

P_{AO_2} : alveolar oxygen partial pressure (mmHg)

P_B : ambient barometric pressure (mmHg)

P_{H_2O} : water vapor partial pressure (dog = 50 mmHg)

FiO_2 : oxygen fraction of inspired air

$PaCO_2$: arterial carbon dioxide partial pressure (mmHg)

RQ: respiratory quotient (CO_2 eliminated/ O_2 consumed) ("mammal" aka dog = 0.8)

Arterial Oxygen Content Equation → $CaO_2 = (SaO_2 * HgbCC * Hgb) + (0.0031 * PaO_2)$

CaO_2 : arterial oxygen content (ml O_2 /dl)

SaO_2 : arterial hemoglobin oxygen saturation (%)

HgbCC: hemoglobin carrying capacity ("domestic animal" aka dog = 1.34 ml O_2 /g)

Hgb: hemoglobin level (g/dl)

PaO_2 : arterial oxygen partial pressure (mmHg)

Tissue Oxygen Delivery Equation → $DO_2 = (CaO_2 * CO)/Wt$

DO_2 : tissue oxygen delivery (ml O_2 /kg/min)

CaO_2 : arterial oxygen content (ml O_2 /dl)

CO: cardiac output (heart rate x stroke volume, L/min or dl/min)

Wt: weight (kg)

Several assumptions were made in the construction of these tables. They are as follows:

1. The weight of the average MWD is assumed to be that of the 135 dogs in this study.
 - a. Mean = 32 kg, SD = 5 kg, range = 15-46 kg, N = 128.
2. Cardiac Output is assumed to be on a par with that reported for a conditioned greyhound.
 - a. Cardiac Output (resting) = 4.4 L/min. (Poole, 2015)
 - b. Cardiac Output (exercising) = 8.1 L/min. (Poole, 2015)
 - c. MWDs are very well conditioned dogs, making this assumption reasonable.
3. The MWD's oxyhemoglobin dissociation curve is assumed like that of the human. (Reece, 2015)
 - a. Oxygen saturations are from Ernsting's Aviation and Space Medicine. (Gradwell, 2016)
4. HgbCC ("domestic animal" aka dog) = 1.34 ml O_2 /g. (Reece, 2015)
5. P_{H_2O} = 50 mmHg. (Robinson, 2002)
6. $PaCO_2$ = 40 mmHg. (Robinson, 2002)
7. Alveolar-arterial gradient = 8 mmHg (range = 5-10 mmHg). (Robinson, 2002)
8. RQ ("mammal" aka dog) = 0.8. (Robinson, 2002)
9. DO_{2crit} = 9.8 ml O_2 /kg/min.
 - a. Based on mongrel dogs (14-17 kg). (Cain, 1965; Cain, 1977)

MWD Tissue Oxygen Delivery Tables

Effects of Hemoglobin, FiO ₂ , and Altitude on Tissue Oxygen Delivery												
Hgb (g/dl)	% O ₂ Delivered	Altitude (Ft)	Atmospheric Pressure (mmHg)	Ambient Dry O ₂ (mmHg)	Moist (37C) O ₂ (mmHg)	RQ	Alveolar O ₂ (mmHg) w/ typical PCO ₂ 40 mmHG	Arterial O ₂ (mmHg) w/ A-a = 8	O ₂ %Sat (from dissociation curve)	CaO ₂	DO ₂ w/ exercising CO	DO ₂ w/ resting CO
15.0	21%	0	760	160	149	0.80	99	91	0.98	20.0	50.6	27.5
15.0	21%	1000	733	154	143	0.80	93	85	0.97	19.8	50.0	27.2
15.0	21%	2000	707	148	138	0.80	88	80	0.96	19.5	49.5	26.9
15.0	21%	3000	681	143	133	0.80	83	75	0.96	19.5	49.4	26.8
15.0	21%	4000	656	138	127	0.80	77	69	0.95	19.3	48.9	26.6
15.0	21%	5000	633	133	122	0.80	72	64	0.95	19.3	48.8	26.5
15.0	21%	6000	609	128	117	0.80	67	59	0.94	19.1	48.3	26.2
15.0	21%	7000	587	123	113	0.80	63	55	0.93	18.9	47.7	25.9
15.0	21%	8000	565	118	108	0.80	58	50	0.93	18.8	47.7	25.9
15.0	21%	9000	543	114	104	0.80	54	46	0.91	18.4	46.7	25.3
15.0	21%	10000	522	110	99	0.80	49	41	0.89	18.0	45.6	24.8
15.0	50%	0	760	160	355	0.80	305	297	0.99	20.8	52.7	28.6
15.0	50%	1000	733	154	342	0.80	292	284	0.99	20.8	52.6	28.6
15.0	50%	2000	707	148	329	0.80	279	271	0.99	20.7	52.5	28.5
15.0	50%	3000	681	143	316	0.80	266	258	0.99	20.7	52.4	28.5
15.0	50%	4000	656	138	303	0.80	253	245	0.99	20.7	52.3	28.4
15.0	50%	5000	633	133	292	0.80	242	234	0.99	20.6	52.2	28.4
15.0	50%	6000	609	128	280	0.80	230	222	0.99	20.6	52.1	28.3
15.0	50%	7000	587	123	269	0.80	219	211	0.99	20.6	52.0	28.3
15.0	50%	8000	565	118	258	0.80	208	200	0.99	20.5	51.9	28.2
15.0	50%	9000	543	114	247	0.80	197	189	0.99	20.5	51.8	28.2
15.0	50%	10000	522	110	236	0.80	186	178	0.99	20.5	51.8	28.1
15.0	100%	0	760	160	713	0.80	663	655	0.99	21.9	55.5	30.2
15.0	100%	1000	733	154	686	0.80	636	628	0.99	21.8	55.3	30.0
15.0	100%	2000	707	148	660	0.80	610	602	0.99	21.8	55.1	29.9
15.0	100%	3000	681	143	634	0.80	584	576	0.99	21.7	54.9	29.8
15.0	100%	4000	656	138	609	0.80	559	551	0.99	21.6	54.7	29.7
15.0	100%	5000	633	133	586	0.80	536	528	0.99	21.5	54.5	29.6
15.0	100%	6000	609	128	562	0.80	512	504	0.99	21.5	54.3	29.5
15.0	100%	7000	587	123	540	0.80	490	482	0.99	21.4	54.2	29.4
15.0	100%	8000	565	118	518	0.80	468	460	0.99	21.3	54.0	29.3
15.0	100%	9000	543	114	496	0.80	446	438	0.99	21.3	53.8	29.2
15.0	100%	10000	522	110	475	0.80	425	417	0.99	21.2	53.6	29.1

Effects of Hemoglobin, FiO ₂ , and Altitude on Tissue Oxygen Delivery												
Hgb (g/dl)	% O ₂ Delivered	Altitude (Ft)	Atmospheric Pressure (mmHg)	Ambient Dry O ₂ (mmHg)	Moist (37C) O ₂ (mmHg)	RQ	Alveolar O ₂ (mmHg) w/ typical PCO ₂ 40 mmHG	Arterial O ₂ (mmHg) w/ A-a = 8	O ₂ %Sat (from dissociation curve)	CaO ₂	DO ₂ w/ exercising CO	DO ₂ w/ resting CO
10.0	21%	0	760	160	150	0.80	100	92	0.98	13.4	34.0	18.4
10.0	21%	1000	733	154	144	0.80	94	86	0.97	13.3	33.6	18.2
10.0	21%	2000	707	148	139	0.80	89	81	0.96	13.1	33.2	18.0
10.0	21%	3000	681	143	133	0.80	83	75	0.96	13.1	33.2	18.0
10.0	21%	4000	656	138	128	0.80	78	70	0.95	12.9	32.8	17.8
10.0	21%	5000	633	133	123	0.80	73	65	0.95	12.9	32.7	17.8
10.0	21%	6000	609	128	118	0.80	68	60	0.94	12.8	32.4	17.6
10.0	21%	7000	587	123	113	0.80	63	55	0.93	12.6	32.0	17.4
10.0	21%	8000	565	118	109	0.80	59	51	0.93	12.6	31.9	17.4
10.0	21%	9000	543	114	104	0.80	54	46	0.91	12.3	31.2	17.0
10.0	21%	10000	522	110	100	0.80	50	42	0.89	12.1	30.5	16.6
10.0	50%	0	760	160	357	0.80	307	299	0.99	14.2	35.9	19.5
10.0	50%	1000	733	154	343	0.80	293	285	0.99	14.1	35.8	19.5
10.0	50%	2000	707	148	330	0.80	280	272	0.99	14.1	35.7	19.4
10.0	50%	3000	681	143	317	0.80	267	259	0.99	14.1	35.6	19.3
10.0	50%	4000	656	138	305	0.80	255	247	0.99	14.0	35.5	19.3
10.0	50%	5000	633	133	293	0.80	243	235	0.99	14.0	35.4	19.2
10.0	50%	6000	609	128	281	0.80	231	223	0.99	14.0	35.3	19.2
10.0	50%	7000	587	123	270	0.80	220	212	0.99	13.9	35.2	19.1
10.0	50%	8000	565	118	259	0.80	209	201	0.99	13.9	35.2	19.1
10.0	50%	9000	543	114	248	0.80	198	190	0.99	13.9	35.1	19.1
10.0	50%	10000	522	110	238	0.80	188	180	0.99	13.8	35.0	19.0
10.0	100%	0	760	160	713	0.80	663	655	0.99	15.3	38.7	21.0
10.0	100%	1000	733	154	686	0.80	636	628	0.99	15.2	38.5	20.9
10.0	100%	2000	707	148	660	0.80	610	602	0.99	15.1	38.3	20.8
10.0	100%	3000	681	143	634	0.80	584	576	0.99	15.1	38.1	20.7
10.0	100%	4000	656	138	609	0.80	559	551	0.99	15.0	37.9	20.6
10.0	100%	5000	633	133	586	0.80	536	528	0.99	14.9	37.7	20.5
10.0	100%	6000	609	128	562	0.80	512	504	0.99	14.8	37.5	20.4
10.0	100%	7000	587	123	540	0.80	490	482	0.99	14.8	37.4	20.3
10.0	100%	8000	565	118	518	0.80	468	460	0.99	14.7	37.2	20.2
10.0	100%	9000	543	114	496	0.80	446	438	0.99	14.6	37.0	20.1
10.0	100%	10000	522	110	475	0.80	425	417	0.99	14.6	36.9	20.0

MWD Tissue Oxygen Delivery Tables

Effects of Hemoglobin, FiO ₂ , and Altitude on Tissue Oxygen Delivery												
Hgb (g/dl)	% O ₂ Delivered	Altitude (Ft)	Atmospheric Pressure (mmHg)	Ambient Dry O ₂ (mmHg)	Moist (37C) O ₂ (mmHg)	RQ	Alveolar O ₂ (mmHg) w/ typical PCO ₂ 40 mmHG	Arterial O ₂ (mmHg) w/ A-a = 8	O ₂ %Sat (from dissociation curve)	CaO ₂	DO ₂ w/ exercising CO	DO ₂ w/ resting CO
9.0	21%	0	760	160	150	0.80	100	92	0.98	12.1	30.6	16.6
9.0	21%	1000	733	154	144	0.80	94	86	0.97	12.0	30.3	16.5
9.0	21%	2000	707	148	139	0.80	89	81	0.96	11.8	29.9	16.3
9.0	21%	3000	681	143	133	0.80	83	75	0.96	11.8	29.9	16.2
9.0	21%	4000	656	138	128	0.80	78	70	0.95	11.7	29.5	16.1
9.0	21%	5000	633	133	123	0.80	73	65	0.95	11.7	29.5	16.0
9.0	21%	6000	609	128	118	0.80	68	60	0.94	11.5	29.2	15.8
9.0	21%	7000	587	123	113	0.80	63	55	0.93	11.4	28.8	15.7
9.0	21%	8000	565	118	109	0.80	59	51	0.93	11.4	28.8	15.6
9.0	21%	9000	543	114	104	0.80	54	46	0.91	11.1	28.1	15.3
9.0	21%	10000	522	110	100	0.80	50	42	0.89	10.9	27.5	14.9
9.0	50%	0	760	160	357	0.80	307	299	0.99	12.9	32.6	17.7
9.0	50%	1000	733	154	343	0.80	293	285	0.99	12.8	32.5	17.6
9.0	50%	2000	707	148	330	0.80	280	272	0.99	12.8	32.4	17.6
9.0	50%	3000	681	143	317	0.80	267	259	0.99	12.7	32.3	17.5
9.0	50%	4000	656	138	305	0.80	255	247	0.99	12.7	32.2	17.5
9.0	50%	5000	633	133	293	0.80	243	235	0.99	12.7	32.1	17.4
9.0	50%	6000	609	128	281	0.80	231	223	0.99	12.6	32.0	17.4
9.0	50%	7000	587	123	270	0.80	220	212	0.99	12.6	31.9	17.3
9.0	50%	8000	565	118	259	0.80	209	201	0.99	12.6	31.8	17.3
9.0	50%	9000	543	114	248	0.80	198	190	0.99	12.5	31.7	17.2
9.0	50%	10000	522	110	238	0.80	188	180	0.99	12.5	31.6	17.2
9.0	100%	0	760	160	713	0.80	663	655	0.99	14.0	35.4	19.2
9.0	100%	1000	733	154	686	0.80	636	628	0.99	13.9	35.1	19.1
9.0	100%	2000	707	148	660	0.80	610	602	0.99	13.8	34.9	19.0
9.0	100%	3000	681	143	634	0.80	584	576	0.99	13.7	34.7	18.9
9.0	100%	4000	656	138	609	0.80	559	551	0.99	13.6	34.5	18.8
9.0	100%	5000	633	133	586	0.80	536	528	0.99	13.6	34.4	18.7
9.0	100%	6000	609	128	562	0.80	512	504	0.99	13.5	34.2	18.6
9.0	100%	7000	587	123	540	0.80	490	482	0.99	13.4	34.0	18.5
9.0	100%	8000	565	118	518	0.80	468	460	0.99	13.4	33.8	18.4
9.0	100%	9000	543	114	496	0.80	446	438	0.99	13.3	33.7	18.3
9.0	100%	10000	522	110	475	0.80	425	417	0.99	13.2	33.5	18.2

Effects of Hemoglobin, FiO ₂ , and Altitude on Tissue Oxygen Delivery												
Hgb (g/dl)	% O ₂ Delivered	Altitude (Ft)	Atmospheric Pressure (mmHg)	Ambient Dry O ₂ (mmHg)	Moist (37C) O ₂ (mmHg)	RQ	Alveolar O ₂ (mmHg) w/ typical PCO ₂ 40 mmHG	Arterial O ₂ (mmHg) w/ A-a = 8	O ₂ %Sat (from dissociation curve)	CaO ₂	DO ₂ w/ exercising CO	DO ₂ w/ resting CO
8.5	21%	0	760	160	150	0.80	100	92	0.98	11.4	29.0	15.7
8.5	21%	1000	733	154	144	0.80	94	86	0.97	11.3	28.6	15.6
8.5	21%	2000	707	148	139	0.80	89	81	0.96	11.2	28.3	15.4
8.5	21%	3000	681	143	133	0.80	83	75	0.96	11.2	28.3	15.4
8.5	21%	4000	656	138	128	0.80	78	70	0.95	11.0	27.9	15.2
8.5	21%	5000	633	133	123	0.80	73	65	0.95	11.0	27.9	15.2
8.5	21%	6000	609	128	118	0.80	68	60	0.94	10.9	27.6	15.0
8.5	21%	7000	587	123	113	0.80	63	55	0.93	10.8	27.2	14.8
8.5	21%	8000	565	118	109	0.80	59	51	0.93	10.8	27.2	14.8
8.5	21%	9000	543	114	104	0.80	54	46	0.91	10.5	26.6	14.4
8.5	21%	10000	522	110	100	0.80	50	42	0.89	10.3	26.0	14.1
8.5	50%	0	760	160	357	0.80	307	299	0.99	12.2	30.9	16.8
8.5	50%	1000	733	154	343	0.80	293	285	0.99	12.2	30.8	16.7
8.5	50%	2000	707	148	330	0.80	280	272	0.99	12.1	30.7	16.7
8.5	50%	3000	681	143	317	0.80	267	259	0.99	12.1	30.6	16.6
8.5	50%	4000	656	138	305	0.80	255	247	0.99	12.0	30.5	16.6
8.5	50%	5000	633	133	293	0.80	243	235	0.99	12.0	30.4	16.5
8.5	50%	6000	609	128	281	0.80	231	223	0.99	12.0	30.3	16.5
8.5	50%	7000	587	123	270	0.80	220	212	0.99	11.9	30.2	16.4
8.5	50%	8000	565	118	259	0.80	209	201	0.99	11.9	30.1	16.4
8.5	50%	9000	543	114	248	0.80	198	190	0.99	11.9	30.0	16.3
8.5	50%	10000	522	110	238	0.80	188	180	0.99	11.8	30.0	16.3
8.5	100%	0	760	160	713	0.80	663	655	0.99	13.3	33.7	18.3
8.5	100%	1000	733	154	686	0.80	636	628	0.99	13.2	33.5	18.2
8.5	100%	2000	707	148	660	0.80	610	602	0.99	13.1	33.3	18.1
8.5	100%	3000	681	143	634	0.80	584	576	0.99	13.1	33.1	18.0
8.5	100%	4000	656	138	609	0.80	559	551	0.99	13.0	32.9	17.9
8.5	100%	5000	633	133	586	0.80	536	528	0.99	12.9	32.7	17.8
8.5	100%	6000	609	128	562	0.80	512	504	0.99	12.8	32.5	17.7
8.5	100%	7000	587	123	540	0.80	490	482	0.99	12.8	32.3	17.6
8.5	100%	8000	565	118	518	0.80	468	460	0.99	12.7	32.2	17.5
8.5	100%	9000	543	114	496	0.80	446	438	0.99	12.6	32.0	17.4
8.5	100%	10000	522	110	475	0.80	425	417	0.99	12.6	31.8	17.3

MWD Tissue Oxygen Delivery Tables

Effects of Hemoglobin, FiO ₂ , and Altitude on Tissue Oxygen Delivery												
Hgb (g/dl)	% O ₂ Delivered	Altitude (Ft)	Atmospheric Pressure (mmHg)	Ambient Dry O ₂ (mmHg)	Moist (37C) O ₂ (mmHg)	RQ	Alveolar O ₂ (mmHg) w/ typical PCO ₂ 40 mmHG	Arterial O ₂ (mmHg) w/ A-a = 8	O ₂ %Sat (from dissociation curve)	CaO ₂	DO ₂ w/ exercising CO	DO ₂ w/ resting CO
8.0	21%	0	760	160	149	0.80	99	91	0.98	10.8	27.3	14.8
8.0	21%	1000	733	154	143	0.80	93	85	0.97	10.7	27.0	14.7
8.0	21%	2000	707	148	138	0.80	88	80	0.96	10.5	26.7	14.5
8.0	21%	3000	681	143	133	0.80	83	75	0.96	10.5	26.6	14.5
8.0	21%	4000	656	138	127	0.80	77	69	0.95	10.4	26.3	14.3
8.0	21%	5000	633	133	122	0.80	72	64	0.95	10.4	26.3	14.3
8.0	21%	6000	609	128	117	0.80	67	59	0.94	10.3	26.0	14.1
8.0	21%	7000	587	123	113	0.80	63	55	0.93	10.1	25.7	13.9
8.0	21%	8000	565	118	108	0.80	58	50	0.93	10.1	25.6	13.9
8.0	21%	9000	543	114	104	0.80	54	46	0.91	9.9	25.1	13.6
8.0	21%	10000	522	110	99	0.80	49	41	0.89	9.7	24.5	13.3
8.0	50%	0	760	160	355	0.80	305	297	0.99	11.5	29.2	15.9
8.0	50%	1000	733	154	342	0.80	292	284	0.99	11.5	29.1	15.8
8.0	50%	2000	707	148	329	0.80	279	271	0.99	11.5	29.0	15.7
8.0	50%	3000	681	143	316	0.80	266	258	0.99	11.4	28.9	15.7
8.0	50%	4000	656	138	303	0.80	253	245	0.99	11.4	28.8	15.6
8.0	50%	5000	633	133	292	0.80	242	234	0.99	11.3	28.7	15.6
8.0	50%	6000	609	128	280	0.80	230	222	0.99	11.3	28.6	15.5
8.0	50%	7000	587	123	269	0.80	219	211	0.99	11.3	28.5	15.5
8.0	50%	8000	565	118	258	0.80	208	200	0.99	11.2	28.4	15.4
8.0	50%	9000	543	114	247	0.80	197	189	0.99	11.2	28.3	15.4
8.0	50%	10000	522	110	236	0.80	186	178	0.99	11.2	28.3	15.4
8.0	100%	0	760	160	710	0.80	660	652	0.99	12.6	32.0	17.4
8.0	100%	1000	733	154	683	0.80	633	625	0.99	12.6	31.8	17.3
8.0	100%	2000	707	148	657	0.80	607	599	0.99	12.5	31.6	17.1
8.0	100%	3000	681	143	631	0.80	581	573	0.99	12.4	31.4	17.0
8.0	100%	4000	656	138	606	0.80	556	548	0.99	12.3	31.2	16.9
8.0	100%	5000	633	133	583	0.80	533	525	0.99	12.2	31.0	16.8
8.0	100%	6000	609	128	559	0.80	509	501	0.99	12.2	30.8	16.7
8.0	100%	7000	587	123	537	0.80	487	479	0.99	12.1	30.6	16.6
8.0	100%	8000	565	118	515	0.80	465	457	0.99	12.0	30.4	16.5
8.0	100%	9000	543	114	493	0.80	443	435	0.99	12.0	30.3	16.4
8.0	100%	10000	522	110	472	0.80	422	414	0.99	11.9	30.1	16.4

Effects of Hemoglobin, FiO ₂ , and Altitude on Tissue Oxygen Delivery												
Hgb (g/dl)	% O ₂ Delivered	Altitude (Ft)	Atmospheric Pressure (mmHg)	Ambient Dry O ₂ (mmHg)	Moist (37C) O ₂ (mmHg)	RQ	Alveolar O ₂ (mmHg) w/ typical PCO ₂ 40 mmHG	Arterial O ₂ (mmHg) w/ A-a = 8	O ₂ %Sat (from dissociation curve)	CaO ₂	DO ₂ w/ exercising CO	DO ₂ w/ resting CO
7.5	21%	0	760	160	149	0.80	99	91	0.98	10.1	25.6	13.9
7.5	21%	1000	733	154	143	0.80	93	85	0.97	10.0	25.3	13.8
7.5	21%	2000	707	148	138	0.80	88	80	0.96	9.9	25.0	13.6
7.5	21%	3000	681	143	133	0.80	83	75	0.96	9.9	25.0	13.6
7.5	21%	4000	656	138	127	0.80	77	69	0.95	9.8	24.7	13.4
7.5	21%	5000	633	133	122	0.80	72	64	0.95	9.7	24.7	13.4
7.5	21%	6000	609	128	117	0.80	67	59	0.94	9.6	24.4	13.2
7.5	21%	7000	587	123	113	0.80	63	55	0.93	9.5	24.1	13.1
7.5	21%	8000	565	118	108	0.80	58	50	0.93	9.5	24.1	13.1
7.5	21%	9000	543	114	104	0.80	54	46	0.91	9.3	23.5	12.8
7.5	21%	10000	522	110	99	0.80	49	41	0.89	9.1	23.0	12.5
7.5	50%	0	760	160	355	0.80	305	297	0.99	10.9	27.5	14.9
7.5	50%	1000	733	154	342	0.80	292	284	0.99	10.8	27.4	14.9
7.5	50%	2000	707	148	329	0.80	279	271	0.99	10.8	27.3	14.8
7.5	50%	3000	681	143	316	0.80	266	258	0.99	10.7	27.2	14.8
7.5	50%	4000	656	138	303	0.80	253	245	0.99	10.7	27.1	14.7
7.5	50%	5000	633	133	292	0.80	242	234	0.99	10.7	27.0	14.7
7.5	50%	6000	609	128	280	0.80	230	222	0.99	10.6	26.9	14.6
7.5	50%	7000	587	123	269	0.80	219	211	0.99	10.6	26.8	14.6
7.5	50%	8000	565	118	258	0.80	208	200	0.99	10.6	26.8	14.5
7.5	50%	9000	543	114	247	0.80	197	189	0.99	10.5	26.7	14.5
7.5	50%	10000	522	110	236	0.80	186	178	0.99	10.5	26.6	14.4
7.5	100%	0	760	160	710	0.80	660	652	0.99	12.0	30.3	16.5
7.5	100%	1000	733	154	683	0.80	633	625	0.99	11.9	30.1	16.3
7.5	100%	2000	707	148	657	0.80	607	599	0.99	11.8	29.9	16.2
7.5	100%	3000	681	143	631	0.80	581	573	0.99	11.7	29.7	16.1
7.5	100%	4000	656	138	606	0.80	556	548	0.99	11.6	29.5	16.0
7.5	100%	5000	633	133	583	0.80	533	525	0.99	11.6	29.3	15.9
7.5	100%	6000	609	128	559	0.80	509	501	0.99	11.5	29.1	15.8
7.5	100%	7000	587	123	537	0.80	487	479	0.99	11.4	28.9	15.7
7.5	100%	8000	565	118	515	0.80	465	457	0.99	11.4	28.8	15.6
7.5	100%	9000	543	114	493	0.80	443	435	0.99	11.3	28.6	15.5
7.5	100%	10000	522	110	472	0.80	422	414	0.99	11.2	28.4	15.4

MWD Tissue Oxygen Delivery Tables

Effects of Hemoglobin, FiO ₂ , and Altitude on Tissue Oxygen Delivery												
Hgb (g/dl)	% O ₂ Delivered	Altitude (Ft)	Atmospheric Pressure (mmHg)	Ambient Dry O ₂ (mmHg)	Moist (37C) O ₂ (mmHg)	RQ	Alveolar O ₂ (mmHg) w/ typical PCO ₂ 40 mmHG	Arterial O ₂ (mmHg) w/ A-a = 8	O ₂ %Sat (from dissociation curve)	CaO ₂	DO ₂ w/ exercising CO	DO ₂ w/ resting CO
7.0	21%	0	760	160	149	0.80	99	91	0.98	9.5	24.0	13.0
7.0	21%	1000	733	154	143	0.80	93	85	0.97	9.4	23.7	12.9
7.0	21%	2000	707	148	138	0.80	88	80	0.96	9.3	23.4	12.7
7.0	21%	3000	681	143	133	0.80	83	75	0.96	9.2	23.4	12.7
7.0	21%	4000	656	138	127	0.80	77	69	0.95	9.1	23.1	12.5
7.0	21%	5000	633	133	122	0.80	72	64	0.95	9.1	23.1	12.5
7.0	21%	6000	609	128	117	0.80	67	59	0.94	9.0	22.8	12.4
7.0	21%	7000	587	123	113	0.80	63	55	0.93	8.9	22.5	12.2
7.0	21%	8000	565	118	108	0.80	58	50	0.93	8.9	22.5	12.2
7.0	21%	9000	543	114	104	0.80	54	46	0.91	8.7	22.0	11.9
7.0	21%	10000	522	110	99	0.80	49	41	0.89	8.5	21.5	11.7
7.0	50%	0	760	160	355	0.80	305	297	0.99	10.2	25.8	14.0
7.0	50%	1000	733	154	342	0.80	292	284	0.99	10.2	25.7	14.0
7.0	50%	2000	707	148	329	0.80	279	271	0.99	10.1	25.6	13.9
7.0	50%	3000	681	143	316	0.80	266	258	0.99	10.1	25.5	13.9
7.0	50%	4000	656	138	303	0.80	253	245	0.99	10.0	25.4	13.8
7.0	50%	5000	633	133	292	0.80	242	234	0.99	10.0	25.3	13.8
7.0	50%	6000	609	128	280	0.80	230	222	0.99	10.0	25.2	13.7
7.0	50%	7000	587	123	269	0.80	219	211	0.99	9.9	25.2	13.7
7.0	50%	8000	565	118	258	0.80	208	200	0.99	9.9	25.1	13.6
7.0	50%	9000	543	114	247	0.80	197	189	0.99	9.9	25.0	13.6
7.0	50%	10000	522	110	236	0.80	186	178	0.99	9.8	24.9	13.5
7.0	100%	0	760	160	710	0.80	660	652	0.99	11.3	28.6	15.5
7.0	100%	1000	733	154	683	0.80	633	625	0.99	11.2	28.4	15.4
7.0	100%	2000	707	148	657	0.80	607	599	0.99	11.1	28.2	15.3
7.0	100%	3000	681	143	631	0.80	581	573	0.99	11.1	28.0	15.2
7.0	100%	4000	656	138	606	0.80	556	548	0.99	11.0	27.8	15.1
7.0	100%	5000	633	133	583	0.80	533	525	0.99	10.9	27.6	15.0
7.0	100%	6000	609	128	559	0.80	509	501	0.99	10.8	27.4	14.9
7.0	100%	7000	587	123	537	0.80	487	479	0.99	10.8	27.3	14.8
7.0	100%	8000	565	118	515	0.80	465	457	0.99	10.7	27.1	14.7
7.0	100%	9000	543	114	493	0.80	443	435	0.99	10.6	26.9	14.6
7.0	100%	10000	522	110	472	0.80	422	414	0.99	10.6	26.8	14.5

Effects of Hemoglobin, FiO ₂ , and Altitude on Tissue Oxygen Delivery												
Hgb (g/dl)	% O ₂ Delivered	Altitude (Ft)	Atmospheric Pressure (mmHg)	Ambient Dry O ₂ (mmHg)	Moist (37C) O ₂ (mmHg)	RQ	Alveolar O ₂ (mmHg) w/ typical PCO ₂ 40 mmHG	Arterial O ₂ (mmHg) w/ A-a = 8	O ₂ %Sat (from dissociation curve)	CaO ₂	DO ₂ w/ exercising CO	DO ₂ w/ resting CO
6.5	21%	0	760	160	149	0.85	102	94	0.98	8.8	22.3	12.1
6.5	21%	1000	733	154	143	0.85	96	88	0.97	8.7	22.1	12.0
6.5	21%	2000	707	148	138	0.86	91	83	0.96	8.6	21.8	11.9
6.5	21%	3000	681	143	133	0.86	86	78	0.96	8.6	21.8	11.8
6.5	21%	4000	656	138	127	0.87	81	73	0.95	8.5	21.5	11.7
6.5	21%	5000	633	133	122	0.87	76	68	0.95	8.5	21.5	11.7
6.5	21%	6000	609	128	117	0.88	72	64	0.94	8.4	21.2	11.5
6.5	21%	7000	587	123	113	0.88	67	59	0.93	8.3	21.0	11.4
6.5	21%	8000	565	118	108	0.89	63	55	0.93	8.3	20.9	11.4
6.5	21%	9000	543	114	104	0.89	59	51	0.91	8.1	20.5	11.1
6.5	21%	10000	522	110	99	0.90	55	47	0.89	7.9	20.0	10.9
6.5	50%	0	760	160	355	0.85	308	300	0.99	9.6	24.2	13.1
6.5	50%	1000	733	154	342	0.85	294	286	0.99	9.5	24.1	13.1
6.5	50%	2000	707	148	329	0.86	282	274	0.99	9.5	24.0	13.0
6.5	50%	3000	681	143	316	0.86	269	261	0.99	9.4	23.9	13.0
6.5	50%	4000	656	138	303	0.87	257	249	0.99	9.4	23.8	12.9
6.5	50%	5000	633	133	292	0.87	246	238	0.99	9.4	23.7	12.9
6.5	50%	6000	609	128	280	0.88	234	226	0.99	9.3	23.6	12.8
6.5	50%	7000	587	123	269	0.88	223	215	0.99	9.3	23.5	12.8
6.5	50%	8000	565	118	258	0.89	213	205	0.99	9.3	23.4	12.7
6.5	50%	9000	543	114	247	0.89	202	194	0.99	9.2	23.3	12.7
6.5	50%	10000	522	110	236	0.90	192	184	0.99	9.2	23.3	12.6
6.5	100%	0	760	160	710	0.85	663	655	0.99	10.7	27.0	14.6
6.5	100%	1000	733	154	683	0.85	636	628	0.99	10.6	26.8	14.5
6.5	100%	2000	707	148	657	0.86	610	602	0.99	10.5	26.6	14.4
6.5	100%	3000	681	143	631	0.86	584	576	0.99	10.4	26.4	14.3
6.5	100%	4000	656	138	606	0.87	560	552	0.99	10.3	26.2	14.2
6.5	100%	5000	633	133	583	0.87	537	529	0.99	10.3	26.0	14.1
6.5	100%	6000	609	128	559	0.88	514	506	0.99	10.2	25.8	14.0
6.5	100%	7000	587	123	537	0.88	492	484	0.99	10.1	25.6	13.9
6.5	100%	8000	565	118	515	0.89	470	462	0.99	10.1	25.5	13.8
6.5	100%	9000	543	114	493	0.89	448	440	0.99	10.0	25.3	13.7
6.5	100%	10000	522	110	472	0.90	428	420	0.99	9.9	25.1	13.6

Sometimes, the dog being transported may not be a MWD, but rather a detection working dog, such as a US Customs and Border Protection beagle. These dogs weigh-in at 9-14 kg, seriously less than the MWD. (American Kennel Club; open access, accessed on 28 December 2020: <https://www.akc.org/dog-breeds/beagle/>) Generally speaking, their cardiac output is lower than the larger dog. And, even if akin to the unconditioned mongrel dog with a cardiac output around 2.5-2.7 L/min (Taylor, 2007; Poole, 2015), there is little chance for the DO₂ to drop below the DO_{2crit}, short of exsanguination and/or cabin decompression.

On the other hand, a large dog with a resting cardiac output at the very low end of the normal range at 2.4 L/min (Stephenson, 2002) could see hints of DO₂ impairment at altitude (as low as 2,000 feet) even with a hemoglobin of 10 g/dl. See the DO₂ table below. Fortunately, most MWDs are highly conditioned with a resting cardiac output well above the low end of normal, ranging from 4.4 L/min at rest to 8.1 L/min exercising. (Poole, 2015) For the ill or injured or at-altitude MWD, an upped cardiac output and the splenic release response are natural adaptations, making a compromised DO₂, short of exsanguination and/or cabin decompression, unlikely.

MWD Tissue Oxygen Delivery Table

Effects of Hemoglobin, FiO ₂ , and Altitude on Tissue Oxygen Delivery												
Hgb (g/dl)	% O ₂ Delivered	Altitude (Ft)	Atmospheric Pressure (mmHg)	Ambient Dry O ₂ (mmHg)	Moist (37C) O ₂ (mmHg)	RQ	Alveolar O ₂ (mmHg) w/ typical PCO ₂ 40 mmHG	Arterial O ₂ (mmHg) w/ A-a = 8	O ₂ %Sat (from dissociation curve)	CaO ₂	DO ₂ w/ active CO	DO ₂ w/ rest CO
10.0	21%	0	760	160	149	0.80	99	91	0.98	13.4	40.2	10.1
10.0	21%	1000	733	154	143	0.80	93	85	0.97	13.3	39.8	9.9
10.0	21%	2000	707	148	138	0.80	88	80	0.96	13.1	39.3	9.8
10.0	21%	3000	681	143	133	0.80	83	75	0.96	13.1	39.3	9.8
10.0	21%	4000	656	138	127	0.80	77	69	0.95	12.9	38.8	9.7
10.0	21%	5000	633	133	122	0.80	72	64	0.95	12.9	38.8	9.7
10.0	21%	6000	609	128	117	0.80	67	59	0.94	12.8	38.3	9.6
10.0	21%	7000	587	123	113	0.80	63	55	0.93	12.6	37.9	9.5
10.0	21%	8000	565	118	108	0.80	58	50	0.93	12.6	37.9	9.5
10.0	21%	9000	543	114	104	0.80	54	46	0.91	12.3	37.0	9.3
10.0	21%	10000	522	110	99	0.80	49	41	0.89	12.1	36.2	9.0
10.0	50%	0	760	160	355	0.80	305	297	0.99	14.2	42.6	10.6
10.0	50%	1000	733	154	342	0.80	292	284	0.99	14.1	42.4	10.6
10.0	50%	2000	707	148	329	0.80	279	271	0.99	14.1	42.3	10.6
10.0	50%	3000	681	143	316	0.80	266	258	0.99	14.1	42.2	10.5
10.0	50%	4000	656	138	303	0.80	253	245	0.99	14.0	42.1	10.5
10.0	50%	5000	633	133	292	0.80	242	234	0.99	14.0	42.0	10.5
10.0	50%	6000	609	128	280	0.80	230	222	0.99	14.0	41.9	10.5
10.0	50%	7000	587	123	269	0.80	219	211	0.99	13.9	41.8	10.4
10.0	50%	8000	565	118	258	0.80	208	200	0.99	13.9	41.7	10.4
10.0	50%	9000	543	114	247	0.80	197	189	0.99	13.9	41.6	10.4
10.0	50%	10000	522	110	236	0.80	186	178	0.99	13.8	41.5	10.4
10.0	100%	0	760	160	710	0.80	660	652	0.99	15.3	45.9	11.5
10.0	100%	1000	733	154	683	0.80	633	625	0.99	15.2	45.6	11.4
10.0	100%	2000	707	148	657	0.80	607	599	0.99	15.1	45.4	11.3
10.0	100%	3000	681	143	631	0.80	581	573	0.99	15.0	45.1	11.3
10.0	100%	4000	656	138	606	0.80	556	548	0.99	15.0	44.9	11.2
10.0	100%	5000	633	133	583	0.80	533	525	0.99	14.9	44.7	11.2
10.0	100%	6000	609	128	559	0.80	509	501	0.99	14.8	44.5	11.1
10.0	100%	7000	587	123	537	0.80	487	479	0.99	14.8	44.3	11.1
10.0	100%	8000	565	118	515	0.80	465	457	0.99	14.7	44.0	11.0
10.0	100%	9000	543	114	493	0.80	443	435	0.99	14.6	43.8	11.0
10.0	100%	10000	522	110	472	0.80	422	414	0.99	14.5	43.6	10.9

APPENDIX C --- Toolkit for TVFS's Validation of MWDs for AE

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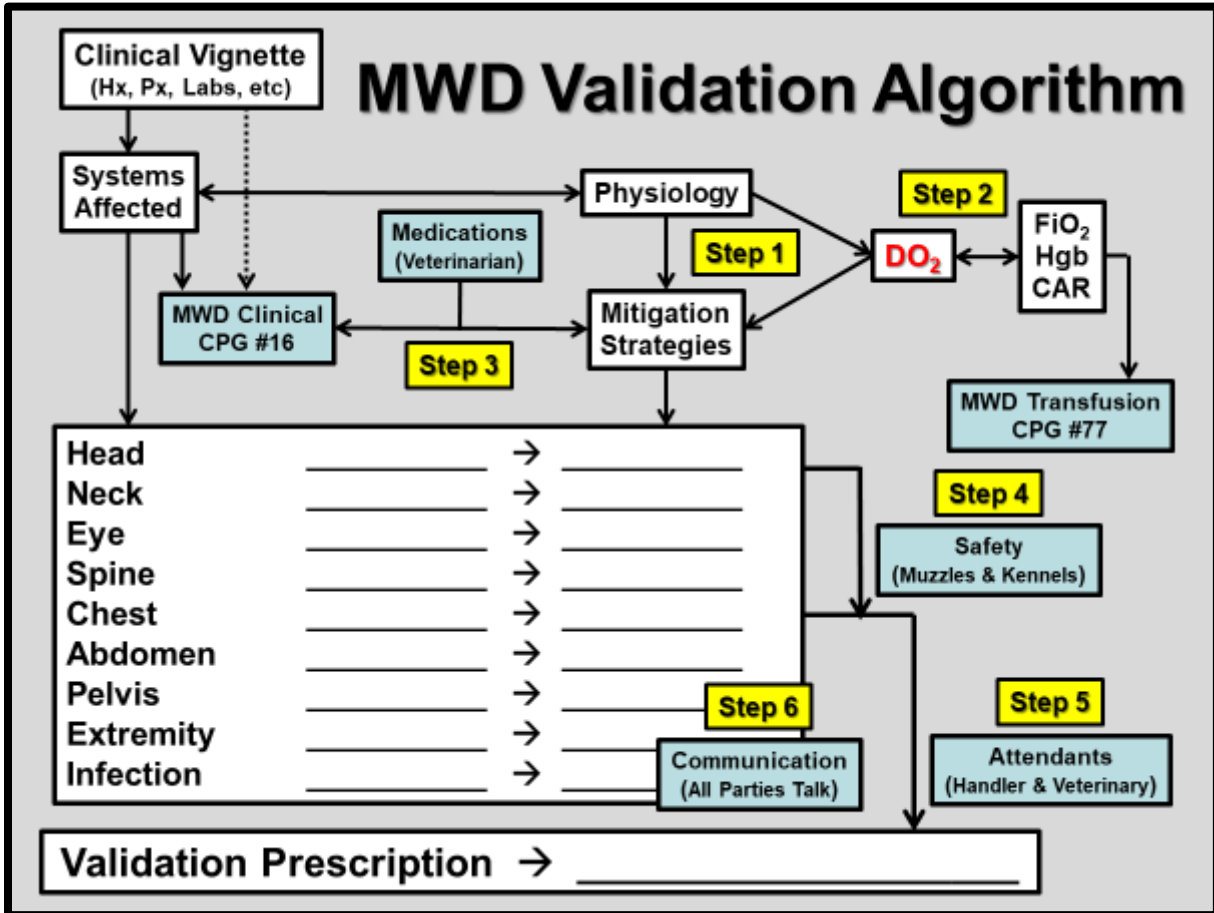
Introduction

In order to validate a MWD for regulated, fixed-wing AE, it is imperative for the TVFS or, for that matter, the on-the-ground local clearing Flight Surgeon to have a basic knowledge of the canine emergent veterinary care. Although there are some courses and/or training available, they are not yet either routine or easily available. (**Newcomer, 2012; Butcher, 2015; Dufour, 2015**) However, there are a few very good resources that are readily available and, once studied, will establish a baseline MWD physiological and clinical foundation for the TVFS. They include the following references:

- Clinical Practice Guideline (CPG). Clinical practice guidelines for military working dogs. Joint Theater Trauma System Clinical Practice Guideline. CPG ID: 16. Released: 12 December 2018.
- Clinical Practice Guideline (CPG). Transfusion for the military working dog. Joint Theater Trauma System Clinical Practice Guideline. CPG ID: 77. 10 December 2019.
- Taylor WM. Canine tactical field care, part 1, the physical examination and medical assessment. J Spec Oper Med. 2008; 8(3):54-60.
- Taylor WM. Canine tactical field care, part 2, massive hemorrhage control and physiologic stabilization of the volume depleted, shock-affected, or heatstroke-affected canine. J Spec Oper Med. 2009; 9(2):13-21.
- Taylor WM. Canine tactical field care, part 3, thoracic and abdominal trauma. J Spec Oper Med. 2010; 10(1):50-58.
- Toffoli CA, Rolfe DS. Challenges to military working dog management and care in the Kuwait theater of operation. Mil Med. 2006; 171(10):1002-1005.
- Vogelsang R. Care of the military working dog by medical providers. J Spec Oper Med. 2007; 7(2):33-47.

With this sort of canine physiological and clinical foundation, the TVFS is better prepared to employ the following tools while considering the MWD for AE. These tools are designed to facilitate prescribing both aircraft and canine interventions in such a way as to optimize fitness for flight and minimize postflight morbidity and mortality. In this way, the TVFS can safely validate the MWD for AE.

MWD Validation Algorithm



Note: Hx (history), Px (physical exam), MWD (Military Working Dog), CPG (Clinical Practice Guideline), DO₂ (tissue oxygen delivery), FiO₂ (oxygen fraction of inspired air), Hgb (hemoglobin level), CAR (cabin altitude restriction).

Precedence Guidance as Extracted from the MWD Clinical Practice Guideline

MWD Clinical Practice Guideline		
Clinical Situation	Recommended Precedence	CPG (page)
Abdominal Trauma --- AFAST score increasing	Urgent	50-51, 54
Gastric Dilatation and Volvulus --- emergent surgery in 2-4 hrs --- shock management	Urgent	59-60
Heat Stroke --- pending shock --- associated bleeding disorder	Urgent	67
Hypothermia --- pending shock --- associated bleeding disorder --- <i>afterdrop & rewarming shock</i>	Urgent	72
Envenomations* --- spiders (anti-venom) ---- diphenhydramine dosed	Urgent	78
--- scorpions (anti-venom) ---- diphenhydramine dosed	Urgent	78
--- snakes (anti-venom) ---- upper limb & torso bites ---- diphenhydramine/epinephrine dosed	Urgent	79
Eye Globe Foreign Body --- eye unbandaged	Urgent	101
Acute Spinal Cord Injury --- confined to kennel --- mild to moderate injury	Urgent	107
Blast Injury --- delayed onset signs & sxms	<i>asap</i>	83
Burns --- debridement needed	<i>evacuate</i> most likely Priority	86
Crush Injury/Crush Syndrome --- crush syndrome in 4-6 hrs ---- rhabdomyolysis & reperfusion injury	<i>evacuate</i> most likely Priority or Urgent	89
Open Fracture --- confined to kennel --- requires emergency surgery	<i>evacuate</i> most likely Priority or Urgent	91
Long Bone Fracture --- confined to kennel	<i>evacuate</i> most likely Priority or Urgent	93
Wounds --- wound vac equipment --- can wait until w/ Veterinarian	<i>evacuate</i> most likely Routine or Priority	96
Traumatic Brain Injury --- mild to moderate injury	<i>evacuate</i> most likely Priority or Urgent	111
Post-Traumatic Stress Disorder	Routine	115

Note: * In areas where envenomation is particularly high risk, antivenom, found at the Role II and/or Role III level of care, is highly regulated. When intravenously dosed, it can be life-saving. (CPG, 2018) AFAST (Abdominal Focused Assessment with Sonography for Trauma), hrs (hours), sxms (symptoms), asap (as soon as possible).

TVFS Prescribing Considerations --- Inflight Physiological Stressor Counters

Prescribing Considerations for the TVFS with MWDs --- Inflight Physiological Stressors			
Inflight Stressors	Physiological Effects	Clinical Effects	Countermeasures
Gravity	acceleration-deceleration	hemodynamic flow	head-first load, tail-first load, head of bed elevation, long steady take-off, gentle climb out, long slow landing
Humidity	reduced humidity	dehydration	rehydration (oral, intravenous), humidified breathing gases
Temperature	thermal instability	hypothermia, hyperthermia	Hypothermia: upped aircraft heat , blankets (reflective, heated), warmed IV fluids; Hyperthermia: upped aircraft cooling, upped airflow , cool misting (ground)
Noise	temporary threshold shift	temporary hearing loss	earplugs, earmuffs
Vibration	vibration	increased pain intensified pressure points upped metabolic activity tissue edema	damping with cushions (preferably air bladder* or jelly/gel), seat/litter isolation (hammock-like), centered fuselage loading away from engines, aircraft routing
Barometric Pressure	pressure-volume-diameter changes	trapped gas expansion	supplemental O ₂ , head-first load, HOB elevation, long slow take-off & landing, CAR
	-- <i>pneumocephalus</i>	-- agitation, confusion, vomiting (<i>tension pneumocephalus</i>)	needle/chest tube, Heimlich valve/suction water seal, supplemental O ₂ , CAR
	-- <i>pneumothorax</i>	-- dyspnea, no breath sounds, tympany (<i>tension pneumothorax</i>)	bedrest, supplemental O ₂ , CAR
	-- <i>pneumomediastinum</i>	-- dyspnea, subcutaneous neck air (<i>"malignant" pneumomediastinum</i>)	bedrest, supplemental O ₂ , needle/tube drain suction water seal, CAR
	-- <i>pneumopericardium</i>	-- distention, tympany, oliguria (<i>abdominal compartment syndrome</i>)	gastric tube, supine, bedrest, supplemental O ₂ , CAR
	-- <i>pneumoperitoneum</i>	-- peri-orbital/orbital emphysema	supplemental O ₂ , humidity, CAR
	-- <i>pneumatoxis oculi</i>	-- damaged/disrupted globe	recline w/ HOB elevated, patching per veterinarian, supplemental O ₂ , slow take-off/landing, CAR
	-- <i>miscellaneous (equipment)</i>	ETT (or tracheostomy) cuffs: <i>tracheal pressure necrosis</i> bladder catheter balloon: <i>balloon rupture</i>	air exchange with ascent/descent; air replacement w/ saline air replacement w/ saline (for balloon inflation, saline is generally preferred over air)
	venous gas emboli effect	closed system drains: <i>air and/or drain fluids into wound</i> ostomies: <i>ostomy dislodgement</i> air splints: <i>tourniquet-like effect</i>	venting drain on ascent/descent "burping" or "pinholing" appliance air exchange with ascent/descent; substitute plaster splint
	altered tissue dynamics	evolved, infused (tissue edema effect)	CAR
Oxygen	-- <i>inflammatory upregulation</i>	leaky vessels, tissue edema	CAR
	-- <i>Starling dysequilibrium</i>	leaky vessels, tissue edema	CAR
	drop in DO₂	ischemia	CAR , transfusion, supplemental O ₂
	hypoxia	ischemia	supplemental O ₂ (at least ground level equivalent)
	-- <i>injured bone & soft tissue</i> -- <i>on supplemental oxygen</i> drop in DO₂	tissue ischemia hypoxia & ischemia ischemia	supplemental O ₂ (at least ground level equivalent) supplemental O ₂ (at least ground level equivalent) CAR , transfusion, supplemental O ₂

Note: Red text denotes aircraft prescriptions. * Air bladder cushions provide better vibration damping, but are subject to asymmetric Boyle's Law expansion with hypobaria. Table is adapted from that in a US government publication and, as such, is not subject to copyright. (Butler, 2020c) IV (intravenous), CAR (cabin altitude restriction), O₂ (oxygen), ETT (endotracheal tube), DO₂ (tissue oxygen delivery).

TVFS Prescribing Considerations --- Interventions

Prescribing Considerations for the TVFS with MWDs --- Interventions		
Prescriptive Category	Prescription	Clinical Setting
Medical Adjuncts	cardiac monitor; suction; pulse oximeter medical attendant (Veterinary tech, Veterinarian) CCATT (rarely ever)	Cardiac, Pulmonary, Critical Care Cardiac, Psychiatric Critical Care, Cardiac, Pulmonary
Medical Interventions	protect airway (orotracheal intubation) gastric tube supplemental O ₂ (blow-by, mask), ventilator (rarely ever) sedation/muzzle-kennel blood components (per CPG & direct consultation with Veterinarian) medications (direct consultation with Veterinarian) extended ground stabilizing (per CPG & direct consultation with Veterinarian)	Critical Care, Immediately Post-Operation Critical Care, Abdominal Surgery (GI, splenectomy) Critical Care, Pulmonary, Trauma, Burns Psychiatric Trauma, Anemia All Settings Trauma, Critical Care
Middle Ear Adjuncts	generally not an issue	All Settings
Patient Paraphernalia	endotracheal (or tracheostomy) tube cuffs - cuff inflation w/ water chest tube - suction or Heimlich valve (no clamping of tubing) Jackson-Pratt™ drain - open on ascent and descent Hemovac™ drain - open on ascent and descent colostomy bag - decompress on ascent ("pinhole", "burp") bladder catheter - balloon inflation w/ water bivalve casts; control air splints cushions (litter, head, heel) blankets	Trauma, Pulmonary Trauma, Pulmonary Orthopedic, ENT, Thoracic, Abdominal Surgery Orthopedic, ENT, Thoracic, Abdominal Surgery Abdominal Surgery All Settings Orthopedic Neurologic, Orthopedic, Critical Care All Settings
Positioning Interventions	head first loading litter at aircraft airflow outlet valves head of bed elevation headrest to elevate and protect head	Neurologic, Ophthalmologic Infectious Neurologic, Ophthalmologic, ENT, Pulmonary, Cardiac Neurologic, Ophthalmologic, ENT
Safety	muzzle, kennel sedation handler	All Settings
Aircraft Manipulations	cabin altitude restriction full use of runway length modify rate of climb and descent (long, slow landings; long steady climbs) cabin airflow rates and patterns, control outlet airflow volumes aerial refueling no RONs (remain overnight); no stops	Trapped Gas, DO ₂ optimizing, Pulmonary, DCS Neurologic, Pulmonary, Cardiac Neurologic, Pulmonary, Cardiac Infectious Cabin Altitude Restriction, Extended AE Flight Critical Care, Cardiac, Pulmonary

Note: Peach highlights denote Safety Prescriptions. Gold highlights denote Aircraft Prescriptions. Table is adapted from that in a US government publication and, as such, is not subject to copyright. **(Butler, 2020c)**
CCATT (Critical Care Air Transport Team), GI (gastrointestinal), O₂ (oxygen), CPG (Clinical Practice Guideline), ENT (Ears, Nose, Throat – Otolaryngology), DO₂ (tissue oxygen delivery), DCS (decompression sickness), RONs (remain overnights).

MWD Hearing Protection --- Custom Constructed Earplugs

The MWD has very sensitive hearing. To protect that hearing over prolonged AE missions, custom constructed earplugs may be prescribed. The construction is a readily doable and relatively simple process:

1. Cut off the fingers from a latex glove.
2. Stuff the fingers with cotton or gauze. Do not overstuff.
3. Tie off the filled fingers. Alternatively, the fingers can be sealed with silk suture ties.
4. Lightly coat the earplugs with a lubricant (e.g., VaselineTM, KYTM jelly).
5. Gently insert the earplugs into the MWD's ears.
6. Monitor the MWD. Not infrequently, the dog will attempt to dislodge the earplugs.

These earplugs have proven to be easily constructed and largely effective in the field. (*personal communication*, Colonel (ret) Michelle Bryce, DO, MTM&H)



Note: The photograph was taken by and courtesy of Col (ret) Michelle Bryce, DO, MTM&H.

Normal MWD Clinical Parameters

MWD Clinical Practice Parameters		
Parameter	Normal	Source
Vital Signs		
--- Temperature (F)	101-103	CPG, 2018
--- Heart Rate (beats/min)	60-80	
--- Respiratory Rate (breaths/min)	16-30	
--- Blood Pressure (mmHg)	Systolic = 120 Diastolic = 80	
--- Capillary Refill (seconds)	< 2	Vogelsang, 2007
--- Weight (kg)	15-46 (mean = 32)	present study
Laboratory Values		
--- WBC (cells/uL)	6-17	CPG, 2018
--- Hgb (g/dl)	12-18	
--- Hct (%)	35-45	
--- Glucose (mg/dl)	60-110	
Arterial Blood Gas Values		
--- pH	7.35-7.45	CPG, 2018
--- PaO ₂ (mmHg)	85-100	
--- PaCO ₂ (mmHg)	24-38	
--- HCO ₃ (mmol/L)	17-25	
--- Lactate (mmol/L)	1.5-2.0	
Tissue Oxygen Delivery Factors		
--- CO (conditioned greyhound) (L/min)	4.4-8.1	Poole, 2015
--- CO (large dog) (L/min)	2.4-9.6	Stephenson, 2002
--- CO (unconditioned mongrel) (L/min)	2.7	Poole, 2015
--- DO _{2crit} (ml O ₂ /kg/min)	9.8	Cain, 1965; Cain, 1977

Note: F (Fahrenheit), min (minute), mmHg (pressure in millimeters of Mercury), kg (kilogram), uL (microliter), g (gram), dl (deciliter), Hct (hematocrit), % (percent), mg (milligram), mmol (millimole), L (liter), pH (serum acid-base level), PaO₂ (partial pressure of arterial oxygen), PaCO₂ (partial pressure of arterial carbon dioxide), HCO₃ (serum bicarbonate level), CO (cardiac output), DO_{2crit} (critical level of tissue oxygen delivery), O₂ (oxygen).

Table for Determining Sea Level Oxygen Equivalency at Altitude

Altitude (Ft)	Atmospheric Pressure (mmHg)	Oxygen 21% (mmHg)	Oxygen Requirements to Maintain Sea Level Equivalency**																		
10000	522	110		32	38	45	53	60	68	75	83	90	98								
9000	543	114		30	36	43	50	58	65	72	79	86	93								
8000	565	119		29	34	41	48	55	62	69	76	83	89	96							
7000	587	123		28	33	40	46	53	59	66	73	79	86	92	99						
6000	609	128		27	32	38	44	51	57	63	70	76	82	89	95	101					
5000	633	133		26	30	37	43	49	55	61	67	73	79	85	91	97					
4000	656	138		25	29	35	41	47	53	59	64	70	76	82	88	94	100				
3000	681	143		24	28	34	39	45	51	56	62	67	73	79	84	90	96				
2000	707	148		23	27	32	38	43	49	54	59	65	70	76	81	86	92	97			
1000	733	154		22	26	31	36	42	47	52	57	62	68	73	78	83	88	94	99		
0	760	160	PiO ₂	150	178	214	250	285	321	357	392	428	463	499	535	570	606	642	677	713	
			FiO ₂	0.21	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00	
O ₂ Source			RA	Nasal Cannula (1-6 L/min)						Non-Rebreathing Mask (7-15 L/min)											
				Simple Mask (5-10 L/min)						Partial Rebreathing Mask with Bag (7-15 L/min)											
			**Pertinent Formula:																		
			PiO ₂ = FiO ₂ x (P _{sea level} – P _{H2O})																		
			Required FiO ₂ = [FiO ₂ x (P _{sea level} – 47 mmHg)] / (P _{altitude} – 47 mmHg)																		

Note: Table employs formulae described by McLaughlin et al and oxygen delivery device capabilities described in the Air Force Instruction. (McLaughlin, 2003; AFI 48-307 Vol 1, 2017) It was taken from US government publication and, as such, is not subject to copyright. (Butler, 2020c) Although this table is determined for sea level equivalency, another could be easily created with any desired ground level equivalency. Rule of Thumb: Nasal Cannula (~4% per each added L O₂/min); Simple Mask (~6% per each added L O₂/min); Non-Rebreathing Mask (~4-6% per each added L O₂/min). Despite it being devised for the human, it is a good approximation for the dog. Ft (feet), mmHg (pressure in millimeters Mercury), % (percent), PiO₂ (oxygen partial pressure of inspired air), FiO₂ (oxygen fraction of inspired air), O₂ (oxygen), RA (room air), L (liter), min (minute), P (pressure).

Trapped Air Pressure-Volume-Diameter Relationships

Pressure-Volume-Diameter Relationships			
Altitude (feet)	Pressure (mmHg)	Volume Change (%)	Diameter Change (%)
10000	523	45.3	13.3
9000	543	40.0	11.8
8000	565	34.5	10.4
7000	587	29.5	9
6000	609	24.8	7.7
5000	632	20.3	6.3
4000	656	15.9	5
3000	681	11.6	3.7
2000	707	7.5	2.4
1000	733	3.7	1.2
500	746	1.9	0.6
Sea Level	760	0	0
33	1520	-50	-21
66	2280	-67	-31
99	3040	-75	-37
132	3800	-80	-41
165	4560	-83	-45

Note: The table was derived with the ideal application of Boyle's Law ($P_1 \cdot V_1 = P_2 \cdot V_2$) and the volume of a spherical bubble ($V = \frac{4}{3} \pi r^3$). The table was taken from US government publication and, as such, is not subject to copyright. (Butler, 2020c) mmHg (pressure in millimeters Mercury), % (percent), P_1 (initial pressure), V_1 (initial volume), P_2 (end pressure), V_2 (end volume), V (volume), π (pi, constant = 3.14), r (radius).

MWD Medication Dosing

It is especially important to remember that the TVFS does not independently prescribe medications for the MWD. Such prescribing is performed only with the direct ongoing consultation of the theater veterinarian.

MWD Medication Dosing (TVFS does <i>not</i> prescribe without theater veterinarian consultation)			
Drug	Dose	Route	Source
Antibiotics			
Amoxicillin	20-30 mg/kg q12h	PO	CPG,2018
Amoxicillin-Clavulanic Acid	13.75 mg/kg q12h	PO	Vogelsang, 2007
Ampicillin	20-30 mg/kg q8h	IV	CPG,2018
Ampicillin-Sulbactam	20-30 mg/kg q8h	IV	CPG,2018
Cefazolin	20-30 mg/kg q8h	IV	Vogelsang, 2007
Cefotaxime	22-25 mg/kg q8h	IV/IM/SQ	CPG, 2018; DD Form 3073, 2019
Ceftriaxone	25 mg/kg q8-12h	IV	Vogelsang, 2007
Cephalexin	20-30 mg/kg q8-12	PO	Vogelsang, 2007; CPG, 2018
Ciprofloxacin	35 mg/kg q12h	PO	CPG, 2018
Ertapenem	15 mg/kg	IV/SQ	DD Form 3073, 2019
Pain Medications			
Morphine	0.5-2.0 mg/kg q3-4h	IM/SQ	Vogelsang, 2007
Fentanyl	4-10 ug/kg		Vogelsang, 2007
Meloxicam	0.1-0.2 mg/kg	IV/SQ/PO	DD Form 3073, 2019
Propofol	3-6 mg/kg slow, then 0.1-0.6 mg/kg/min	IV	Vogelsang, 2007
Sedatives			
Diazapine	0.2-0.3 mg/kg	IV	Vogelsang, 2007
Ketamine	2-10 mg/kg	IV/IM	Vogelsang, 2007; DD Form 3073, 2019
Midazolam	0.1-0.3 mg/kg	IV/IM	DD Form 3073, 2019
Other Medications			
Diphenhydramine	2 mg/kg	IM	Vogelsang, 2007
Epinephrine	0.02 mg/kg	IV	Vogelsang, 2007
Methylprednisolone	30 mg/kg	IV	Vogelsang, 2007

Note: The TVFS is not an independent veterinary prescriber. This dosing chart is provided to aid the TVFS while in direct consultation with the theater veterinarian. mg (milligram), kg (kilogram), h (hours), qXh (dosed at X hour intervals), PO (*per os* = oral), IV (intravenous), IM (intramuscular), SQ (subcutaneous), CPG (Clinical Practice Guideline), DD (Department of Defense).

LIST OF ABBREVIATIONS AND ACRONYMS

AE	aeromedical evacuation (tactical and strategic); usually regulated, fixed wing
AFAST	Abdominal Focused Assessment with Sonography for Trauma
AFB	Air Force Base
AFRICOM	Africa Command
asap	as soon as possible
BI	Battle Injury
CaO₂	arterial oxygen content (ml O ₂ /dl blood = vol%)
CAR	cabin altitude restriction
CCATT	Critical Care Air Transport Team
CENTCOM	Central Command
CO	cardiac output (L/min or dl/min)
CONUS	Continental United States
CPG	Clinical Practice Guideline
DCS	decompression sickness
DD	Department of Defense
df	degrees of freedom
dl	deciliter
DNBI	Disease, Non-Battle Injury
DO	Doctor of Osteopathy
DO₂	tissue oxygen delivery (ml O ₂ /kg/min)
DO_{2crit}	critical level of tissue oxygen delivery (ml O ₂ /kg/min)
DoD	Department of Defense
DVM	Doctor of Veterinary Medicine
ENT	Ears, Nose, Throat (aka Otolaryngology)
ETT	endotracheal tube
EUCOM	European Command
F	temperature in degrees Fahrenheit
FiO₂	oxygen fraction of inspired air
FS	Flight Surgeon
g	gram
GI	gastrointestinal

GSW	gunshot wound
HCP	Health Care Provider (aka human health care provider)
HCO₃	serum level of bicarbonate (mmol/L)
Hct	hematocrit (%)
Hg	Mercury
Hgb	hemoglobin level (g/dl)
HgbCC	hemoglobin oxygen content constant (dog = 1.34 ml O ₂ /g Hgb)
hr(s)	hour(s)
Hx	history
Hz	Hertz (cycles per second)
ICAO	International Civil Aviation Organization
ID	identification number
IED	improvised explosive device
IM	intramuscular
IV	intravenous
K-9	canine
kg	kilogram
L	liter
MD	Doctor of Medicine
MEDEVAC	medical evacuation (tactical); most commonly rotary wing
mg	milligram
min	minute
ml	milliliter
mmHg	pressure in millimeters Mercury
mmol	millimoles
MTF	medical treatment facility
MWD	military working dog
NATO	North Atlantic Treaty Organization
NBI	Non-Battle Injury
NPO	<i>non per os</i> (aka nothing by mouth)
NSAID	non-steroidal anti-inflammatory drug
O₂	oxygen
OEF	Operation Enduring Freedom (Afghanistan)

OIF	Operation Iraqi Freedom (Iraq)
P	pressure
P₁	initial pressure
P₂	end pressure
PaCO₂	partial pressure of arterial carbon dioxide (mmHg)
PACOM	Pacific Command
PaO₂	partial pressure of arterial oxygen (mmHg)
P_AO₂	partial pressure of alveolar oxygen (mmHg)
P_B	ambient barometric pressure (mmHg)
PDSA	People's Dispensary for Sick Animals
pH	"power of hydrogen," denotes acid-base status of a solution (pH = 7 = neutral)
PhD	Doctor of Philosophy
P_{H2O}	partial pressure of water vapor (dog = 50 mmHg)
PiO₂	oxygen partial pressure of inspired air
PMR	Patient Movement Request
PO	<i>per os</i> (aka by mouth or oral)
PTSD	Post-Traumatic Stress Disorder
Px	physical exam
qXh	dosed at X hour intervals
r	radius
RA	room air
RN	Registered Nurse
RON	remain overnight
RQ	respiratory quotient (dog = 0.8)
SaO₂	arterial hemoglobin oxygen saturation (%)
SD	standard deviation
Sgt	Sergeant
SOUTHCOM	Southern Command
SpO₂	percent oxygen saturation of hemoglobin by pulse oximetry
SQ	subcutaneous
sxms	symptoms
TRAC²ES	TRANSCOM Regulating and Command and Control Evacuation System
TRANSCOM	Transportation Command

TVFS	Theater Validating Flight Surgeon
US	United States
USAF	United States Air Force
USS	United States Ship
V	volume
V₁	initial volume
V₂	end volume
WBC	white blood cell count (cell/uL)
Wing	American Theater Wing
Wt	weight (kg)
uL	microliter
%	percent
π	pi (constant = 3.14)