Contributions of Griffith Pugh to High Altitude and Environmental Physiology and Medicine: A Narrative Review

by

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ABSTRACT

The high-altitude environment, which is characterized by low ambient temperature, precipitation (rain and snowfall), increased windchill, and hypoxia [low partial pressure of inspired oxygen (PiO_2)] caused by decreased barometric pressure poses several challenges for athletes, industrial/commercial workers, military personnel, and researchers. All these factors decrease performance and survival. One famous example of the deleterious impacts of altitude on performance and survival, is human experiences on Mount Everest. The British experienced 30 years of failure in attempting to reach the summit of Everest. However, on the 29th of May, 1953 Everest was successfully climbed. Success on Everest may not have been possible without the indefatigable scientific recommendations and contributions of Dr. Griffith Pugh (pioneer Everest physiologist) who was a major contributor to the field of altitude science in general. The purpose of this review project was to investigate the scientific contributions of Dr. Pugh to the understanding of physiology of performance and injury treatment related to cold and altitude by systematically reviewing all his publications on these topics. We searched Medline database and Web of Science for publications by Lewis Griffith Pugh which revealed 61 and 75 articles respectively. Two reviewers independently screened for all articles that met the inclusion criteria (articles related to altitude, and/or cold physiology, and/or exercise physiology). At the end of the screening process, 61 papers (peer reviewed, n=52; and gray literature, n=9) met the inclusion criteria which were analysed. This narrative review revealed that Pugh was a model of a dedicated researcher who has contributed immensely to the field of high-altitude medicine and environmental physiology by conducting several physiological studies which have earned him significant academic recognition. Pugh had a long storied career among notable researchers. Interestingly, some of his scientific recommendations are still valid and reliable . His scientific work led to many significant practical applications.

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CHAPTER 1: INTRODUCTION

Cold environments pose several challenges for adventurers, athletes, military, search and rescue (SAR) and law enforcement personnel, commercial/industrial workers, and researchers [1]. These challenges mainly include decreased performance, risk of cold injuries (including frostbite, hypothermia, and non-freezing cold injury), and survival [2]. Altitude enhances the effects of cold and introduces altitude-specific challenges including decreased aerobic capacity [3], altitude sicknesses [e.g., acute mountain sickness (AMS), high altitude cerebral edema (HACE), high altitude pulmonary edema (HAPE)], and survival [4].

Cold exposure decreases nerve conduction velocity [5] and muscle contraction velocity [6] and intensity [7, 8] resulting in decreased manual dexterity [9, 10], strength [11] and endurance [12, 13]. For example, whole body cooling studies have demonstrated that exposure to cold, decreased skin (T_{sk}), muscle (T_{mus}) and core (T_{co}) temperature, impaired arm performance, progressing from fine to gross motor movements [9, 10].

Cold exposure not only inhibits physical performance, but presents a risk for cold injury including frostbite, hypothermia, and non-freezing cold injury. For instance, Golden, Francis et al. a case report on the morbidity of cold injury among British soldiers during the Falkland Islands war in 1982 that lasted for 74 days, reported that the majority of the British soldiers who were in the infantry unit were affected with cold-associated injuries [14]. It follows that any stress, such as cold, that diminishes performance and causes injury, could compromise survival [2].

High altitude poses its own specific challenges to the overall wellbeing of climbers, some military personnel, and to a lesser extent, high altitude residents. One major challenge humans face at high altitude is hypoxia [low partial pressure of inspired oxygen (PiO_2)] caused by decreased barometric pressure (hypobaria) which leads to hypoxemia [low arterial blood oxygen

(PaO_2)] and tissue hypoxia (low tissue oxygen) which has a deleterious effect on performance, health (e.g., altitude sickness) and survival [4]. For instance, Grover and Reeves investigated exercise performance at sea level and 3,100 m (10,170 ft) altitude [15]. They reported that exercise capacity decreased to approximately 70% of the sea level values. Similarly, these findings were in agreement with another study West and Wagner which reported that on Mount Everest, the maximum oxygen uptake, or aerobic capacity, of climbers, decreases with altitude [3].

When discussing the deleterious impacts of altitude on performance and survival, one famous example is human experiences on Mount Everest. Everest is the world's highest mountain (8,848 m – 29,029 ft) located at the edge of Tibetan Plateau on the border between Nepal and China. According to various studies, in an attempt to reach the summit of Everest, more than 300 people have died [16]. Most of the deaths recorded have been attributed to serac collapse [17], avalanches [18], extreme cold exposure [19], falls [20], frostbite, and high altitude illness [21, 22]. Interestingly, Everest was successfully climbed on 29th May, 1953 by the British expedition after 7 documented failed attempts in 1921, 1922, 1924, 1933, 1935, 1936 and 1938.

According to the book "*Everest the First Ascent*" written by Harriet Tuckey, previously failed British expeditions to Everest had given little regard to science [124]. For instance, it was stated in the book that British climbers believed that the use of supplemental oxygen to ascend Everest was considered unsportsmanlike and cheating. Thus, they believed that reaching the summit of Everest should only be achieved by their climbing skills and not with the aid of a supplementary oxygen. However, it was recorded that some of the climbers in the failed expeditions still made use of supplemental oxygen despite the fact that they weren't convinced of its usefulness [23]. The success achieved on the 29th May, 1953 in reaching the summit of Everest was aided greatly by the use of supplemental oxygen and other scientific contributions. One of the early, and most significant, scientific contributors to success at altitude was Dr. Griffith Pugh. After extensive and thorough scientific research, Dr. Pugh was able to identify that lack of oxygen (hypoxia), dehydration, poor diet/inadequate food, loss of appetite, lack of hygiene, poor clothing design, poor acclimatization, failed oxygen systems were factors that had undermined the previously failed British expeditions to Everest [24, 23]. For instance, inadequate fluid intake predisposed climbers to dehydration which in turn, became debilitating and negatively affected climber performance at high altitude. For example, after conducting several series of applied scientific experiments Dr. Pugh recommended that to avoid dehydration at high altitude, climbers should ingest 3-4 liters of fluid per day [24]. The above recommendation is one out of the numerous scientific recommendations offered by Dr. Pugh to ensure success at high altitude. It is noteworthy that Dr. Pugh was a major contributor to environmental science in general and to the success on Everest specifically.

The purpose of this thesis is to investigate the scientific contributions of Dr. Griffith Pugh to the understanding of physiology of performance and injury treatment related to cold and altitude by reviewing all his publications on these topics.

CHAPTER 2: REVIEW OF LITERATURE

History of Griffith Pugh

Griffith Pugh was a British physiologist and mountaineer. He was born on November 30, 1909 and died on December 22, 1994 [23], after suffering from several episodes of stroke [124]. Going into Pugh's early life, he was said to have attended a well-known English public-school (Harrow). Because Pugh's father was a barrister, he persuaded Pugh to study law. Thus, from 1928-1931, Pugh took a degree in law at the New College Oxford. However, in 1932, he abandoned the law program and switched to study medicine. In 1939 Pugh qualified as a medical doctor at St. Thomas's Hospital, London. Interestingly, he walked down the aisle with Josephine and the marriage was blessed with four children. Among the four children was Harriet Tuckey who painstakingly wrote the book *("Everest – The First Ascent" The untold story of Griffith Pugh, the man who made it possible*) [124]. Griffith Pugh's life history won't be complete without mentioning the fact that he was a keen skier, having represented Britain in the world championships in 1935 and 1937. He was enlisted for the 1936 Olympic cross-country 18-km event but unfortunately, he could not participate owing to a severe back injury [23]. Griffith Pugh joined the army in September 1939, during the World War II (WWII) as a junior doctor and served as a Captain in the Royal Army Medical Corps. While at the warfront, Pugh treated many cases of frostbite, hypothermia and venereal diseases. During WWII, in the summer of 1942, Pugh was posted to the Mountaineering Warfare Training School in Lebanon to assist W.J. Riddell who was the chief instructor of the school. It was put on record that Riddell specifically requested for Pugh to become the exercise physiologist of the training school knowing very well that Pugh had a penchant in extreme climate conditions studies. Interestingly, upon arrival at the training school, Pugh faulted the training sessions (7.5 hours/day of skiing for 3 weeks) of incoming trainees for the 50% failure rate at the end of skiing test [23]. He considered the training sessions as extremely physically and mentally demanding and thus, gave recommendations for a gradual increase in training (3 hours/day of skiing for the first week, followed by a gradual increase to 6 hours/day in the third week) [23]. These recommendations resulted in a increase to a 90% success rate at the end of their skiing test [23]. According to several studies, Pugh's career in physiology took off at the warfare training school in Lebanon where he was given full responsibility for physiological research and training of troops; he had an almost unlimited supply of experimental subjects and had no bureaucratic restraints [23]. For instance, he carried out research on adaptation to altitude, physiology of exercise, and effects of cold stress on physical performance. He was also instrumental in designing protective clothing, stoves, and tents used by the troops. According to Ward and Millege, Pugh wrote a string of papers for the training school. Those papers were later used in the army training manual [23]. Owing to his tremendous research and accomplished achievements at the training school, he was regarded as "*someone who knows about cold"*. On October 1945, Pugh was demobbed from the army.

History has it that because of his continued interest in altitude and cold physiology research, in 1950 Pugh joined the Department of Human Physiology at the Medical Research Council (MRC) in Hampstead. He worked along side the director of MRC, Otto Edolm a professor of physiology from the University of Western Ontario, Canada. Pugh did a lot of cold physiology research at MRC. For instance, in 1951 he almost suffered from being paralysed due to cold while in the middle of a 25-minute self-imposed hypothermia experiment in an ice bath. Going forward, Pugh who was regarded as an expert in altitude and cold physiology studies was contacted to assist the Everest Committee in the bid to climb Mount Everest after 30 years of failure by the British. The Everest Committee was a conservative body that was comprised of individuals from the *Alpine Club* (mundane professionals who did not believe in science) and the *Royal Geographical Society* (professionals that believed in the principle of science). According to Tuckey it was evident that previously failed Everest expeditions were organized by amateurs who never deemed it fit to adopt professional and scientific approaches [124]. In 1952, Pugh carried out several experimental studies on the British expedition to Cho Oyu (sixth highest mountain in the world) [23]. According to Ward and Milledge the Cho Oyu expedition made it evident to Pugh that for Everest to be successfully climbed, factors such as lack of oxygen, poor hygiene, dehydration, poor diet, poor acclimatization, poor clothing design needed to be addressed [23]. Fortunately, Pugh was able to address all these factors that undermined the previously failed Everest expeditions. Thus, on May 29, 1953 Everest was successfully summited by two men, Sir Edmund Hillary and Tensing Norgay.

Reaching the summit of Everest would not have been successful without the indefatigable scientific contributions of Griffith Pugh. The success at Everest opened the door to what was described as a *"cornucopia of science"* [124]. Sadly, Pugh wasn't given fair credit for his contributions that led to the success at Everest. John Hunt who was the leader of the expedition, failed to inform the public about Pugh's scientific contributions. However, years later John Hunt conceded that Pugh was the man behind the success at Everest. In 1975, Pugh retired at the Medical Research Council [124]. However, before retirement, he had a lot of articles published in reputable journals; all his published articles were stored in a special archive of high-altitude medicine at the University of California library. Even after death, Pugh was still regarded as the pioneer Everest physiologist and as one of the fathers of the burgeoning discipline of high-altitude medicine and physiology.

Thermoregulation- General

Humans are regarded as *endothermic homeotherms* meaning we have the ability to produce our own heat and regulate our own body temperature [25]. The ability to maintain core temperature is crucial for optimal physiological function and survival, especially when faced with thermal stress [25]. However, an abnormal core temperature deviation might prove detrimental to the health (cardiovascular, neuromuscular, respiratory) of an individual. The body's thermoregulatory model is divided into two thermal compartments (central core and peripheral shell) [25, 26]. The central core temperature reflects the temperature within the deep body tissue and organs with high levels of basal metabolism such as liver, lungs, brain and heart [25, 27]. The normal core body temperature is approximately 37°C, although it fluctuates throughout the day (circadian rhythm) [25]. It has been established that the core temperature is the primary regulated variable for thermoregulation. On the other hand, the peripheral shell temperature reflects the skin temperature [27]. The average skin temperature in a thermoneutral air environment is approximately 33-34°C. The skin serves as a defensive mechanism for the core against thermal stress. One major difference between the core and skin temperature, is that the skin temperature displays more heterogeneity than the core temperature when exposed to thermal stress (either warm or cold).

Thermal Balance and Mechanism of Heat Loss

The body core temperature depends on a dynamic balance between heat loss and heat gain. To ensure human survival, the body should be able to preserve its own core temperature (within the head, thorax and abdomen) in the face of environmental challenges. It is noteworthy that the heat balance equation represents the balance between heat gain and heat loss [25]. The formulae for the heat balance equation is:

Heat storage = metabolism – evaporation ± conduction ± convection ± radiation.

Metabolism refers to the chemical reactions occurring within the body that produce not only work, but heat. For instance, muscular activity during exercise produces a larger percentage of heat. The four mechanisms of heat transfer are conduction, convection, radiation and evaporation. Conduction, convection and radiation are bidirectional heat transfer (suggesting either heat loss or heat gain is possible) as heat is transferred down from a thermal gradient (hot to cold temperature). Conversely, evaporation is a unidirectional heat transfer (suggesting only heat loss is possible). Evaporation refers to heat loss to the environment as water vaporizes from the respiratory passages and skin surface (sweating). Evaporative cooling is the only mechanism of heat loss once ambient temperature exceeds body temperature. Radiation refers to electromagnetic radiation (heat) transferred to bodies that are not directly in contact. Conduction refers to movement of heat between two bodies that are directly in contact. Lastly, convective heat transfer refers to transfer of heat to a moving gas or liquid. For instance, when the body is warm, the air molecules that make contact with the body become warm with heat taken from the body [28, 29].

Thermoregulatory Responses – Behavioral and Physiological

Human thermoregulation is achieved via a combination of autonomic, physiological and behavioural thermoeffector responses [30, 27]. Behavioural thermoeffector responses ultimately aim at promoting heat balance. For instance, in humans, behavioural responses can either be a *simple action* such as changing of clothing or a *complex action* such as relocating to an environment that has a heating or cooling system [30]. On the other hand, physiological responses are controlled as follows; the hypothalamus is the central coordinating/integrating center for temperature regulation. Many studies have indicated that it is the preoptic-anterior hypothalamus that responds to temperature changes by receiving afferent thermal signals from peripheral thermoreceptors on the skin, and central thermoreceptors in the spinal cord and brain [31]. This afferent information is integrated [e.g., the integrated thermal signal (ITS)] in the hypothalamus. As it either increases or decreases, it initiates an efferent response for heat loss or heat gain depending on whether the body is cold or warm [32, 33]. In a cold condition, the ITS is decreased such that heat loss is reduced as a result of vasoconstriction (decrease in skin blood flow) and shivering (generating metabolic heat). Conversely, in a warm condition, the ITS is increased such that heat loss is achieved by vasodilation (to increase in skin blood flow) and sweating (to promote evaporative heat loss).

It is important to note that behavioural and physiological thermoeffector responses have three parameters which include: Threshold – the value of the ITS at which the response is initiated; Gain (sensitivity) – the relative increase in response for a given change in ITS; and Maximum – the maximum intensity of the response. Several thermoregulatory control models reflect organization of physiological and behavioral responses [34]. According to Kingma, Frijins et al. the onset and perception of thermoregulatory response can be defined as follows: The "thermal comfort zone" is the ambient temperature range that is perceived as comfortable and does not evoke any behavioural changes [35]. The "thermoneutral zone" is the range in ITS in which the core temperature is maintained only by changes in skin blood flow. Finally, the "null zone" is the range in ITS between the thresholds for shivering and sweating [32, 33, 36]. The range in ITS increases from the thermal comfort zone to the thermoneutral zone to the null zone are seen in Figure 1.

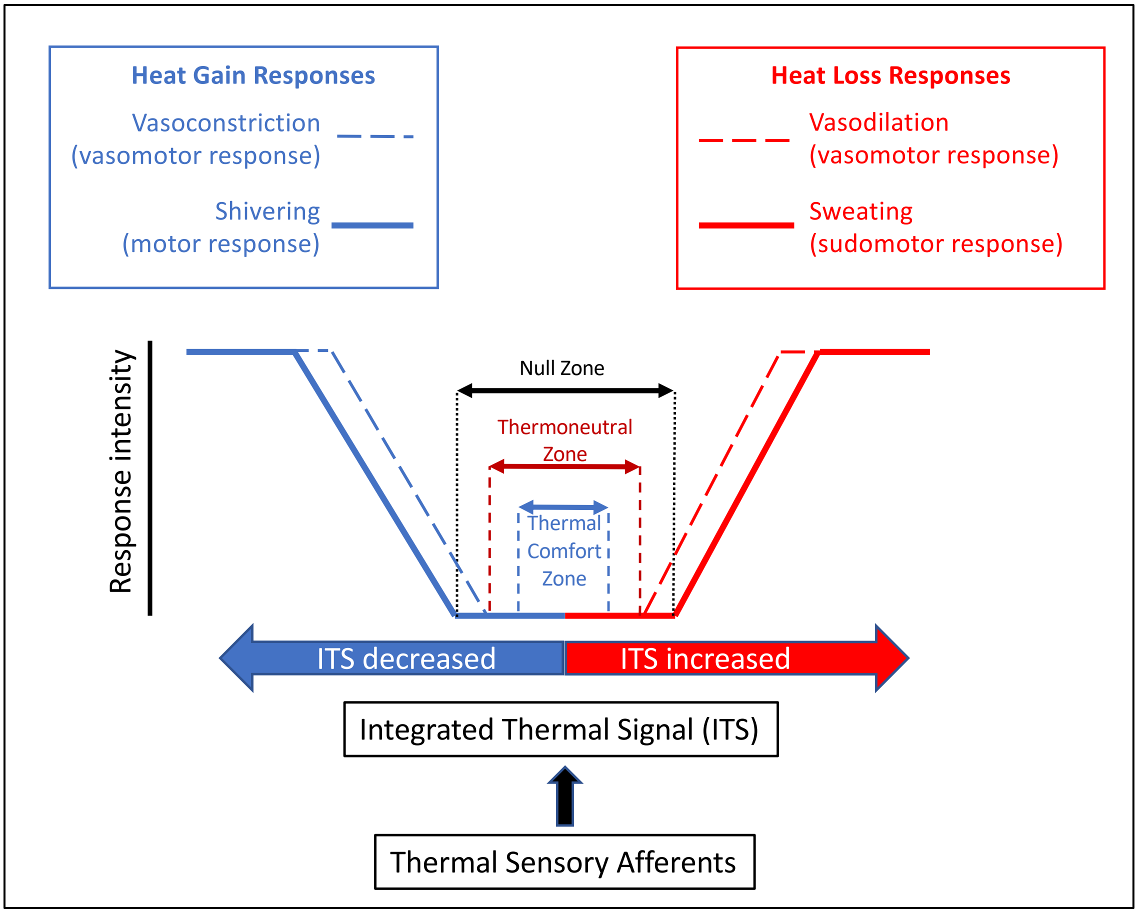

Figure 1. The integrated thermal signal model. Solid lines represent sweating (red) and shivering (blue) intensity. Dashed lines represent vasodilation (red) and vasoconstriction (blue) intensity. As ITS deviates from normal values, responses are initiated and increase to a maximum value.

Cold Physiology – Short- and Long-Term Adaptation

It is believed that when an individual is exposed to cold, thermoregulatory responses are triggered in order to maintain thermal hemostasis [2]. According to various studies there are short-term (acute) and long-term (chronic) physiological adaptations to cold [2].

Short-Term Physiological Adaptation Response

Short-term physiological adaptation to cold includes cutaneous vasoconstriction and shivering, which reduces heat loss and increases metabolic heat production, respectively [2]. According to Veicsteinas, Ferretti et al. vasoconstriction begins immediately in response to a decline in skin temperature (< 35°C) [38]. It has been established that vasoconstriction is either caused by a reflexive response (when a part of the body exposed to cooling which elicits a reflex vasoconstriction to an unexposed part) [39], and by local cooling of the skin blood vessels [mediated by norepinephrine, α_2 adrenergic and transient receptor potential melastatin 8 (TRPM8)] [40].

According to various studies, short term physiological responses to cold are influenced by body composition, sex, age, fatigue. For instance, females are generally known to have a greater body surface area (BSA)-to-mass ratio than males which predisposes them to a greater heat loss and decline in body temperature during cold exposure [41]. Studies have observed that during the menstrual cycle, women are less sensitive to shivering response during the luteal phase compared to the follicular phase [42]. Individuals who are above 60 years old have lower tolerance to cold due to reduced vasoconstriction and heat conservation when compared to younger individuals [43, 44]. Studies have shown that norepinephrine and neuropeptide Y levels which are the primary sympathetic neurotransmitters responsible for reflex cold-induced cutaneous vasoconstriction, are decreased with aging, whereas in younger individuals there is an increase in the release of these neurotransmitters [45]. Furthermore, when an individual experiences exertional fatigue, there is an increased risk of being exposed to cold due to degraded thermoregulatory effector responses (shivering and vasoconstriction) [46]. Thermoregulatory responses during cold exposure are also influenced by body composition. Individuals with significant amounts of subcutaneous fat tissue are better protected from heat loss as they are able to maintain their core temperature during cold exposure [47, 48]. It has been established that fat has the highest thermal resistivity when compared to all the other body tissues [2]. Therefore, subcutaneous fat tissue provides better insulation from cold [2].

Long-Term Physiological Adaptation Response

When individuals are exposed to cold for a long period of time, their body experiences some physiological adjustments in order to better tolerate the cold. The long-term physiological response to cold are also known as cold habituation and acclimation/acclimatization [2]. According to various studies, there are three physiological responses to long-term cold exposure [2];

1) Cold Habituation – Decreased response to cold due to blunted vasoconstriction and shivering [49]. According to various studies, blunted vasoconstriction and shivering has been linked to a decrease in norepinephrine. It has been established that approximately 60% of the reflex cold-induced cutaneous vasoconstriction is caused by noreprinephrine release [50]. For instance, Leppaluoto, Korhonen et al. conducted a study on habituation of thermal sensation, skin temperature and norepinephrine in men exposed to cold air [51]. Healthy men were exposed to 10°C cold air for 120 minutes daily for 11 days. The result of their study showed significant decrease in thermal sensation, and norepinephrine production. Furthermore, the results of this study revealed that skin temperature decreases initially during the first few days of exposure but later increases after repeated exposure. Based on their findings, it was concluded that habituation of cold sensation and norepinephrine response provides benefits to individuals residing and working in cold environments;

2) Metabolic Acclimation – This is characterized by an increase in thermogenesis [2]. Studies have shown that individuals with metabolic acclimation have higher resting metabolic rates when exposed to cold. For instance, Young conducted a study on human cold acclimatization among native Americans residing in the circumpolar region [49]. It was observed that they maintained higher resting metabolic rates than people residing in the temperate region. Thus, the native Americans maintained warmer skin temperature with less shivering during cold exposure. It is believed that during metabolic acclimation, there is an increase in non-shivering thermogenesis [which relies on brown adipose tissue (BAT)]. For instance, a study conducted by [52] exposed 7 men to 1 hour daily of cold-water immersion (14°C) for 7 consecutive days. The result of their study showed a significant decrease in shivering intensity and a significant increase in non-shivering thermogenesis;
3) Insulative Acclimation – Insulative acclimation is characterized by mechanisms such as a cutaneous vasoconstrictor response that helps in the conservation of body heat during long-term exposure to cold [49]. One study showed that during insulative acclimation, there is a decreased thermal conductance [53].

<u>Cold Exposure – Medical Risks</u>

Hypothermia

Extreme exposure to cold can predispose an individual to hypothermia. Hypothermia occurs when the body core temperature falls below its physiological normal limit < 35°C [54]. According to various studies, hypothermia can be classified based on the severity of the reduction of core temperature (mild – 35-32°C, moderate – 32-28°C and severe < 28°C) [55]. Each of the classification levels are characterized by its own clinical features such as (Mild – tachycardia, tachypnea, shivering, decreased physical performance; Moderate – decrease heart rate and respiratory rate, decrease level of consciousness; and Severe – apnea, coma, pulmonary edema, cardiac arrest, death) [56, 29]. Several studies have shown that individuals such as military troops and high-altitude climbers are often exposed to extreme cold temperatures and thus, predisposed to hypothermia. It is believed that factors such as poor clothing, wet and windy climatic conditions, and fatigue, which are often seen in cold environments, overwhelm the body physiological response to cold and thus, predispose individuals to hypothermia [57]. For instance, Pugh conducted a study on clothing insulation and accidental hypothermia in youth [58]. He was asked to investigate the deaths of three boys who died in an annual Four Inns Walk in Britain in March, 1964. The result of his investigation showed that wet/wind conditions significantly reduced the thermal insulation value of the cloths worn by the competitors.

Frostbite

Frostbite, also known as *tissue-freezing injury* is a traumatic *c*ondition caused by extreme exposure to cold often seen during winter, at high altitude and windy conditions, resulting in damage to the body (skin) cells and tissues [59]. Frostbite is classified based on the level of severity (first degree – superficial; second degree – full skin; third degree – subcutaneous tissue; and fourth degree – extensive tissue and bone) [60]. According to various studies, symptoms of frostbite include, but are not limited to, numbness, swelling, blisters, redness of the skin, and blackened skin [59]. It is believed that troops, skiers, high altitude climbers are often predisposed to frostbite [61, 62]. According to Killian a notable example of frostbite case is the Operation Typhoon that started in the winter of 1941-1942. It was reported that about 250,000 German troops sustained frostbite injuries [63].

Non-Freezing Cold Injury (NFCI)

NFCI is a clinical syndrome that develops after sustained exposure to cold temperatures close to the freezing point (0-15°C) which result in tissue cooling but not freezing [64]. Thus, the fact that tissue does not freeze distinguishes NFCI from frostbite [65]. NFCI results in persistent sensory impairment of the hands and feet, numbness, paresthesia and chronic pain [66]. It accounts for significant morbidity among military personnel, high altitude climbers, and commercial/industrial workers who work in a cold environment [64].

Control of Breathing – General

The physiological function of the lungs is to ensure that adequate gas exchange takes place in order to meet the metabolic needs of the body tissues, and also ensure regulation of acid/base balance which is crucial for survival [67]. When the gaseous exchange in the lungs matches tissue metabolism, respiratory homeostasis is maintained [67]. When it comes to breathing, the diaphragm and the external intercostal muscles which are innervated by the phrenic and external intercostal nerves are the chief muscles responsible for inspiration [67]. Whereas, the abdominal and internal intercostal muscles are the primary muscles responsible for active expiration.

Breathing Control Centre

The pons and medulla oblongata are the primary respiratory control centers in the brainstem [68, 69], although each performs different functions. The medulla oblongata is responsible for stimulating the respiratory muscles to cause breathing to occur. On the other hand, the chief responsibility of the pons is to control the rate of involuntary respiration. The medulla oblongata consists of three areas that control respiration : 1) Pre-Botzinger complex – it principally ensures activation of the dorsal respiratory group [70, 71]; 2) Dorsal respiratory group (DRG) - it is the principal inspiratory center which controls the efferent activity of the phrenic and external intercostal nerve; and 3) Ventral respiratory group (VRG) – it principally drives active expiration and controls the efferent activity of the abdominal muscles and internal intercostal nerve/muscles [72]. On the contrary, the pons consists of two areas: 1) Pneumotaxic center – which inhibits the apneustic center, turns off inspiration and allows expiration [73, 74]; and 2) Apneustic center – it actively prolongs inspiration, and controls efferent activity of the phrenic nerve by activating the DRG.

Mechanism of Breathing Control

According to various studies, there are many factors such as central input, chemoreceptors and mechanoreceptors that control breathing [75]. It is noteworthy that physiological control of breathing can be achieved through a combination of feed forward and negative feed-back response loops [75]. The negative feed-back response consists of three compartments: sensors (central and peripheral chemoreceptors); central controller/integrator (pons/medulla); and effectors (respiratory muscles) . Chemoreceptors are sensors that detect changes in blood pH and arterial gas tensions (PaO_2 and $PaCO_2$) [76]. Chemoreceptors are divided into central chemoreceptors (mostly sensitive to changes in $PaCO_2$), and peripheral chemoreceptors (principally sensitive to low PaO_2) [77], which are found in the carotid and aortic bodies [76] . Upon detecting changes in blood pH and arterial gas tensions, the chemoreceptors send afferent signals to the central controller (pons and medulla), which stimulate the respiratory muscles, and in turn modulate alveolar ventilation in order to normalize the blood pH and arterial gas tensions [76] . For instance, in a case of acidosis (low blood pH), the body physiologically responds by increasing the alveolar ventilation rate, reducing the $PaCO_2$ and thus, increasing the blood pH.

Control of Breathing During Exercise

The respiratory system in the body is challenged during exercise [75]. For instance, during submaximal exercise, alveolar ventilation increases in proportion to an increase in metabolic rate in order to maintain respiration homeostasis (i.e., ensuring a balance in the $PaCO_2$, PaO_2 and pH) [78]. According to several studies, there are three dynamic phases of ventilation during exercise which are regulated by specific respiratory control mechanisms [79, 75, 80]: 1) Phase 1 – This is the first response that occurs immediately at the onset (15 s) of exercise [75, 67]. During this phase, neurally mediated muscle mechanoreceptors (receptors from the exercising muscles) send afferent impulses to the central command center (cerebral cortex) which in turn stimulates the respiratory control centers (pons and medulla) to cause an increase in ventilation [75]; 2) Phase 2 – The feedback response from the muscle mechanoreceptors to the central command, together with input from peripheral chemoreceptors (in the carotid bodies), causes an exponential increase in ventilation starting at (15 s to 2-3 min) of exercise [75]. For instance, a study conducted by Froster and Pan on the role of carotid chemoreceptors in the control of breathing during exercise showed that carotid chemoreceptors increase alveolar ventilation during exercise hyperpnea in order to minimize the disruption of arterial blood gas [81]; 3) Phase 3 – 3 min onwards to the end of exercise, ventilation reaches a steady state as a result of regulation from the central and humoral control mechanisms [67, 75].

High Altitude Hypoxia – General

According to Storz and Scott exposure to high altitude has been regarded as a hypoxia (low inspired oxygen – PiO_2) exposure, which compromises human performance and survival [4]. West reported that 5,950 m (11,516 ft) is the highest point in which humans can permanently inhabit [82]. Heights > 5,950 m pose some physiological (cardiovascular and respiratory) challenges to humans thus, making it inhospitable to sustain life [83]. Therefore, for a human to at least survive in high altitude due to the physiological challenges, adaptation is inevitable. According to Zubieta-Calleja, Paulev et al. adaptation to high altitude is dependent on altitude and time [84].

$$Adaptation = Time\ (in\ days)/Altitude\ (in\ km)$$

According to various studies, the adaptation factor at any altitude, ascending from sea level is 11.4 [84]. Therefore, to calculate the number of days needed for an individual to fully adapt to any altitude, the high-altitude adaptation factor (11.4) is multiplied by the altitude (in km). For instance, it will take 40 days for an individual to achieve full adaptation at an altitude of 3,510 m [84].

High Altitude Hypoxia – Barometric Pressure

Barometric pressure declines in a nonlinear fashion with altitude [85]. For instance, West observed decreases in barometric pressure at 6 (Flagstaff, Rainier, Foraker, Denali, Kilimanjaro and Everest) different altitudes [86]. The author reported that there was an approximately 25% and 33% decrease in barometric pressure at altitudes of 2,510 m (Flagstaff) and 8,850 m (Everest) respectively.

High Altitude Hypoxia – Alveolar Gas

According to Brown and Grocott alveolar partial pressure of oxygen (P_AO_2) decreases with altitude as a result of the decrease in partial pressure of inspired oxygen (P_iO_2) [87]. Similarly, according to West, Hackett et al. at high altitude, the alveolar partial pressure of oxygen (P_ACO_2) decreases as a result of extreme hyperventilation [88]. The authors observed that at about 7000 m, there was no further decrease in P_AO_2 due to extreme hyperventilation (defence zone).

High Altitude Hypoxia – Maximal Oxygen Uptake

According to several studies done at Everest, maximal oxygen uptake or aerobic capacity of climbers decreases with altitude [3]. They observed that the maximum oxygen uptake at the summit of Everest is equal to the basal oxygen uptake.

High Altitude Hypoxia – Hematologic Blood Parameters

A study conducted by Hasim, Florian et al. investigated changes in blood parameters among the student population during a 10-day ski-trip in a high altitude environment (1800-2300 m) [89]. They showed that the hemoglobin, erythrocytes and hematocrit values increased after the ski-trip. For example, before the ski-trip, hemoglobin, erythrocytes, and hematocrit values among the female students was 123.9 g/l, $4.09x10^{12}$/L and 33.98% respectively. However, after the trip, the results of their study showed increased in hemoglobin (to 127.8g/l), erythrocytes (to $4.42x10^{22}$/L) and hematocrit (to 36.61%) values. The authors attributed the increased to stimulation of bone marrow and increased number of circulating reticulocytes which occurs during adaptation of the body to high altitude.

<u>High Altitude Hypoxia Adaptation.</u>

Upon ascent to high altitude, there is an nonlinear decrease in barometric pressure despite the fact that the concentration of oxygen in air remains constant at ~21% [90]. The decrease in barometric pressure at high altitude results in a decrease in PaO_2 (arterial partial pressure of oxygen in the blood), SaO_2 (arterial blood oxygen saturation), CaO_2 (arterial oxygen content in tissue) and VO_{2max} (maximal oxygen uptake) [91, 92, 93]. Thus, the decrease in availability of oxygen triggers some physiological changes in the cardiovascular system. Several studies have reported that in order for the cardiovascular system to compensate for the reduced availability of oxygen at high altitude, two adaptation responses (short-term and long-term) are involved [93];

Short-Term High-Altitude Hypoxia Cardiovascular Adaptation

According to Jun, Lei et al. short-term high-altitude hypoxia adaptation is an immediate compensatory adjustment to the cardiovascular system in order to meet the oxygen demands for tissue metabolism [93]. During short-term adaptation, upon ascent to high altitude, climbers experience increases in cardiac output, heart rate, mean arterial pressure, arterial blood pressure, left ventricular ejection fraction but no change in stroke volume [93]. A study conducted by Liu, Zhang et al. reported that after acute exposure to 3,700 m altitude, climbers experienced an increase in diastolic, systolic and mean arterial blood pressure [94]. Various studies have reported that the increase in heart rate, cardiac output and blood pressure observed during short term adaptation is as a result of changes occurring in the autonomic nervous system activity [93]. Upon ascent to high altitude, the body tends more towards sympathetic activity than parasympathetic activity [95].

Also, another short-term adaptation is the immediate triggering of hypoxic pulmonary vasoconstriction (HPV). HPV leads to increase in pulmonary vascular resistance (tone) and an increase in pulmonary artery pressure [93]. According to Talbot, Balnos et al. pulmonary vascular resistance increases to a maximum after 5 min ascent into high altitude [96]. Therefore, short-term high-altitude adaptation due to an increased pulmonary artery pressure predisposes a climber to pulmonary hypertension. In addition, the cerebrovascular system also responds to changes during short-term high-altitude adaptation. Upon short-term high-altitude exposure, the peripheral chemoreceptors (carotid bodies) sense a decrease in PaO_2 that triggers an increase in cerebral blood flow (CBF) in order to meet the oxygen demands for brain tissue metabolism [93, 97-99]. Therefore, a decrease in PaO_2 is known to induce cerebral vasodilation [93]. Consequently, it is also known that hyperventilation occurring during exposure to high altitude causes a decrease in $PaCO_2$ [93]. The decrease in $PaCO_2$ induces cerebral vasoconstriction. Therefore, changes in CBF during short term exposure is dependent on the balance between PaO_2 and $PaCO_2$ [97]. A study conducted by Lucas, Burgess et al. reported that there is a 40% increase in cerebral blood flow immediately upon ascent to 5,050 m altitude. This percentage increase is suggestive of a low PaO_2-$PaCO_2$ ratio [97].

Long-term High-Altitude Hypoxia Cardiovascular Adaptation

According to Jun, Lei et al. residents of high-altitude show compensative changes in their cardiovascular system, which enables them to adapt to chronic high altitude hypoxia [93]. After long-term exposure to high altitude, individuals experience increased heart rate and arterial blood pressure, decrease in stroke volume and cardiac output returning to baseline values after 3-4 weeks of acclimatization at 3,800 m altitude [100]. Similarly, Saltin, Grover et al. observed that at 4,300 m (14,100 ft) there was a 20% reduction in maximum cardiac output after 2 weeks at altitude [101]. It has been established that one major characteristic of long-term high-altitude hypoxia is to ensure adjustment of cardiac function in order to maintain homeostasis. For instance, long-term high-altitude hypoxia has been shown as a protective mechanism from development of coronary heart disease [102]. Mortimer, Monson et al. conducted a study to investigate the mortality rate of coronary heart disease among men residing at high altitude [103]. They reported that there was a significant decrease in the mortality rate of ischaemic heart disease among men residing in high altitude. Similarly, several animal experimental studies have reported that animals adapting to long-term high-altitude hypoxia developed better functional recovery following ischaemic attack [102, 104].

It is also believed that during long-term high-altitude hypoxia, cardiac structural changes such as right ventricle hypertrophy develops [93]. According to Kolar and Ostadal right ventricle hypertrophy that develops during long-term high-altitude hypoxia is a beneficial adaptation that ensures normal cardiac output is maintained by counteracting increased afterload caused by pulmonary hypertension [105]. In addition, the cerebrovascular system also responds to changes during long-term high-altitude exposure. Similar to what happens during short-term high-altitude hypoxia, cerebral blood flow also increases during long-term high-altitude hypoxia. However, according to Jun, Lei et al. within 1-3 weeks upon ascent to high altitude, CBF will decrease and return to near sea level values [93]. The decrease in CBF is attributed to increased hematocrit level seen at high altitude. Several studies have reported that high altitude native residents have lower CBF values compared to sea level natives due to a gradual increase in hematocrit [93]. For instance, a study conducted by Zubieta-Calleja, Paulev et al. investigated altitude adaptation to hematocrit changes. They observed that hematocrit increased in a high-altitude native resident who traveled from 35 m (sea level) to high altitude (3,510 m) [84].

High Altitude Diseases – General

It is believed that physiological responses at high altitude are triggered as a result of hypoxia in order to allow for adaptation [93]. However, there are some maladaptive responses that can occur at high altitude which predispose an individual to high altitude diseases such as acute mountain sickness (AMS), high altitude cerebral edema (HACE), high altitude pulmonary edema (HAPE), and chronic mountain sickness (CMS) [106]. Several studies have reported that individuals start manifesting symptoms of high-altitude diseases within 1-5 days at altitude ≥ 2,500 m (8,202 ft) [106].

Acute Mountain Sickness (AMS)

This is a syndrome of nonspecific symptoms such as headache, disturbed sleep (insomnia), dizziness, fatigue, nausea, anorexia and (loss of appetite) [107, 106]. AMS occurs as a result of lack of acclimatization to high-altitude ≥ 2,500 m [106]. Several studies have reported that rapid ascent to high altitude by climbers predisposed them to AMS [107]. For instance, Murdoch reported that about 85% of tourists who ascend rapidly into an altitude of 3,740 m in Nepal suffered from symptoms of AMS [108]. It is believed that individuals manifest symptoms of AMS for 2-3days upon ascent to high altitude after which symptoms disappear [109].

High Altitude Cerebral Edema (HACE)

This is a potentially life-threatening illness. According to several studies, the clinical hallmarks of HACE are ataxia (lack of muscle control and coordination) and decreased consciousness [106]. HACE occurs when an individual fails to acclimatize while ascending to high altitude [93] . Thus, HACE can be prevented, or at least reduced, by gradual ascent to high altitude [107]. Apart from ataxia and decreased consciousness, several studies have shown some characteristic changes in the brain MRI, which suggest HACE [110]. For instance, Bartsch and Bailey reported that the brain MRI of a 65-year old female climber who had suffered from HACE at an altitude of 3,450 m showed edema in the corpus callosum [111]. Several studies have attributed hypoxia as the major cause of HACE [93]. In addition, it is believed that the pathophysiology of HACE is as a result of an increased vascular permeability of the brain endothelium [112], due to increased intracranial pressure [113, 93].

High Altitude Pulmonary Edema (HAPE)

This is a common high-altitude illness which occurs in healthy individuals at an altitude of > 2,500-3000 m within 1-5 days after ascent [111]. It is believed that HAPE rarely occurs at altitudes < 2,500 m or after a week of acclimatization [106]. Symptoms attributed to HAPE are excessive exertional dyspnea, chest tightness, cough, and reduce exercise performance [106, 24]. Symptoms of HAPE often occur at night after climbing, and progress rapidly [24]. Hypoxia is said to be the initial cause of HAPE [93]. However, hypoxic pulmonary vasoconstriction (HPV) which is caused as a result of increase pulmonary vascular resistance can predispose an individual to HAPE [93, 114, 115].

Chronic Mountain Sickness (CMS)

This is a syndrome of chronic hypoxia exposure seen in residents of high altitude such as Andeans, Tibetans and Ethiopians [116]. CMS is characterized by severe polycythemia abnormal increase in hemoglobin level, pulmonary hypertension, hypoventilation and finally heart failure [92]. Interestingly, several studies have observed the phenotypical differences between high-altitude residents in relation to the development of CMS [117]. For instance, high altitude residents (Tibetans) have low prevalence of CMS compared to other high-altitude residents (Andeans) [118, 119]. This was attributed to the fact that Tibetans have lower hemoglobin concentration than the Andeans [120, 121].

Conclusion

It is evident that some of the hallmarks of high-altitude are hypoxia and severe cold exposure. Interestingly, this review of literature critically discussed these factors through various experimental investigations conducted by some reserachers. However, it is noteworthy that most of the information shared in this review of literature came from the original research work conducted by Dr. Pugh. Therefore, this project investigated the contributions of Pugh's original research in the field of high-altitude medicine and environmental physiology

CHAPTER 3: METHODS

Search Strategy

MEDLINE® and Web of Science database was searched for publications by Lewis Griffith Pugh. Both database search revealed 61 and 75 articles respectively. All of these articles were imported into EndNote® reference citation manager software and then exported to a web-based review management tool (Rayyan QCRI®) for further screening such as title and abstract, and full-text screening. The criteria for inclusion was all articles related to altitude and/or cold physiology, and/or exercise physiology. The criteria for exclusion was all articles that were not related to altitude and/or cold physiology, and/or exercise physiology (see Figure 2).

Two reviewers (MO and GG) independently (blinded) assigned each article as “include”, “maybe” or “exclude”. The results were then unblinded revealing agreement to include 56 papers and exclude 9 papers. The reviewers then met to discuss the 7 conflicts and agreed to include 5 papers and exclude 2 papers. Thus, 61 papers (peer reviewed, n=52; and gray literature, n=9) were finally included in the analysis. Cohen’s Kappa statistic (which measures the level of agreement between the two reviewers) was 0.667 (see Figure 3). The titles of the 61 papers are listed and categorized in Appendix B.

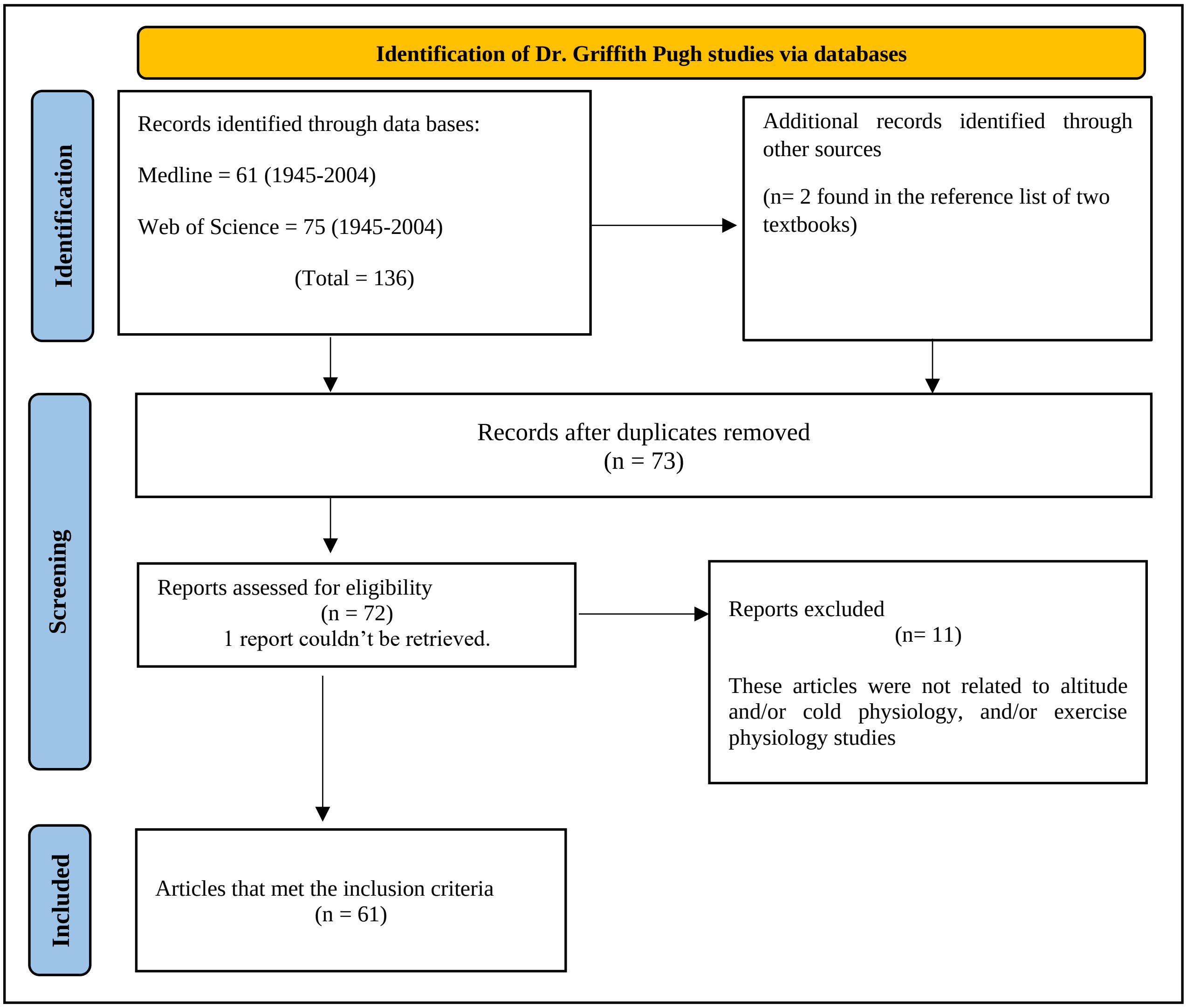

Figure 2. Flow chart for article search and selection.

COHEN's KAPPA STATISTIC CALCULATOR				
Reviewer 1	**Reviewer 2**			
		No	**Yes**	**Total**
	No	9	7	16
	Yes	0	56	56
	Total	9	63	72
Observed Agreement [P_0]				90%
Chance Agreement [P_e]				71%
Kappa [k]				0.667

Figure 3. Cohen's Kappa calculation for agreement on article inclusion.

Compilation and Analysis of Articles

The 61 articles were analysed as follows: 1) academic recognition (Dr. Pugh's H-index, and the number of citationsfor each paper); 2) each paper was summarized in an annotated bibliography; articles were analysed for their effect on practice in the field of cold, altitude science and clinical practice by responders; and 3) articles were analysed for their effect on subsequent and future research.

CHAPTER 4: RESULTS and DISCUSSION

Academic Recognition

According to Web of Science, from 1945-2022 Pugh's H-Index is 27 and he has a total number of 2,711 citations for the 61 papers that met the inclusion criteria (articles related to altitude and/or cold physiology, and/or exercise physiology) (see Appendix A). Pugh was the primary author in 48 of these papers. All papers and their citation history are listed in Appendix B. Appendix C provides specific citation information for Pugh's top 10 articles.

Pugh, who was regarded as one the fathers of the burgeoning disciplines of high-altitude medicine and physiology, made significant contributions to many academic, clinical, and professional textbooks. Apart from the fact that he was a contributor in some textbook chapters, his research works were cited in many of these textbooks. Therefore, Pugh's influence on textbooks cannot be underestimated. Some of the names of the textbooks and chapters where Pugh's research works were cited are listed in Appendix D.

Pugh's legacy has inspired some notable scientists and researchers in the field of high-altitude medicine and environmental physiology. Some of the notable researchers who were at some points were greatly influenced by Pugh in their career are:

1. **Dr. Jim Milledge** – (Nationality – British). Born in 1930. He studied medicine at the Birmingham Medical School. He is a respiratory physician and physiologist [122]. He has been involved in high altitude medicine and physiology research for more than 50 years after serving as one of the members of the 1960-1961 Himalayan Scientific and Mountaineering Expedition (Silver Hut) in which he served under Dr. Griffith Pugh who was the leader of the scientific team [122]. He was an honorary professor at the University College London where

he taught high altitude medicine and physiology courses [122]. Milledge retired in 1995 from the National Health Service and Medical Research Council [122]. In 2007, he was honored by the International Hypoxia Symposium for his outstanding contributions to the field of high-altitude medicine and physiology. To his credit, Milledge has 177 published articles in web of science and with an H-Index of 31. In 2012, he published an article titled *"Career Perspective: Jim Milledge"* where he listed Dr. Griffith Pugh as one of the people who influenced him in his career pursuit in the field of high-altitude medicine and physiology [122].

2. **Dr. Michael Phelps Ward –** (Nationality – British). He was born in 1925 and died at the age of 80 years. He studied medicine at the Cambridge Medical School [123]. Ward was known as one of the leading scholars in high-altitude and wilderness medicine, especially for his outstanding contributions to research in high-altitude sicknesses [123]. He was a member of the 1951 Mount Everest Reconnaissance and the expedition doctor for the 1953 first ascent to Everest [123]. He served as Dr. Pugh's research assistant during the 1953 expedition [123]. In 1993, he retired from the British National Health Service. Ward acknowledged the scientific contribution of Dr. Pugh to high-altitude medicine. In 1973 during the 20th anniversary of the first successful ascent to Everest, Ward dedicated some of his scientific research achievement in high altitude medicine to Dr. Pugh in the presence of the Duke of Edinburg. Among one of his notable books was the 2003 published historical book titled *Everest: A Thousand Years of Exploration*, where he narrated the medical, physiological and geographical aspects of Mount Everest [123]. In his speech at the 40th anniversary of the 1953 Everest expedition, Dr. Ward said, "what I want to talk about tonight is the most important reason why the 1953 expedition to Mount Everest succeeded where all its predecessors failed, and that is the work of the unsung hero of Everest, Dr. Griffith Pugh" [124].

3. **Dr. John B. West** – (Nationality – Australian). Born in 1928. He earned his Medical degree in Adelaide, Australia. He is one of the world's renowned respiratory physiologists [125]. He is a leading figure in the field of high-altitude medicine and physiology especially with his outstanding contributions to research on lung physiology in extreme environments [126]. He was a member of the scientific team of the 1960-1961 Silver Hut Expedition and he worked under Dr. Griffith Pugh who accepted him into his research team despite not having any prior experience on a high-altitude expedition [126]. While serving under Dr. Griffith Pugh, he conducted research by investigating adaptation of sea level residents during long term exposure to high altitude [126]. He has written many physiology books. One of the notable books was *High Altitude Medicine and Physiology*. West's relationship with Dr. Griffith Pugh was a cordial one after his encounter with Pugh at the 1960-1961 expedition. After Pugh's death, West was instrumental in making sure that all of Pugh's scientific papers were archived in the Mandeville Special Collections Library at the University of California where he served as a professor of medicine and physiology [125]. To his credit, West has 580 published articles in web of science with an H-Index of 71.

4. **Dr. Sukhamay Lahiri –** (Nationality – Indian). He was born in 1933 and died at the age of 76 years. He completed his B.Sc., M.Sc., and Ph.D. in physiology from Calcutta University [127, 128]. He is one of the notable researchers in the field of high-altitude medicine and physiology especially with his outstanding contributions on oxygen sensing in the body at high-altitude [127, 128]. Lahiri was also a member of the 1960-1961 Silver Hut expedition where he served under Dr. Pugh [127]. His participation in the Silver Hut expedition as well as serving under Dr. Pugh greatly influenced his career and further stimulated his interest to the field of high-altitude medicine and physiology [127]. He retired in 2008 as a physiology professor at the

University of Pennsylvania Medical School, USA. To his credit, he has 101 published scientific papers in web of science with and H-Index of 25.

Dr. Pugh's Research Tree

Pugh worked under Dr. Otto Edom who was the director of Medical Research Council (MRC) in Hampstead as seen in Figure 4. Otto was a professor of physiology from the University of Western Ontario, Canada [124]. Pugh being an outstanding researcher in the field of high-altitude medicine and environmental physiology, left indelible footprints in the sands of time among some notable researchers such as Dr. Jim Milledge, Dr. John B. West, Dr. Sukhamay Lahiri, Dr. Michael Ward, Dr. Joseph Sutton, Dr. Nicola Jones (Figure 4). Interestingly, all these notable researchers whom Pugh has inspired have also been an inspiration to other researchers (Figure 4).

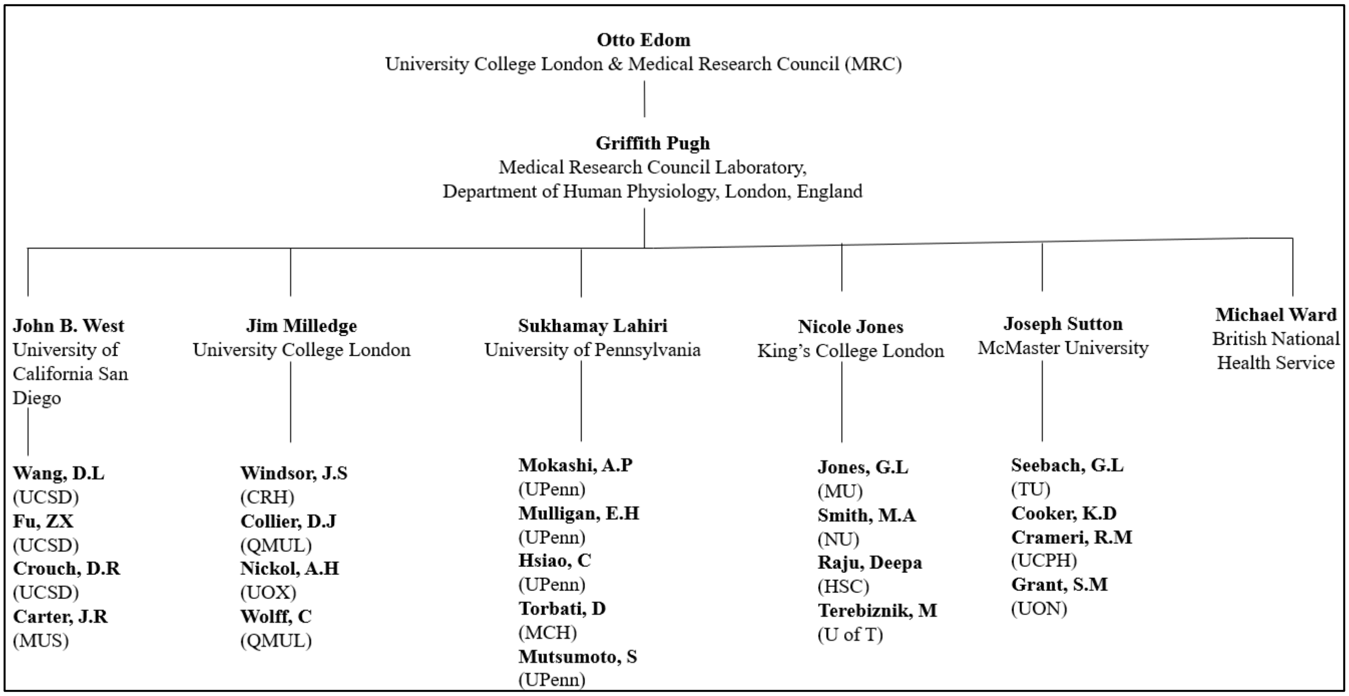

Figure 4. Pugh's Research Tree

Abbreviations: UCSD – University of California San Diego; MUS – Montana State University; CRH – Chesterfield Royal Hospital; QMUL – Queen Mary University London; UOX – University of Oxford; UPenn – University of Pennsylvania; MCH – Miami Children Hospital; MU – McMaster University; NU – Northumbria University; HSC – Hospital of Sick Children; U of T – University of Toronto; TU – Transylvania University; UCPH – University of Copenhagen; UON – University of Newcastle.

Summary of Publications

All of Dr. Pugh's papers that meet the criteria for inclusion were summarized in an annotated bibliography in Appendix E.

Dr. Pugh's Contributions to Physiology and Their Effect on Further Research

1. ***The importance of supplemental oxygen at altitude***. Pugh was one of the first physiologists who recognized and acknowledged the numerous benefits of oxygen to man, especially when man is in a state or environment deprived of oxygen. Pugh's research studies showed that the impact of oxygen to life cannot be overemphasized. His research studies on supplemental oxygen at high altitudes (Cho Oyu and Mount Everest) was a clear demonstration that oxygen is essential for human survival and existence [129, 130]. For instance, in one of his studies, it was evident that arterial oxygen saturation (SaO_2) decreases at high altitude as compared to sea level due to the hypoxic nature of high altitude [131]. Furthermore, it was evident that exercising at high altitude caused a further decrease in SaO_2 [131, 132]. Pugh was an astute researcher whose curiosity on studies relating to the effects of oxygen on man at high altitude made him act as subject in several of his experimental studies. For instance, he acted as a subject in a decompression chamber at the Royal Aircraft Establishment, in Farnborough, England [133]. He was said to have experienced symptoms of anoxia at a simulated height of 29,000 ft having weaned himself off supplemental oxygen [133]. Therefore, it is important to state that Pugh's research on the influence of oxygen on man at high-altitude has been illuminating and spawned further research in the field of critical care medical practice (i.e., importance of oxygen to patients and victims suffering from high-altitude sicknesses), and aerospace medicine (importance of oxygen to military crew members who fly at altitude).

2. ***Hypothermia prevention and treatment***. Pugh can also be recognized as one of the first researchers who gave recommendations on how to prevent hypothermia and treat victims of hypothermia [124]. His studies and findings on hypothermia can be considered as timely research because, at that period in time, there was a dearth of information in the public about the etiology, prevention and treatment of hypothermia. Pugh's research studies on how he unraveled the deaths of three boys who participated in an annual walking event in Britain [58, 134, 135] illuminated and spawned further research in the field of accident/emergencies and wilderness medicine. Pugh's findings were eye-opening to medical practitioners, paramedics, first responders on how to prevent and administer treatment to victims of hypothermia. In order to prevent hypothermia, Pugh advocated that climbers should avoid getting wet [57, 136, 137]; they should seek shelter when in significant cold stress [57, 136]. They must recognize the signs and symptoms of early onset of hypothermia [134] and must immediately seek warm shelter in-order to alleviate further body cooling [57, 136]. They must also have easy accessibility to campsites during expeditions [136] and should avoid exercising in wet windy cold climatic conditions [134]. They should also avoid clothing and footwear that are not waterproof and windproof [134, 136]. On treatment of hypothermia, Pugh advocated for on-the-spot resuscitation (as a form of prehospital management) instead of the conventional evacuation of victims on a stretcher [136], a scenario in which many had lost their lives due to delay and a long period of rescue operations [57, 136]. Pugh believed that on-the-spot resuscitation would help prevent cardiopulmonary arrest and also prevent further decrease in victims core temperature. Pugh believed that victims of hypothermia respond immediately to any kind of treatment administered to them once further cooling is prevented [136]. He also advocated for proper handling of victims of hypothermia [57, 136]. He believed that apart from victims suffering from hypothermia, victims may have as well sustained musculoskeletal and

neurological injuries such as fractured bones, dislocations, ligament sprain, and head injuries [57]. Therefore, proper handling of victims at the site of injury and during transportation is important for the overall short- and long-term prognosis. Pugh also advocated for proper rewarming techniques [57, 136]. Rewarming of victims should start at the site of transportation and not when victims arrive at the hospital [136]. This advice is contrary to dogma held during the late 1960s to 1980s but has been readopted in recent decades [138, 139]. Pugh advocated that rescue teams should undergo adequate training on how to treat victims of hypothermia [57]. He believed that during such training, rescue teams would be educated on how to watch out for some red flags associated with the treatment of hypothermia. For instance, the danger of head-up positioning [57, 136] which could predispose victims to orthostatic hypotension or convulsion (now known as rescue collapse) as well as the danger of core temperature afterdrop during rewarming which could predispose victims to cardiac arrythmias or arrest [57].

3. ***Physiologic responses at high altitude***. Several physiological experiments such as investigating the functions of the heart, pulmonary functions, renal functions, hematological functions, respiratory regulation, and gas exchange, were conducted during the 1960-1961 Himalayan Scientific and Mountaineering (*Silver Hut*) expedition [131, 140]. All the physiological experiments that emanated from this expedition were said to have further heightened Pugh's career, and consequently illuminated and spawned further research in the field of high-altitude medicine and physiology. Interestingly, all these physiological investigations were conducted in a temperature-controlled laboratory (prefabricated hut) which was known to be the highest laboratory structure in the world situated at 5,800 m (19,000 ft) altitude above sea level [131, 141]. Some of the key findings of the physiological investigations conducted during the 1960-1961 Silver Hut Expedition are:

a) Heart Functions – It was revealed that climbers heart rate increases with altitude as compared to sea level at the same low-to-moderate work rate [131, 142, 143]. However, at maximum work rate, heart rate decreases with altitude as compared to sea level [131, 142, 143]. For instance, the maximum heart rate at 19,000 ft altitude and sea level was 130-150 beats/min and 180-190 beats/min respectively. Consequently, it was revealed that cardiac output decreases with altitude as compared to sea level when exercising at the same maximum work rate [131, 142]. For instance, the cardiac output at 19,000 ft altitude and sea level was 16-18 l./min and 25-30 l./min respectively. Furthermore, the electrocardiograph (ECG) imaging done on climbers at 19,000 ft revealed right axis deviation (increased convexity of the right border of the heart) which is suggestive of right ventricular hypertrophy [140].

b) Kidney functions – Urinalysis investigation conducted on climbers at 19,000 ft altitude revealed that the sodium-potassium (Na/k) ratio was significantly increased [140]. The increase in the sodium-potassium ratio was attributed to inhibition of the antidiuretic hormone (ADH) and adrenal cortical function [140].

c) Hematological functions – It was revealed that hemoglobin concentration and red cell volume increase significantly with altitude as compared to sea level [140, 144]. Whereas, plasma volume decreases with altitude as compared to sea level [140, 144]. For instance, the hemoglobin concentration of climbers residing at 19,000 ft altitude and sea level was 19.6 g./100ml and 14.1 g./ml respectively. It was stated that changes in hemoglobin concentration is dependent on changes in plasma volume [144].

4. ***Performance and survival at altitude.*** Pugh who was recognized as the first pioneer Everest physiologistperformed some innovative human physiological research on how to prevent and survive the debilitating effects of altitude on man. According to Pugh, some of the debilitating

effects of high altitude on man are deprivation of oxygen (hypoxia), dehydration due to diuresis, loss of appetite (anorexia), loss of body weight, easy fatiguability, high-altitude illnesses [i.e., acute mountain sickness (AMS), high altitude pulmonary edema (HAPE), and high altitude cerebral edema (HACE)] [130, 145, 146]. Interestingly, Pugh's recommendations on how to prevent and survive the debilitating effects of altitude are still in use up till today. Many of his findings and conclusions have spawned further research into understanding and preventing the debilitating effects of high altitude on man. Pugh recommended that climbers should be fed with food with adequate calories [(regular ration > 4,500 kcal/man/day, and assault ration > 2,500 kcal/man/day)] which will give climbers the much-needed energy for climbing [145-147]. Pugh advocated that climbers should eat more of a high-carbohydrate diet and less of high-fat diet because consuming a high-carbohydrate diet has been shown to improve climbers performance at high-altitude. For instance, in one of his studies, the results showed that all the climbers who participated in the study suffered from ketosis. In order to substantiate Pugh's belief in aa high carbohydrate diet, Dr. Wayne Askew who is a Professor of Human Nutrition and Integrative Physiology from the University of Utah, published an article titled *Food for High-Altitude Expeditions: Pugh Got It Right in 1954.* He stated that the benefits of carbohydrate improving climbers performance at high altitude which was originally advocated by Pugh has been significantly supported by several research studies done in the past and recently such as those conducted on Pikes Peak in 1969 [148] and the summit of Mauna Kea in 1985 [149]. However, Askew stated that Pugh's claim that climbers at high-altitude craved more for carbohydrate foods was based on Pugh's anecdotal belief as no research studies have been able to substantiate this claim [150]. Pugh advocated that climber's individual food preference and palatability should be considered prior to any high-altitude expeditions [147]. However, climbers should avoid eating "junks". Pugh recommended that in-order to prevent dehydration, climbers should take 3-4 litres of fluid/day (i.e., in the form of soup or beverages) [145, 146, 151] and maintain a urine output of 1,500 ml/day [151]. Pugh recommended an open-circuit oxygen system supplying with a flow rate of 4 litres/min at high altitude ≥ 23,000 ft., and 1 litre/min during sleep [129, 145, 146]. Pugh recommended gradual ascent to high altitude as one of the measures to reduce the signs and symptoms of high-altitude illnesses. Pugh believed that climbers should maintain a high level of hygiene during high-altitude expeditions [145]. This would help prevent some gastrointestinal diseases, such as diarrhoea, and upper respiratory infections [145]. Pugh advised that climbers should be aware that high altitude environment potentially predisposes them to cardiovascular diseases such as stroke, pulmonary hypertension, and heart failure [141]. For instance, in one of his research studies conducted at the 1960-1961 Silver Hut Expedition, it was revealed through urinalysis, that there was a significant increase in the sodium/potassium ratio among climbers due to inhibition of the adrenal cortical and gonadal function [140]. Subsequently, increased sodium/potassium ratio has been associated with some cardiovascular diseases such as hypertension and stroke. Pugh also recommended adequate acclimatization (i.e., 4 weeks) to high altitude as a way to mitigate it's debilitating effects [145, 146] .

5. ***Nutrition***. Pugh was one of the earliest physiologists to recognized and acknowledged the fact that "to be fat is good" [152]. For instance, his research studies on physiology of performance in a cold environment revealed that having a significant amount of adipose tissue is the main contributory factor to preventing hypothermia [152]. In addition, body types/somatotypes are also one of the contributory factors to prevent hypothermia [152, 153]. Based on Pugh's findings, one can rightly state that more lives could be saved during exposure to extreme cold conditions, if individuals were fatter because they have better thermal comfort and decrease thermal conductance compared to thin victims [154]. Pugh's findings on the physiology of

channel swimmers showed that the majority of those swimmers who participated in this cold-water event, were obese/stocky and had a high level of fitness prior to the competition, which enabled them to maintain their core temperature over a long period of time due to a combination of adequate heat production (thermogenesis) and insulation [153, 154].

6. ***Behaviour in the cold***. Pugh was also one of the first set of researchers to investigate and acknowledged that lying still or motionless in cold water has numerous benefits compared to continued swimming following a shipwreck [152, 154]. His findings proved Glaser wrong who admonished that in-order to survive a shipwreck, victims should continue swimming instead of clinging on wreckage or floating on lifeboats [155]. Pugh's findings showed that when an individual lies motionless in water, heat loss is reduced, core temperature would be relatively maintained, and energy is conserved compared to swimming, during which a significant amount of heat would be lost, core temperature would reduce, and energy expenditure and oxygen consumption would increase [152, 154]. Based on Pugh's findings, one can deduce that more lives could be saved when lying still or motionless as compared to continued swimming which would further lead to exhaustion and core cooling.

7. ***Oxygen dynamics at altitude***. Pugh's research studies on the physiology of performance at high altitude emphasized that maximum oxygen consumption (VO_2 max) is an indicator for cardiorespiratory fitness and endurance capacity [156-158]. His findings showed that oxygen demand at high altitude outweighs oxygen supply due to the hypoxic nature of high-altitude environment. Pugh's studies on the relationship between oxygen intake/aerobic power and high altitude revealed that VO_2max decreases with increase in altitude and as such, performance and endurance level of climbers deteriorates [157]. Pugh strongly believed that individuals participating in expeditions to high altitude should attain a high level of physical fitness prior to the expedition [130, 159]. He also advised the reduction the quantities of loads to be carried

to expeditions in order to conserve energy during climbing [158]. In addition, Pugh believed that the individual's level of experience to high altitude environment should be considered prior to joining an expedition [158]. This could serve as important advice to organizers of high-altitude expeditions when selecting participants.

8. ***Acclimation and success at altitude***. Pugh was a critical thinking researcher whose research studies didn't stop only at investigating physiological responses of climbers at high altitude, but also went further to investigate why some men do better at high altitude while others struggle or face difficulties to perform at high altitude. Pugh was one of the first physiologists to compare responses of acclimatized (high-altitude native residents – "*Sherpas"*) and non-acclimatized (lowlander or sea level residents) men at high altitude [156, 160]. Interestingly, his research findings have spawned much further research into this area of study. Some of his findings revealed that acclimatized men (Sherpas) have larger hearts [24], they are less sensitive to hypoxia (i.e., higher tolerance to hypoxia) [24, 161], they have significant increase in blood volume and hemoglobin concentration [144, 161], have reduced or normal hypoxic ventilatory response [24, 161], and show a long delay in experiencing signs and symptoms of high-altitude sicknesses [24, 130] compared to non-acclimatized men (lowlanders). Pugh concluded that acclimatized men have higher aerobic capacity (VO_2max) and thus, better physical performance at high altitude than non-acclimatized men [161].

9. ***Tissue thermal conductivity***. Pugh together with his colleague (Dr. Hatfield Stafford) were the first physiologists to investigate thermal conductivity of human tissue and fat using a thermo-electric heat flow disk [162]. Interestingly, they conducted this exceptional study by extracting samples of muscle tissue and fat from five dead human bodies. Their findings clearly revealed that thermal conductivity of human muscle tissue was significantly higher than that of human fat and as such, fat should be considered a better thermal insulator than muscle tissue [162].

Based on their findings, it was concluded that a *"fat"* individual will be better insulated from cold than a *"thin"* individual. Fortunately, the findings of this study have since spawned further research into this area.

Contributions to Exercise Physiology

Pugh was an outstanding researcher who combined both laboratory and field research in order to tackle real-life situtaions [163]. Pugh contributed tremendously to the field of exercise physiology. As an expert in exercise physiology, he was appointed as a member of the advisory committee of the British Olympic Association to investigate the influence that high altitude would have on endurance performance of British atheletes prior to participating in the 1968 Olympic games in Mexico City situated at 2,270 m (7,500 ft) altitude above sea level [163, 124]. In Pugh's article titled *Atheletes at altitude*, six of the UK's best endurance athletes participated in this experimental study by performing 1- and 3-mile timed runs at sea level and at the beginning and end of 4 weeks at 7,500 ft altitudes. During the 1-mile timed runs, times were increased by 3.6% during the first week at altitude, but only by 1.5% in the 4^{th} week at altitude. Thus, indicating a 2.1% improvement [164]. Similarly, during the 3-mile timed runs, times were increased by 8.5% on the 4^{th} day at altitude, but only by 5.7% on the 29^{th} day. Thus, indicating a 2.8% improvement [164]. Pugh established that these improvements could be attributed to acclimatization to altitude [164]. Therefore, he concluded that in order for athletes to perform better in competitions taking place at high altitude, at least 4 weeks of acclimatization should be recommended, as these would help improve athletes performance and enhance recovery. However, it was rather unfortuate that the British Olympic Association did not accept Pugh's scientific findings and recommendations owing to political reasons (likely finances) rather than science [163, 124].

Some of Pugh's other key findings on exercise physiology studies are:

a) ***Effect of air/wind resistance on performance*** – Pugh was one of the first physiologists to investigate and acknowledge that oxygen consumption is the most direct method for measuring running economy. His research studies on the influence of wind velocity during exercise, revealed that oxygen consumption increases with increases in wind velocity [165]. For instance, it was established that athletes running at a constant speed of 15.9 km/hr in the absence of wind and then in the presence of wind (16.2 km/hr) increased oxygen consumption from 2.92 to 3.09 L/min [165]. Furthermore, oxygen consumption decreased significantly when drafting and slipstreaming [166]. In addition, it was revealed that 80% of the energy cost of overcoming air resistance can be abrogated by drafting/slipstreaming while running [166]. Therefore, Pugh concluded that in order to improve running economy, athlethes should adopt the drafting/slipstreaming techniques.

b) ***Performance during endurance training*** – Pugh was one of the earliest physiologist to investigate and recognized some thermal physiological factors such as sweat rate and core temperature in limiting performance of athletes during long distance marathon running [167]. It was established that limited heat elimination has debilitating effects on long distance marathon runners and thus, limits performance [167]. For instance, Pugh revealed that athletes who experienced significant amounts of fluid loss and muscle vasodilation during prolonged exercise training are predisposed to collapse [167]. However, in order to prevent fluid loss, Pugh advocated that atheletes performing long distance marathon events should always stay hydrated at all times [167, 124]. He advocated that the guideline which was established by marathon organizers, to prevent and discourage marathon runners from having access to various drinking stations during the first 10 miles of a marathon events, should be eliminated [124].

Influence of air density on short duration exercise training – Pugh was the first physiologist to acknowledge the effects of air density on performance at high altitude [168]. He conducted a retrospective study titled *Altitude and athletic performance* where he compared the performance of runners in the 1955 Pan American games held in Mexico City (at altitude of 7,500 ft) and the 1956 Olympic games held in Melbourne (at sea level) [168]. Pugh compared the times of the first 3 finishers in the finals of the running events (short distance: 100 m, 200 m, and 400 m; and long distance: 800 m, 1,500 m and 10,000 m). Race times of runners in long distance events were longer in Mexico City than in Melbourne [168]. Conversely, race times of runners during short distance events were shorter in Mexico City than in Melbourne [168]. Pugh concluded that improved performance in short distance races at altitude is due to decreased air density [168].

Contributions Regarding Technical and Practical Factors

Pugh was a researcher par excellence. He was privileged to be among those who participated in the 1957-1958 Anglo-American expedition to the Antarctica sponsored by the Office of Naval Research, United States of America [169]. During this expedition, several studies on the adaptation of man in the Antarctic region were conducted. For instance, he conducted a study that investigated the effects of solar radiation on man in Antarctica [170]. The findings of this study provided explorers traveling to the Antarctica with useful practical knowledge on how to survive considering the fact that Antarctic regions are best known for having high albedo effect (significant amount of sun radiation reflect back and away from the planet by the earth's surface). To survive the severe climatic conditions of the Antarctic regions, Pugh recommended that explorers should construct and camp inside a single walled lightweight yellow Wyncol nylon cotton tent [170]. This specific type of tent is a better representation of the greenhouse effect, as it provides adequate warmth and thermal comfort [170]. Furthermore, Pugh's article titled, *The logistics of polar journeys of Scott, Shackleton and Amundsen* gave further insight on the technicality and practicality on how to survive in Antarctica with respect to the physiological and medical aspects. The findings of this article clearly demonstrated the "Do's and Don'ts" in Antarctica. Pugh in this article was able to establish that explorers should have good and sound logistic policies and planning in-order to survive in Antarctica [171]. For instance:

1. Explorers traveling to the Antarctica should have sound prior experience on how to use skis.
2. They should travel with a sufficient amount of sledge dogs and ponies (horses) depending on the duration of their stay and distance to be covered.
3. Sledge dogs should be fed with seal meat and not the conventional Antarctica recipe (pemmican) which has been found to cause vitamin deficiencies and hypoglycemic collapse.
4. Explorers should travel with a sufficient amount of food supplies both for themselves and for their sledge dogs.
5. They should endeavour to ration their food for themselves and their sledge dogs.
6. Explorers and their sledge dogs should consume food that offers the same amount of calories (at least 5,000 kcal/day) in-order to prevent weight loss and deterioration in physical performance.
7. They should travel with a sufficient amount of fuel supplies.
8. They should travel with survival gear such as sleeping bags, clothing that offers adequate thermal values, tents and stoves.

Pugh's historical narrative article about the *Isafjourdur trawler disaster* which occurred on the 4th of February 1968, also gave further insight on the technicality and practicality on how trawler crew members can survive when a trawler capsized. According to Pugh, many crew members have died as a result of hypothermia, and drowning due to unforeseen circumstances [137]. Pugh believed that for trawler crew members to survive during unforeseen circumstances, the following factors should be put into practice:

1. Trawler crew members should always anticipate for unforeseen circumstances by making sure that prompt and adequate emergency processes and survival measures are put in place.
2. They should not panic.
3. They should avoid getting wet and endeavour to always stay dry at all times.
4. They should always wear clothing that offers great resistance to water and wind (i.e., clothing that are waterproof and windproof).
5. They should have sufficient dry clothing (outer and inner garments) when on board.
6. They should at all times have inflatable lifejackets and desist from using cork life-jackets.
7. They should avoid getting intoxicated with alcohol when on board as this can adversely affect their sense of reasoning and hinder rescue operations.
8. They should have sufficient amount of self-inflatable closed raft that can accommodate a larger number of those on board.
9. They should undergo theoretical and practical training on how to use self-inflatable raft.
10. They should make adequate provision for bailers.
11. They should make provision for sophisticated communication system such as emergency radios in the raft.
12. Trawler crew members should undergo training on the prevention of hypothermia.

Pugh's research work on the technicality and practicality of how to mitigate carbon monoxide poisoning in Antarctica is noteworthy. It is a common knowledge that explorers traveling to Antarctica are predisposed to carbon monoxide poisoning which can cause some debilitating health conditions such as severe asphyxia, excruciating headaches, shortness of breath (bradypnea) upon exertion or at rest, loss of appetite (anorexia), dizziness, general body weakness [172]. According to Pugh, the exhaust fume coming out of vehicles and tractors used during long-distance traveling in Antarctica are one of the numerous ways in which explorers are exposed to carbon monoxide poisoning [172]. Based on Pugh's research findings, he suggested practical ways to mitigate carbon monoxide poisoning among explorers. For instance:

1. Explorers should endeavour to avoid inhaling the fumes that come out of the exhaust pipes from vehicles and tractors use during Antarctic expeditions.
2. They should construct and camp inside a single-walled lightweight nylon-cotton tent rather than camping inside a double-walled tent made with heavy cotton fabrics.
3. They should reduce the time spent while using the primus stove to melt snow/ice or to cook food. About 30 minutes is recommended for explorers to melt snow/ice or cook food while using the primus stove.
4. They should construct chimneys over the primus stove inside the tent.
5. They should endeavour to make sure they camp in a well-ventilated tent.

Lastly, the success recorded by the British during the 1953 Everest expedition was a clear demonstration and evidence of Pugh's technical and practical scientific approach. In his article titled *Scientific Aspects of the Expedition to Mount Everest 1953,* the technical and practical scientific approach which Pugh adopted to tackle the problems of severe climatic conditions at high altitude were extensive. Pugh designed protective equipment, clothing and footwear that offered climbers the best thermal insulation and comfort against cold [145]. For high-altitude climbers to survive severe climatic conditions, it is imperative that they consider Pugh's scientific recommendations which include:

1. Donning clothing made up of single lightweight cotton-nylon fabric material which are waterproof and windproof.
2. Camping inside a single-walled lightweight cotton-nylon tent which is resistant to tear and well-ventilated with entrances at both ends.
3. Donning footwear/boots with inner and outer coverings made up of thin microcellular rubber soles which offer great resistance to water.
4. Donning silken inner gloves and woollen mitts which offer great resistance to wind.
5. Sleeping bags with inner and outer compartments made up of nylon-lining material which are better adapted for a temperature of -40°C.
6. Sleeping bags should be adequately long in-order to pull over the climber's head and must also be spacious and comfortable.

Pugh's Contributions to Philosophy, Strategy and Equipment at Altitude

In order for climbers to survive the debilitating effects of high-altitude, Pugh recommended three Guiding Principles [124]:

1. Climbers should feel well at all times.
2. They must not lose their appetites.
3. They must not suffer from altitude sickness.

These three guideline principles could be achieved based on the following factors:

1. Adequate fluid intake – 3-4 l/day in order to prevent dehydration [151].

2. Efficient stove for cooking and melting snow [173].
3. Adequate diet – Pugh suggested that due to loss of appetite experienced at high-altitude, climbers should be provided with food with adequate calories, which must be palatable [147]. He recommended European type diet for climbers [147].
4. Tents and clothing – To prevent climbers from extreme cold exposure at high-altitude, tents and clothing should be made of cotton-nylon fabric "Wyncol" which is lightweight, tear resistant, windproof, breathable and with extra pockets [145].
5. Boot design – Made of microcellular rubber, lightweight, with inner and outer proof layer to provide adequate insulation.
6. Hygiene – Climbers camps should be separated far away from villages or houses of local inhabitants [145].
7. Sleeping bags – Sleeping bags well adapted for -40°C to prevent climbers from extreme cold exposure [145].
8. Open circuit oxygen systems – Pugh recommended that at above 23,000 ft, 4 l/min and 1 l/min of open circuit oxygen system for working and sleeping respectively [145]. Furthermore, he suggested that oxygen supplemental should be used by climbers during descent.
9. Adequate acclimatization – Pugh recommended that climbers should acclimatized for 4 weeks [145].
10. Sleeping Duration – Pugh recommended that climbers should sleep at 12,000-13,000 altitudes for the first fourteen days. Thereafter, another fourteen days of sleep at 13,000-15,000 ft altitude. However, at altitudes up to 20,000 ft, climbers should sleep only for 2-3 days. Pugh believed that climbers should climb high during the day and return to lower altitudes to sleep during the night [146].

CHAPTER 5: SUMMARY AND CONCLUSION

The findings of this historical narrative review are one of the numerous ways to remember the life and times of Dr. Griffith Pugh and most importantly to acknowledge and reference his remarkable contributions and achievements to the field of high-altitude medicine and environmental physiology. This historical narrative review revealed that Dr. Pugh's contributions to the field of high-altitude medicine and environmental physiology cannot be underestimated, especially for his indefatigable scientific contributions towards the successful first ascent of Mount Everest in 1953. Pugh gave value to science at a time when science was not valued. Findings from this narrative study were clear demonstrations and evidences that Pugh was an exceptional researcher whose outstanding contributions and recommendations to the field of high-altitude medicine and environmental physiology are still valid up till today. For instance; his recommendations on the use of open circuit oxygen system for climbing and sleeping at high altitude was a major contributory factor that led to the 1953 first ascent on Mount Everest after several years of failed attempts by the British. This system significantly improved the rate of climbing, increased performance, decreased fatigue, promoted sound sleep and improved mental alertness. Pugh's recommendations on food that provides adequate caloric value (i.e., high carbohydrate diet) at high altitude was also a major contribution in tackling the problem of loss of body weight climbers were predisposed to at high altitude. His recommendations on diet were of great impact owing to the fact that he broke away from the usual tradition by dividing climbers' diets into general purpose (prepatory climbing) rations and assault-day rations. He encouraged climbers to consume food with high calorific values which would improve their performance while on high altitude expeditions. Furthermore, Pugh's ability to design clothing and camping materials, that offered climbers the best protection against cold exposure at high altitude, was also one of his major contributions. Clothing materials which are lightweight, resistant to tear, windproof and waterproof were recommended as they provided significant insulation.

This narrative review revealed that Pugh's research studies to the field of high-altitude medicine and environmental physiology are reliable and valid owing to the fact that he was an outstanding researcher who conceived the idea that the most effective and efficient way to study man in various environmental stresses such as high-altitude, cold, hot was to perform research on the field rather than in the laboratory. Results from this historical narrative review showed that Pugh's research works have greatly impacted the field of high-altitude medicine and environmental physiology through various mediums such as publications of research articles in creditable journals, citations history, contributions in notable academic, clinical and professional textbooks. This historical narrative review established that Pugh set a long, storied career in high-altitude medicine and environmental physiology among notable researchers.

The information shared in this historical narrative review would be of immense benefit for future physiologists and researchers who will be interested in pursuing a career in the field of high-altitude and environmental physiology. In addition, the information shared in this historical narrative review would be of significant applications to athletes, health care professionals and explorers/climbers, traveling to high-altitude and polar environment. This historical narrative review should convince future high-altitude and environmental physiologists and researchers, athletes, health care professionals and explorers/climbers to painstakingly search and read about Dr. Pugh and some of his remarkable physiological investigations during high-altitude and polar expeditions. It is believed that the results of this historical narrative review about Pugh's research works would challenge future high-altitude and environmental physiologists and researchers, and further stimulate their interest in this field.

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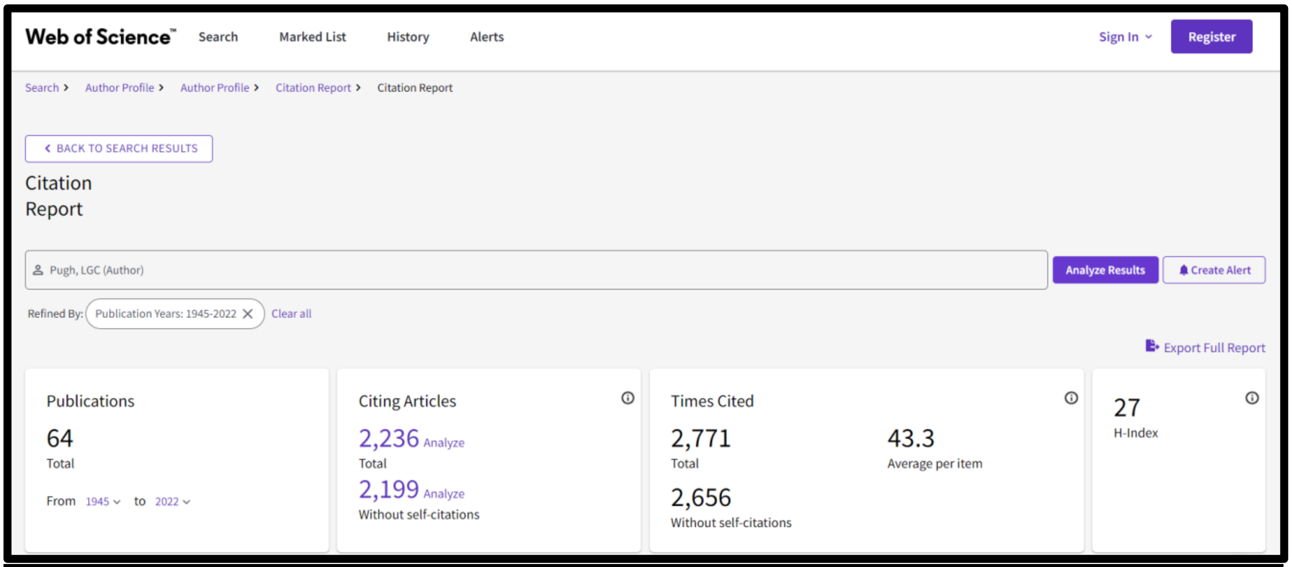
APPENDICES

Appendix A - Dr. Griffith Pugh Citation history and H-Index on Web of Science



Appendix B – List of Papers by Dr. Pugh and Citation History

Total number of papers meeting inclusion criteria =61

Peer reviewed papers (n=52)

Total number of citations (n = 61) = 2,711

Indicates gray literature (n=9)

Title of Articles	Total Citations (1945-2022)
Altitude Studies	
1) Athletes at altitude	54
2) Altitude and athletic performance	7
3) Man at high altitude	1
4) Muscular exercise at great altitude	235
5) Arterial oxygen saturation during exercise at high altitude	118
6) Man at high altitude: studies carried out in the Himalaya	15
7) Alveolar gas composition at 21,000 to 25,700 ft. (6400-7830 m)	27
8) The relation of oxygen intake and velocity of walking and running, in competition walkers	54
9) Basal metabolism and respiration in men living at 5,800m (19,000ft)	72
10) Physiological and medical aspects of the Himalayan scientific and mountaineering expedition, 1960-61	1
11) Muscular exercise on Mount Everest	61
12) Himalayan rations with special reference to the 1953 expedition to Mount Everest. 1954	25
13) Some effects of high altitude on man	14
14) Everest then and now	0
15) The effects of oxygen on acclimatized men at high altitude	7
16) Athletes at altitude. Lesions of the 1968 Olympics games	1
17) Maximum oxygen intake in Himalayan mountaineers	6
18) Blood volume and haemoglobin concentration at altitudes above 18,000 ft (5500m)	103
19) Physiology on Mount Everest (1953) and on the preparatory expedition to Mount Cho Oyu (1952): a demonstration of equipment and results [proceedings]	1
20) Haemoglobin levels on the British Himalayan Expeditions to Cho Oyu in 1952 and Everest in 1953	8

21) Resting ventilation and alveolar air on Mount Everest: with remarks on the relation of barometric pressure to altitude in mountains	49
22) Technique employed for measuring respiratory exchanges on Mount Everest, 1953	0
23) The carbon monoxide dissociation curve of human blood	64
24) Physiological and medical aspects of the Himalayan Scientific and Mountaineering Expedition, 1960-61. 1962	50
25) Climbing Everest without oxygen	0
26) Fitness for high altitude	0
27) Science in Himalaya	3
28) Exercise at altitude	26
29) Mount Cho Oyu 1952, Mount Everest, 1953	0
30) Cardiac output in muscular exercise at 5800 m (19000 ft)	108
31) Scientific aspects of the expedition to Mount Everest, 1953	7
32) Himalayan scientific and mountaineering expedition, 1960/61 – The scientific program	2
Cold Physiology Studies	
1) The physiology of channel swimmers. 1955	4
2) The physiology of channel swimmers	120
3) Clothing insulation and accidental hypothermia in youth	38
4) Cold stress and muscular exercise, with special reference to accidental hypothermia	73
5) Thermal, metabolic, blood, and circulatory adjustments in prolonged outdoor exercise	12
6) Deaths from exposure on four inns walking competition, March 14-15, 1964	45
7) Accidental hypothermia in walkers, climbers, and campers: report to the Medical Commission on Accident Prevention	96
8) Isafjordur trawler disaster: medical aspects	9
9) Tolerance to extreme cold at altitude in a Nepalese pilgrim	23
10) Hypothermia in mountain accidents	22
11) The adrenal cortex and winter sports, with a note on other exercise	6
12) A physiological study of channel swimming	62
13) Physiological expedition to the Antarctic	1
14) Observations of the effects of solar radiation on the thermal environment inside tents in Antarctica	0

15) The logistics of the polar journeys of Scott, Shackleton and Amundsen	10
16) Carbon monoxide hazard in Antarctica	8
17) The effective area of the human body with respect to direct solar radiation	10
18) Thermal conductivity of human fat and muscle	65
19) Contribution of solar radiation to thermal environment of man in Antarctica	16
<u>Exercise Physiology Studies</u>	
1) The relation of oxygen intake and speed in competition cycling and comparative observations on the bicycle ergometer	115
2) Haematological status of middle- and long-distance runners	119
3) Rectal temperatures, weight losses, and sweat rates in marathon running	242
4) The aerobic capacity of forty British women aged 17-27 years	4
5) A modified acetylene method for the determination of cardiac output during muscular exercise	4
6) Proceedings: Heat losses from the moving limbs in running: the 'pendulum' effect	5
7) Blood volume changes in outdoor exercise of 8–10-hour duration	40
8) Skin temperature during running--a study using infra-red colour thermography	58
9) Oxygen intake in track and treadmill running with observations on the effect of air resistance	195
10) The influence of wind resistance in running and walking and the mechanical efficiency of work against horizontal or vertical forces	190

Appendix C - Citation History of Most Influential Articles

Title of Articles in Peer Reviewed Journals	Total Number of Citation (1945-2022)
1) Rectal temperatures, weight losses and sweat rates in marathon running	242
2) Muscular exercise at great altitudes	235
3) Oxygen intake in track and treadmill running with observations on the effect of air resistance	195
4) The influence of wind resistance in running and walking and the mechanical efficiency of work against horizontal or vertical force	190
5) The physiology of channel swimmers	120
6) Hematological status of middle- and long-distance runners	119
7) Arterial oxygen saturation during exercise at high altitude	118
8) The relation of oxygen intake and speed in competition cycling and comparative observations on the bicycle ergometer	115
9) Cardiac output in muscular exercise at 5800 m (19000 ft)	108
10) Blood volume and hemoglobin concentration at altitudes above 18,000 ft (5500m)	103

Appendix D –Textbook Citations

Textbooks References	Articles Cited	Chapters/Sections
Body Composition and Physical Performance: Applications for the Military Services (Editors – Marriott BM and Grumstrup-Scott J.)	• A Physiological Study of Channel Swimming	Ch. 12
Nutritional Needs in Cold and in High-Altitude Environments: Application for the Military Personnel in Field Operations (Editors – Marriott BM and Carlson SJ.)	• Arterial Oxygen Saturation During Exercise at High-Altitude • Basal Metabolism and Respiration in Men Living at 5,800 m (19,000 ft) • Muscular Exercise at Great Altitudes • Accidental Hypothermia in Walkers, Climbers and Campers: Report to the Medical Commission on Accidental Prevention • Physiological and Medical Aspects of the Himalayan Scientific and Mountaineering Expedition, 1960-1961	Ch. 17 Ch. 19 Ch. 17 Ch. 7 & Sec. D Ch. 16 & 18
Nutritional Needs in Hot Environments: Applications for Military Personnel in Field Operations (Editor – Marriott BM)	• Haematological Status of Middle-and Long-Distance Runners	Ch. 7
Monitoring Metabolic Status: Predicting Decrements in Physiological and Cognitive Performance	• Rectal Temperature, Weight Loss, and Sweat Rates in Marathon Running	Sec. D
High Altitude and Man (Authors – John B. West and Sukhamay Lahiri)	• Muscular Exercise at Great Altitudes • Physiological and Medical Aspects of the Himalayan Scientific and Mountaineering Expedition, 1960-1961 • Cardiac Output in Muscular Exercise at 5800 m (19,000 ft) • Blood Volume and Haemoglobin Concentration at Altitude above 18,000 ft (5,500 m)	Ch. 1, 13 & 16 Ch. 4 Ch. 1 Ch. 6
High Altitude Medicine (Author – Herbert N. Hultgren)	• Muscular Exercise at Great Altitudes • Some Effects of High Altitude on Man	Ch. 2 Ch. 8 Ch. 13

	• Acute Pulmonary Edema and Mountaineering: Notes and Queries Practitioners	
Advanced Environmental Exercise Physiology (Author – Stephen S. Cheung)	• Muscular Exercise at Great Altitudes	Ch. 9
Handbook of Physiology Section 4: Environmental Physiology Volume II (Editors – Melvin J. Fregly and Clark M. Blatteis)	• Muscular Exercise at Great Altitudes • Physiological and Medical Aspects of the Himalayan Scientific and Mountaineering Expedition, 1960-1961 • Cardiac Output in Muscular Exercise at 5800 m (19,000 ft) • Animal in High Altitudes: Man above 5000 Meters-Mountain Exploration • Muscular Exercise on Mount Everest • Blood Volume and Haemoglobin Concentration at Altitude above 18,000 ft (5,500 m) • Resting Ventilation and Alveolar Air on Mount Everest: with Remarks on the Relation of Barometric Pressure to Altitude in Mountains	Ch. 50, 57 Ch. 50 & 57 Ch. 53 & 57 Ch. 57 Ch. 50 Ch. 55 Ch. 57
Fluid Replacement and Heat Stress	• Physiological and Medical Aspects of the Himalayan Scientific and Mountaineering Expedition, 1960-1961	Ch. 15
Environmental Effects on Work Performance (Authors – G.R. Cumming, A.W. Taylor and D. Snidal)	• Accidental Hypothermia among Hill Walkers in Britain • Athletes at Altitude	Ch. 4 Ch. 7
Introduction to Environmental Physiology (Authors – G. Edgar and Folk. JR.)	• Animal in High Altitudes: Man above 5000 Meters-Mountain Exploration	Ch. 8
Essentials of Sea Survival	• The Physiology of Channel Swimmers	Ch. 4
Prevention, Recognition and Prehospital Treatment: Hypothermia, Frostbite and other Cold Injuries (Authors – James A. Wilkerson, Cameron C. Bangs and John S. Hayward)	• Deaths from Exposure on Four Inns Walking Competition, March 14-15	Introduction
Hypothermia – Cold-Induced Injuries (Compiled by – Helge Brandstrom)	• A Physiological Study of Channel Swimming	Page 21

Expedition & Wilderness Medicine (Editors – Caroline Knox and Ros Carter)	• Carbon Monoxide Hazard in Antarctica	Ch. 17
Handbook of Physiology, Section 4: Adaptation to the Environment (Author – Dill DB.)	• Animal in High Altitudes: Man above 5000 Meters-Mountain Exploration	Sec. 4
Operation Everest II 1985: Biomedical Studies During a Simulated Ascent of Mt. Everest (Editors – Charles S. Houston, Allen Cymeman, and John R. Sutton)	• Cardiac Output in Muscular Exercise at 5800 m (19,000 ft) • Muscular Exercise at Great Altitudes • British Himalayan Expedition to Mt. Cho Oyu. 1952 • Physiological and Medical Aspects of the Himalayan Scientific and Mountaineering Expedition, 1960-1961 • Some Effects of High Altitude on Man • Animal in High Altitudes: Man above 5000 Meters-Mountain Exploration • Blood Volume and Haemoglobin Concentration at Altitude above 18,000 ft (5,500 m) • Resting Ventilation and Alveolar Air on Mount Everest: with Remarks on the Relation of Barometric Pressure to Altitude in Mountains	Sec. 3

Appendix E – Annotated Bibliography

Altitude Studies

1. Pugh, L. G. (1965). "Altitude and athletic performance. "Nature 207(5004): 1397-1398.

The purpose of this study was to investigate the effects of altitude on athletic performance. What necessitated Pugh (primary author) to conduct this study was due to the fact that the 1968 Olympic games were to be hosted in the city of Mexico, located at an altitude of 7,500 ft above the sea level and as such, the competitors of the games were concerned about the impact of altitude on their performance. In this study, Pugh had to conduct a retrospective analysis by comparing the performances of runners in the 1955 Pan American games held in the city of Mexico (at altitude 7,500 ft) with performances of runners in the 1956 Olympic games held in Melbourne (at sea level). For these two games, Pugh critically compared the times (durations) of the first 3 competitors in the finals of the running events (100 m, 200 m, 400 m, 800m, 1,500 m, 5,000 m 10,000 m).

The results of the study revealed that during the 1955 games (at altitude 7,500 ft) the time (durations) it took the competitors to cover long distance events (i.e., 800 m, 1,500 m, 5,000 m and 10,000 m) was longer as compared to the 1956 games (at sea level). Whereas, during the 1955 games, the time (durations) it took competitors to cover short distance events (i.e., 100 m and 400 m) was shorter as compared to the 1956 games. Pugh concluded that performance decreases with altitude during long distance (endurance) events. Whereas, during short distance (sprint) events, altitude improves performance due to decrease air density.

2. **Gill, M. B., J. S. Milledge, L. G. Pugh and J. B. West (1962). "Alveolar gas composition at 21,000 to 25,700 ft. (6400-7830 m)." J Physiol 163(3): 373-377**

This study provided further insight into changes in alveolar gas composition at high altitude. Pugh (one the secondary authors) and his colleagues reported the alveolar gas composition samples of nine climbers during an expedition to Mount Makalu (5th highest mountain) in the world. The authors of this study collected the alveolar gas samples of the nine climbers at specific altitudes (i.e., 21,000 ft, 24,400 ft and 25,700ft) in an ampoule. The alveolar gas samples of the climbers were taken at the end of a normal expiration. Pugh and his colleagues used the Haldane methods to analyze alveolar gas samples (partial pressure of carbon dioxide - pCO_2 and partial pressure of oxygen - pO_2). Furthermore, the authors were able to determine the respiratory quotient (ratio of volume of CO_2 eliminated/O_2 consumed) from the drawn alveolar gas samples.

The authors observed that barometric pressure decreases as altitude increases. For instance, the average barometric pressure at 21,000 ft, 24,400 ft, and 25,700 ft were 344, 300 and 288 mmHg respectively. Furthermore, the results of the alveolar gas analysis revealed that as altitude increases pCO_2, pO_2 and respiratory quotient decreases. For instance, at altitude 21,000 ft, 24,400 ft and 25,700 ft the average pCO_2 values were 20.7, 15.8 and 14.4 mmHg respectively, while the average pO2 values were 38.1, 33.7 and 32.8 mmHg respectively.

3. **Pugh, L. G. (1969). "Athletes at altitude. Lesions of the 1968 Olympics games." Trans Med Soc Lond 85: 76-83.**

This was a descriptive study by Pugh (primary author) who provided information about how altitude affected athletes' performance who competed in the 1968 Olympic games in Mexico

City (at an altitude 2,270 m). Prior to the start of the 1968 Olympic games, there were speculations by the general public and competitors of the games that altitude would negatively affect their performance in Mexico City. For instance, some people had the notion that athletes who will compete in the 1968 Olympic games would suffer permanent debilitating effects. Interestingly, some perceived that athletes would die during the game. Therefore, in this article Pugh gave a descriptive report on what transpired during the 1968 Olympic games in Mexico City with regards to athletes' performance. For instance, he compared the times (durations) it took athletes to completes certain race (100 m, 200 m, 400 m, 800 m, 5000 m, 10,000 m and marathon) during the 1968 Olympic games and during sea level games. Pugh observed that during the 1968 Olympic games it took athletes longer times (durations) to finish long-distance race (5000 m, 10,000 m and marathon) than during sea level games. On the other hand, it was observed that during the 1968 Olympic games it took athletes shorter times (durations) to finish short-distance race (sprint events – 100 m and 200 m.) than during sea level games. Therefore, it was evidently clear to Pugh that altitude decreases athletes' performance during long-distance race. Whereas, altitude improves athletes' performance during short-distance race.

In this descriptive study, Pugh highlighted the fact that high-altitude athletes showed better performance than sea level athletes competing at high altitude environment. For instance, it was mentioned in this article that high-altitude athletes had higher maximum oxygen intake, maintained faster pace than sea level athletes. Furthermore, this article recognized the debilitating effects of altitude on athletes' performance. Pugh stated that low atmospheric oxygen pressure, low air density, dry air and intense solar radiation affected the performance of athletes who competed in the 1968 Olympic games. For instance, the author reported that 80 athletes who competed in the 1968 Olympic games collapsed due to the intense solar radiation causing heat exhaustion.

4. **Pugh, L. G., M. B. Gill, S. Lahiri, J. S. Milledge, M. P. Ward and J. B. West (1964). "MUSCULAR EXERCISE AT GREAT ALTITUDES." J Appl Physiol 19: 431-440.**

This research paper described the physiological response to exercise at sea level and at various altitudes. This study was conducted during a Himalayan expedition that lasted for 8 months (September 1960-June 1961). Pugh (the primary author) and his colleagues measured oxygen intake, ventilation, heart rate and cardiac output in six subjects who were experienced mountaineers. The six subjects performed ergometer exercises at sea level and at various altitudes (4,650 m to 7,440 m) at various work rate. This study revealed that maximum oxygen intake and work rate decreases with increase in altitude as compared to sea level. In addition, it was observed by the authors that ventilation increases with altitude. It was further revealed that at altitude, subjects heart rate was higher than at sea level.

Furthermore, in this study, Pugh and his colleagues were also interested in investigating factors that limits exercise at high altitudes. For this purpose, they analysed the blood and respiratory parameters such as cardiac output and lung diffusion capacity for oxygen of three subjects. It was revealed that low cardiac output, decrease lung diffusion (resulting in higher oxygen cost) are factors that all contributes to limitation of exercise at high altitudes.

5. **Pugh, L. G. (1954). "Haemoglobin levels on the British Himalayan Expeditions to Cho Oyu in 1952 and Everest in 1953." J Physiol 126(2): 38-39p.**

Pugh (primary author) main focus for this study was to determine the haemoglobin concentration of climbers at altitude. He compared the haemoglobin level of climbers during an expedition to Cho Oyu (6th highest mountain) in 1952 and during the 1953 expedition to Everest (world's highest mountain). In this study, the author measured the haemoglobin concentration of climbers to Cho Oyu and Everest using oxyhaemoglobin method and Iron method respectively. For the Cho Oyu expedition, the haemoglobin concentration of 14 climbers [Europeans – 8, and Sherpas (high altitude native residents) – 6] were estimated. While for the Everest expedition, haemoglobin concentration of 30 climbers [Europeans – 12, and Sherpas (high altitude native residents) – 18] were estimated.

The findings of this study revealed that haemoglobin concentration of climbers increases with altitude in both expeditions. For instance, the mean value of the haemoglobin concentration of climbers on Cho Oyu expedition while at 1,000 ft was (Europeans – 14.7g% and Sherpas – 13.6g%), and while at 17,500 ft was (European – 20.3g% and Sherpas – 19.0g%). Furthermore, Pugh observed that the haemoglobin concentration of the Sherpas (high altitude native residents) was significantly lower than the Europeans in both expeditions. Pugh stated in this study that there was no obvious relationship between haemoglobin level and physical performance. However, this is a limitation of this study because parameters to quantify performance was not analysed.

6. **Pugh, L. G. and J. R. Sutton (1983). "Everest then and now." Prog Clin Biol Res 136: 415-430.**

Everest was successfully climbed on the 29 May, 1953 by two men (Edmund Hillary and Tenzing Norgay) with the aid of oxygen supplement. However, on the 8 May, 1978 precisely 25 years after the first ascent, Peter Habeler and Reinhold Messner successfully climbed Everest without oxygen supplement. The 1978 success at Everest proved a lot of physiologists wrong who had earlier conceived the ideas that Everest cannot be climbed without the aid of oxygen supplement. Therefore, out of curiosity, Pugh (primary author) and his colleague conducted this study by comparing the differences between the climbers of 1953 and 1978 Everest expedition.

The results of their investigation clearly revealed that the 1978 climbers were better adapted to high altitude environment than the 1953 climbers. Pugh and his colleagues stated that the 1978 climbers were exceptional athletes who in many areas demonstrated sound background in physiology, training methods, diet and fluid balance. For instance, this study clearly showed that the 1978 climbers were born and raised in high altitude environment (1,000 m-2,000 m) and as such, they have mild acclimatization to altitude than the 1953 climbers. Furthermore, the 1978 climbers were able to achieve success without oxygen supplement owing to the fact that they had good climbing skill and speed than the 1953 climbers, they have had several series of training in altitude in the past which predisposes them to resist inadequate fluid intake and dehydration. It is worthy of note that this study revealed that due to the frequent training routine of the 1978 climbers at altitude, they had considerably greater maximum aerobic power than the 1953 climbers. For instance, the maximum oxygen intake (VO_2 max) at sea level of the 1978 climbers was 80 ml/kg/min. Whereas, the VO_2 max of 1953 climbers was 51.3 ml/kg/min.

7. **Pugh, L. G. (1976). "Physiology on Mount Everest (1953) and on the preparatory expedition to Mount Cho Oyu (1952): a demonstration of equipment and results [proceedings]." J Physiol 263(1): 95p-97p.**

This historical article was written by Pugh (primary author) who narrated how the 1952 expedition to Cho Oyu (6th highest mountain) led to the success at Mount Everest after several years of failures. Pugh stated in this article that the purpose of the 1952 expedition to Cho Oyu was to select climbers for the 1953 Everest expedition, and also to investigate the physiological challenges of climbing at extreme altitude which had undermined previously failed expeditions to Everest. In this article, Pugh stated that although the 1952 Cho Oyu expedition failed, but it provided a sound basis for planning and equipping the 1953 Everest expedition most especially with focus on the use of efficient oxygen supplement.

The author reported that during the 1952 Cho Oyu expedition battery of physiological experiments such as effects of oxygen on ventilation and work rate at high altitude, climatic and clothing studies. were carried out. It was revealed that while at Cho Oyu expedition factors such as dehydration, inadequate diet and hypoxia predisposes climbers to physical and mental deterioration and as such, if the 1953 Everest expedition was to be successful all the aforementioned factors needed to be addressed. Interesting, it was reported in this article that all these factors were overcame in the 1953 Everest expedition and thus, Everest was successfully climbed. For instance, climbers were provided with oxygen supplement to sleep, special rations, adequate fuel to cook and melt snow.

8. Pugh, L. G. (1964). "Man at high altitude: studies carried out in the Himalaya." Sci Basis Med Annu Rev: 32-54.

This study was a review conducted by Pugh (primary author) who holistically discussed physiological responses of climbers at sea level and various altitudes ranging from 5,800 m (19,000 ft)-7,830 m (25,7000 ft) during the 1960-1961 Himalayan scientific and mountaineering expedition that lasted for 8 and a half months. For instance, in this review, Pugh discussed physiological responses such as heart rate, cardiac output, lung diffusion capacity, and maximum oxygen intake of climbers during muscular exercise at altitude, and compared those parameters with that of sea level values. For instance: it was observed in this study review that maximum oxygen intake or aerobic capacity of climbers exercising at high altitudes significantly decreases than at sea level; heart rate during low or moderate exercise intensities increases at high altitudes than at sea level; lung diffusion capacity during exercise at high altitude was significantly reduced than at sea level. In this review, it was reported that at high altitude barometric pressure, partial pressure of inspired oxygen (P_iO_2), arterial partial pressure of oxygen (P_aO_2), alveolar partial pressure of oxygen (P_AO_2) decreases with increase in altitude than sea level values.

Furthermore, Pugh also discussed the hematological parameters such as red cell mass, hemoglobin concentration, plasma volume, blood volume of climbers during the 1960-1961 expedition. He reported that hemoglobin concentration, red cell mass increases with altitude. Whereas, plasma volume and blood volume decrease with altitude. Pugh also discussed the oxyhemoglobin dissociation curve [(S_aO_2 – arterial oxygen saturation) plotted against (P_aO_2 - arterial partial pressure of oxygen)] at high altitude. He stated that unloading of oxygen takes place at high altitude indicating steep slope of the oxyhemoglobin dissociation curve. Owing to the fact that this is a holistic review, Pugh went further to discuss mental function and nutrition at high altitudes during the 1960-1961 expedition. He stated that after climbers were subjected to series of psychological tests, they started manifesting mental impairment such as being in a depressive state at higher altitude (≈23,000 ft), but such wasn't manifested at lower altitude (≈19,000 ft). In this review, Pugh stated that climbers suffered from dehydration and showed sign of loss of appetite at altitudes. However, it was stated in this review that climbers should take 3-4 litres of fluid every day when at high altitude in order to maintain normal urine output of 1.5 litres/day.

9. **Pugh, L. G. (1954). "Technique employed for measuring respiratory exchanges on Mount Everest, 1953." <u>J Physiol</u> 123(2): 25-26p.**

This study discussed the technique Pugh (primary author) adopted to effectively measured respiratory exchange during the 1953 Everest expedition. What necessitated Pugh to adopt a new technique to measure respiratory exchange was due to that fact that it was observed that the conventional method (i.e., the bag method) was no longer suitable for high altitude studies due to its heavy weight and small containing capacity (i.e., it wasn't able to contain lung ventilation of subject greater than 60 l/min). In this study, Pugh highlighted the new apparatus adopted to effectively measured respiratory exchange and went further to discuss the method/procedure used.

The apparatus adopted to effectively measured respiratory exchange were: lightweight Douglas bag with large containing capacity (i.e., 100, 200 and 300 litres) used to collect expired air at the end of a normal expiration; Intestinal clamps used to close the Douglas bag to prevent the collected expired air from escaping; An Aneroid manometer used to measure the pressure of the expired air in the bag; A sensitive (Casella) thermometer used to measure the temperature of the expired air; An alkathene tube which connect the valve box of the mouthpiece to the Douglas bag; and A portable Scholander gas analyzer. As for the procedure adopted to measure the respiratory exchange, Pugh explained that climbers/subjects would be instructed to carry the clamped empty Douglas bag on their back, put on a mouthpiece with the alkathene tube passed over the head of the climbers/subjects. It was further reported in this study that after 5 minutes of exercise, the Douglas bag would be unclamped for collection of expired air until the bag is full and thus, clamped again. Pugh in this study reported that the time difference when the bag was unclamped and clamped was recorded by a stopwatch. Pugh stated that one limitation of using this technique is that the temperature measurement of the collected expired air when the bag is unclamped might not be accurate because of the insufficient time to allow the expired air to cool to room temperature.

10. Gill, M. B. and L. G. Pugh (1964). "BASAL METABOLISM AND RESPIRATION IN MEN LIVING AT 5,800 M (19,000 FT)." J Appl Physiol 19: 949-954.

The purpose of this study was to investigate the respiratory parameters [i.e., minute ventilation, alveolar ventilation (V_A), alveolar partial pressure of CO_2 (P_ACO_2) and O_2 (P_AO_2)] and the basal metabolic rate of acclimatized (The Sherpas) and unacclimatized (European scientists) climbers at high altitude. Pugh (secondary author) and his colleagues conducted this study on 11 climbers [European scientists – 8, and Sherpas (high altitude native residents) – 3] during a prolonged stay at 5,800 m (19,000 ft). In this study, the authors collected the climbers expired air in a Douglas bag and used the Lloyd-Haldane methods to analyze the gas samples. Several parameters were measured such as oxygen uptake, basal heart rate, alveolar ventilation (V_A), basal metabolic rate, basal heat production.

The results of this study revealed significant decrease in the mean values of V_A, minute ventilation, and P_AO_2 in the Sherpas (acclimatized) than in the European scientists (unacclimatized) climbers. For instance, the mean value of the V_A was 6.2 litres (BTPS)/min and 8.1 litres (BTPS)/min in the Sherpas and European scientists respectively. Furthermore, the authors observed significant increase in the mean values of oxygen uptake, basal metabolic rate, basal heat production, basal heart rate in the Sherpas (acclimatized) than in the European scientists (unacclimatized) climbers. For instance, the mean value of the basal heat production was 46.1 kcal/m^2 hr and 41.7 kcal/m^2 hr in the Sherpas and European scientists respectively. While the basal heart rate was 84 beats/min and 73 beats/min in the Sherpas and European scientists respectively. Interesting, the findings of this study was in agreement with previous studies conducted by other researchers. Based on the findings in this study, it was concluded that acclimatization to high altitude in man is associated with increase in basal metabolism.

11. West, J. B., S. Lahiri, M. B. Gill, J. S. Milledge, L. G. Pugh and M. P. Ward (1962). "Arterial oxygen saturation during exercise at high altitude." J Appl Physiol 17: 617-621.

The purpose of this research study was to determine the effect of high intensity exercise on arterial oxygen saturation (SaO_2) at high altitude of 19,000 ft. Pugh (one of the secondary authors) and his colleagues were interested in this study because the results of this study availed them the opportunity to determine SaO_2 at a very high altitude (19,000 ft) during high intensity exercise, considering the fact that previous studies never measured SaO_2 at such a very high altitude. Interestingly, six healthy subjects participated in this study. It was stated that all the subjects had prior history of great acclimatization to high altitude at 19,000 ft for a long period of time of about 14 weeks. The authors clearly stated that SaO_2 in this study was determined using two indirect methods. 1) ear oximetry and 2) analysis of arterialized venous blood while subjects' hand was heated for about 10 minutes by an electrically heated gloves or hot water immersion. Furthermore, SaO_2 was then determined while subjects were at rest and during 5-10 minutes of high intensity exercise (300 and 900 kg-m/min) on a stationary bicycle. In addition to the SaO_2 that was determined, the authors of this research study, also determined the alveolar oxygen tension (P_AO_2) and oxygen consumption (VO_2).

The authors findings revealed that the values of SaO_2 at rest was higher as compared to during exercise. Consequently, it was revealed that as exercise intensity increases, SaO_2 decreases. For instance, the mean SaO_2 at rest, and during 300 and 900 kg-m/min exercise were 67%, 63% and 56% respectively. Furthermore, it was shown that as exercise intensity increases, the P_AO_2

and VO_2 increases despite the decrease SaO_2. In the discussion section of this study, the authors attributed the decrease SaO_2 during exercise at high altitude to diffusion limitation/restrictions. The authors stated that in order to maintain SaO_2 during high intensity exercise at high altitude, there should be an increase in the rate of oxygen reaction with hemoglobin.

12. Pugh, L. G. (2002). "Physiological and medical aspects of the Himalayan Scientific and Mountaineering Expedition, 1960-61. 1962." Wilderness Environ Med 13(1): 57.

This was an excerpt written by Pugh (primary author) and his colleagues. The purpose of this excerpt was to add to the existing body of knowledge with regards to how humans adapt to extreme high-altitude environment, and also to investigate the effects of hypoxia on men who resides at or above the limit of altitude where acclimatization is achievable. In this excerpt, Pugh and his colleagues briefly narrated the 1960-1961 Himalayan Scientific and Mountaineering Expedition which was led by Sir Edmund Hillary. The authors stated that the members of the expeditions were physiologists, zoologists, glaciologists, and meteorologists.

It was stated that this expedition was the first recorded expedition to winter in the Himalayas at high altitude and also, the first expedition recorded for which human spent more than 6 weeks at high altitude ≥ 19,000 ft. The authors clearly stated that the team spent a period of 8 months (September 14, 1960 – June, 1961) above an altitude of about 15,000 ft. In this excerpt, it was stated that because the team understands what they were likely to encounter at such extreme climatic condition, they already made plans which will prevent them from being exposed to the extreme climatic condition. For instance, it was noted that they had a prefabricated hut which was erected at an altitude of 19,000 ft where they stayed for 5½ months while on the expedition. Most importantly, the authors stated that in May, 1961 the team attempted to ascend the 5th highest mountain (Mt. Makalu – 27,790 ft) without any oxygen supplement. Although, it was clearly stated that oxygen supplement was made available only for those who seek immediate medical and rescue attention after being faced with the challenges of climbing such a high altitude.

13. Pugh, L. G. (1954). "The effects of oxygen on acclimatized men at high altitude." <u>Proc R Soc Lond B Biol Sci</u> 143(910): 14-17.

This article written by Pugh (primary author) narrated that the effects of oxygen supplement on men at high altitude cannot be overemphasized. In this article, Pugh narrated the findings of the physiological experiments conducted on climbers during the Cho Oyu 1952 expedition as well as during the 1953 Everest expedition. it was established that during the Cho Oyu expedition, Pugh and his colleagues investigated the effects of oxygen supplement on climbers work rate and lung ventilation. During this expedition, Pugh and his colleagues recorded the time it took climbers to ascend 300 ft altitude without oxygen supplement and with the use of oxygen supplement of different flow rates (4 and 10 L/min). The author also investigated the effects of carrying heavy oxygen equipment on climbers. The results revealed that climbers ascended as fast as possible when using oxygen supplement as compared to without oxygen supplement. For instance, it was stated that the time it took climbers to climb was reduced by approximately 10% when on oxygen supplement. Although, Pugh stated that there were no significant differences in the climbing rates between climbers that used 4 and 10 L/min flow rate. In this article, it was clearly stated that the use of heavy oxygen equipment slows down the rate of climbing. Furthermore, the effect of oxygen supplement on climber’s lung ventilation was investigated. Pugh narrated that climber were instructed to stand up and down on a box for 20 minutes while ventilation was measured in the last 5 minutes. The results showed that with the use of oxygen supplement there was a significant decrease in ventilation and an increase in alveolar partial pressure of CO_2.

During the Cho Oyu expedition, it was stated that climbers reported significant decrease in dyspnea and fatiguability owing to the use of oxygen supplement. Consequently, the effects of oxygen supplement above 22,000 ft during the 1953 Everest expedition was also discussed in this article. It was clearly stated that the use of 4 L/min and 1 L/min O_2 was considered effective and efficient during climbing and sleeping respectively. For instance, the climbing rate of climbers improved significantly, decrease fatiguability, increase performance, enhance recovery, promote sound sleep, improves mental alertness. Pugh concluded that it wouldn’t have taken 30 years for Everest climbers to successfully ascend to the summit of Everest if they had use adequate oxygen supplement for their expeditions.

14. Pugh, L. G. (1972). "Maximum oxygen intake in Himalayan mountaineers." <u>Ergonomics</u> 15(2): 133-137.

The primary purpose of this study which was conducted by Pugh (primary author) was to determine and compare the maximum oxygen intake (VO_2 max) at sea level among climbers who had participated in Everest expeditions between 1953 to 1971. It was clearly stated that the maximum oxygen intake of climbers in the 1953 and 1960-1970 Everest expeditions were determined while climbers were running on a treadmill at a speed of 6.5 m.ph and cycling for 5 minutes on a stationary bicycle ergometer respectively. However, for the 1971 Everest expedition, it was stated that the maximum oxygen intake was determined while climbers were engaging in running on treadmill as well as during 5 minutes cycling on bicycle ergometer. Apart from the maximum oxygen intake that was determined in this study, climbers heart rate, blood lactate, ventilation was also measured.

The results of this study showed that climbers of the 1953 Everest expedition recorded the highest mean value of VO_2 max as compared to other years. In addition, Pugh analyzed each individual's VO_2 max between 1953 to 1971 expeditions and thus, revealed that only two climbers of the 1960/1961 expedition recorded the highest values of VO_2 max as compared to other years. Furthermore, Pugh compared the results of the VO_2 max during exercise on treadmill and bicycle ergometer for climbers in the 1971 Everest expedition. The results revealed that there was no significant difference in the mean VO_2 max for each climber during exercise on treadmill and bicycle ergometer. In the discussion section of this study, it was stated that previous studies have shown that trained athletes have higher VO_2 max than mountain climbers. However, mountain climbers can still compete well during high altitude expeditions without having exceptionally high VO_2 max.

15. Pugh, L. G. (2004). "Himalayan rations with special reference to the 1953 expedition to Mount Everest. 1954." Wilderness Environ Med 15(2): 125-134.

This historical research paper written by Pugh (primary author) discussed the nutritional and dietary problems climbers faced during the 1952 Cho Oyu expedition, as well as how the problems were addressed that led to successful ascent to the summit of Everest in 1953. Pugh stated that inadequate/insufficient diet intake was one of the contributory factors that led to failure of the climbers to ascend Cho Oyu. For instance, the food consumed had low calorific values which didn't give climbers the much-needed energy during the expedition. It was also revealed that the food consumed by the climbers predisposed them to digestive system disturbance. Climbers experienced significant loss of body weight due to loss of appetite. The loss of appetite experienced by climbers during the Cho Oyu expedition was due to lack of varieties of diet and lack of acclimatization to high altitude. Therefore, it was stated that if climbers were to successfully ascend the summit of Everest after the poor outing at Cho Oyu, adequate diet and acclimatization is of outmost importance.

For the 1953 Everest expedition, the problems of inadequate diet were tackled. For instance, during this expedition there was two types of available diet ration (composite and assault). It was stated that the composite rations are European type diet with sufficient calorific contents that was needed for general purpose. It offered enormous benefits to climbers such as increase climbers' taste for foods, and promote food hygiene. Whereas, the assault rations were food consumed at specific altitudes (≥ 21,000), which gave climbers the much-needed energy to ascend at such great altitudes. It was established that during the 1953 Everest expedition, the rate at which climbers lost body weight was not significant as compared to Cho Oyu expedition. Furthermore, Pugh stated that the problem of dehydration, loss of appetite and lack of acclimatization which contributed to previously failed Everest and Cho Oyu expeditions were all addressed during the 1953 Everest expedition. It was concluded that climbers of the 1953 Everest expedition showed improvement in fitness levels and general state of health which enhances their performance as compared to during the 1952 Cho Oyu expedition.

16. Pugh, L. G. (1964). "BLOOD VOLUME AND HAEMOGLOBIN CONCENTRATION AT ALTITUDES ABOVE 18,000 FT. (5500 M)." J Physiol 170(2): 344-354

The aim of this research study which was conducted by Pugh (primary author) was to determine the blood volume, red cell volume, plasma volume, hematocrit and hemoglobin concentration during the 1960/1961 Himalaya Scientific and Mountaineering expedition to Mingbo glacier (19,000 ft). This research study was conducted on six climbers who were members of the expedition team. According to Pugh, this study was a record breaking one because this was the first ever expedition in which climbers spent longer period of time at greater altitudes (8½ months above 15,000ft and 5 months at 19,000 ft) as compared to previous expeditions (3-6 months). In this study, blood volume, red cell volume, plasma volume, hematocrit and hemoglobin concentration were measured at sea level and at 19,000 ft altitude, and comparison were made. In addition, this study also compared the results of previously collated data of hemoglobin concentration of sea level residents residing at extreme high-altitude during eight different Himalaya expedition with that of high-altitude native residents.

The results of this study revealed that the blood volume initially decreases as compared to sea level when climbers were at altitude 13,000ft – 19,000 ft. However, when climbers spent longer time at ≥ 19,000 ft the blood volume gradually increases as compared to sea level. Furthermore, the results of this study clearly revealed that red cell volume increases as altitude increases. It was evident that red cell volume increases progressively in all the six climbers in relation to the time spent at altitudes. In Contrast, plasma volume significantly decreases at altitudes as compared to sea level. The longer the time spent at altitudes, the lower the plasma volume. Most importantly, the results of this study revealed that hemoglobin concentration increases with altitudes as compared to sea level. Pugh stated that the longer the time spent at altitudes, the higher the hemoglobin concentration. Consequently, it was stated that changes in hemoglobin concentration depends largely by changes in plasma volume. Furthermore, with regards to the data collated during the 8 expeditions to the Himalaya, it was evident that hemoglobin concentration of sea level residents residing at extreme high altitude was lower than that of high-altitude native residents. For instance, the mean value of the hemoglobin concentration for plainsmen was 20.19 g/100ml, while that of high-altitude native residents was 22.9 g/100ml. In the discussion aspect of this article, Pugh discussed the relationship between hemoglobin concentration and performance at altitudes by making comparison with previous studies. It was crystal clear that there was no association between hemoglobin concentration and climbers' performance at altitudes.

17. Pugh, L. G. (1967). "Athletes at altitude." J Physiol 192(3): 619-646.

The purpose of this research paper which was conducted by Pugh (primary author) was to determine how altitude affect athletes' performance and to further determine the effects of acclimatization on athletes' performance. Six international athletes with previous history of running 4,828 m race participated in this study. They performed 4,828 m and 1,609 m timed runs for 4 weeks both at sea level and at 7,450 ft altitude. In addition, subjects also performed 5 minutes of maximum exercise on a bicycle ergometer as well as series of work tests at varying intensities. In this study, Pugh determined the time it took the subjects to complete the 4,828 m and 1,609 m timed runs at sea level and at altitude. Furthermore, parameters such as maximum oxygen intake (VO_2 max), heart rate, ventilation, blood pH and lactate were determined, and comparison were made both at sea level and at 7,450 ft altitude before and after exercise. Consequently, VO_2 max was also determined 40 min post exercise.

The findings of this study revealed that it took the subjects longer time to complete both runs at altitude compared to sea level. Furthermore, it was revealed that when subjects spent longer period of time at altitude, the time to complete both runs decreases progressively. Pugh, stated that the decrease in completion time in relation to the longer period of time spent at altitude may be attributed to adequate acclimatization. The findings of this study revealed that during 5 minutes of exercise, VO_2 max decreases at altitude as compared to sea level. Furthermore, it was revealed that initially work rate decreases at altitude as compared to sea level. However, when subjects spent longer period of time at altitude, work rate increases progressively as compared to sea level.

Pugh also stated that after 40 minutes post exercise, VO_2 max was higher at altitude as compared to sea level. In addition, ventilation increases at altitudes as compared to sea level. It was also revealed that at sea level, blood pH decreases after exercise whereas lactate increases after exercise. In the discussion part of this research paper, it was established that the effect of altitude on performance depends on VO_2 max, oxygen debt and air density.

18. Pugh, L. G. (1958). "Muscular exercise on Mount Everest." J Physiol 141(2): 233-261.

This research paper was conducted by Pugh (primary author) with the main objectives of determining respiratory exchanges during muscular exercise among mountaineers during Himalayan expeditions. 10 members who were both in the 1952 Cho Oyu and 1953 Everest expedition participated in this research study by engaging in different forms of muscular exercise (at varying work rate) such as step tests, uphill walking at sea level and at different levels of altitude. In this study, physiological parameters such as oxygen consumption, pulmonary ventilation in litres (BTPS: body temperature, pressure and saturated with water vapour), ventilation in litres (STPD: standard temperature and pressure and dry gases), as well as climbing rate and efficiency were all determined. Furthermore, the findings of this study were compared with observed results of previous studies done at sea level as well as at lower altitudes.

The results of this study showed that at sea level oxygen consumption was directly proportional to the rate of work. For instance, it was established that as work rate increases, oxygen consumption increases. Similarly, at altitudes, oxygen consumption increases in relation to the rate of work done but it is independent on altitudes. Conversely, as altitude increases, pulmonary ventilation (BTPS) increases as compared to sea level irrespective of the rate of work. Whereas, the finding of this study showed that ventilation (STPD) is independent on altitudes but depends on rate of work. With regards to climbing rate and efficiency, the results of this study revealed that as altitude increases, the rate of climbing decreases. For instance, at great altitudes, rate of climbing decreases. Consequently, efficiency of climbing decreases with altitude as compared with sea level. However, it was established that efficiency of climbing is greatly affected by the nature/terrain of the ground rather than on altitudes. Furthermore, it was crystal clear that the findings of this research study were in agreement with previously similar studies.

19. **Pugh, L. G. (1957). "Resting ventilation and alveolar air on Mount Everest: with remarks on the relation of barometric pressure to altitude in mountains." J Physiol 135(3): 590-610.**

The purpose of this research study was to determine the resting ventilation and alveolar gas tensions on the same set of climbers who participated in both the 1952 Cho Oyu and 1953 Everest British Himalayan expeditions. Pugh (primary author) believed that the findings of this study would contribute to the existing body of knowledge about physiological response on acclimatized individuals at great altitudes. In this study, holistic physiological experiments were done at varying levels of altitude in-order to: compare resting ventilation at altitudes and at sea level; determine the relationship between resting ventilation and barometric pressure; determine the relationship between barometric pressure and altitude; determine alveolar gas tension [alveolar partial pressure of oxygen (pO_2) and alveolar partial pressure of carbon dioxide (pCO_2)]. Furthermore, this study also investigated what effect does breathing 2 L/min flow rate of oxygen supplement would have on alveolar gas tension at great altitudes. It is noteworthy to state that the resting ventilation was determined on one subject who participated in both expeditions while still sleeping. while, the alveolar gas tensions were determined on all the climbers that participated in both expeditions.

The results of this study showed that barometric pressure decrease with increase in altitudes. Furthermore, the results of this study showed that resting ventilation in (BTPS: body temperature, pressure, saturated with water vapour) increase with altitudes as compared to sea level. For instance, resting ventilation in (BTPS) ranges from 13-22 l./min and 5.5-9.8 l./min at 18,000-21,200 ft altitude and sea level respectively. Similarly, as barometric pressure decreases, resting ventilation increases. Conversely, ventilation in (STPD: standard temperature, pressure, dry gases) is independent on altitude. In addition, it was stated in this article that ventilation was significantly higher during the 1953 expedition as compared to the 1952 expedition. With regards to alveolar gas tensions, as altitude increases, pO_2 and pCO_2 decreases. For instance, at 18,000 ft, 20,500 ft and 21, 200 ft, pO_2 was 44.5, 43.5 and 39.1 mmHg respectively. Furthermore, it was evident in this study that breathing oxygen supplement at greater altitudes has significant effects on alveolar gas tensions. The results of this study showed that breathing oxygen supplement at greater altitudes significantly increase alveolar gas tensions (pO_2 and pCO_2). For instance, at 18,000 ft altitude the mean pO2 and pCO2 (with and without breathing oxygen supplement) was 162.7 and 27.9 mmHg and 45.0 and 25.8 respectively.

20. Pugh, L. G. (1962). "Physiological and medical aspects of the Himalayan scientific and mountaineering expedition, 1960-61." <u>Br Med J</u> 2(5305): 621-627.

This was a descriptive article written by Pugh (primary author) who gave a detailed account of the physiological response of man to high altitudes during the 1960-1961 Himalayan Scientific and Mountaineering Expedition. This article discussed among other things, adaptation of man to high altitudes, effect of breathing oxygen supplement at high altitudes, and muscular exercise at high altitudes. It was established that the 1960-1961 expedition was the first expedition in which people spent longer period of time at altitudes above 19,000 ft. In this article, physiological parameters such as partial pressure of inspired oxygen (PiO_2), alveolar partial pressure of oxygen and carbon dioxide (P_AO_2 and P_ACO_2) were all determined in relation to altitudes and barometric pressure. Furthermore, physiological parameters such as oxygen intake, heart rate, ventilation [(BTPS): body temperature, pressure, saturated with water vapour and (STPD): standard temperature, pressure, dry gases] during cycling on a bicycle ergometer (muscular exercise) were all determined. Electrocardiography (ECG), hematological, endocrine functions were all determined. In addition, the medical aspect such as high-altitude sickness and diseases were all discussed in this article.

In this article, it was evident that as altitude increases, barometric pressure, PiO_2, P_AO_2, and P_ACO_2 decreases. Furthermore, it was evident in this article that during the muscular exercise at varying levels of increase altitudes, heart rate, work rate, ventilation in (STPD) all decreases. For instance, heart rate at 15,000 ft, 19,0000 ft and 21,000 ft were 192, 159 and 144 beat/min respectively. While oxygen intake at 15,00, 19,000 ft and 21,000 ft were 3.40, 2.58 and 2.14 liters/min respectively. It was also stated in this article that breathing oxygen supplement, ventilation decreases, maximum heart rate, stroke volume and cardiac output increases. Furthermore, it was stated that acclimatized men showed better physical performance than unacclimatized men. With regards to the hematological findings, hemoglobin concentration increases in altitudes as compared to sea level. For instance, the hemoglobin concentration of men residing at 19,000 ft and sea level was 19.6 g./100ml and 14.1 g./100ml respectively. Furthermore, red cell mass increases with altitudes as compared with sea level. However, plasma cell decreases with altitudes. ECG investigation done on climbers at greater altitudes confirms the presence of right ventricular hypertrophy. Urinalysis investigation on the endocrine system on climbers at greater altitudes confirms significant increase in sodium and potassium ratio which indicates inhibition of adrenal cortical function. In this article, it was established that at high altitudes climbers experience various kinds of sicknesses such as pneumonia, high altitude pulmonary edema, headache, facial weakness, aphasia, cerebral thrombosis gastro-intestinal and respiratory infection. However, all these sicknesses were attributed to absence of oxygen (hypoxia) at high altitude.

21. **Pugh, L. G. and M. P. Ward (1956). "Some effects of high altitude on man." Lancet 271(6953): 1115-1121.**

This article was written by Pugh (primary author) and his colleague who gave a detailed account about the effects of altitude on man, adaptation of man to high altitude, and the effects of breathing oxygen supplement at high altitude. The authors specifically discussed and compared the effects of altitude on members that participated in the 1951, 1952 and 1953 Himalayan Scientific Expeditions. In this article, it was evident that as altitude increases, members of the expeditions encountered several physiological and medical difficulties. To mention but a few some of the debilitating effects of altitudes on man are: dyspnea (shortness of breath); loss of appetite (anorexia); weakness; exhaustion; fatigue; headache; nausea; vomiting; irritability; lassitude; remarkable body weight loss; Cheyne-stoke pattern of breathing during sleep; mental apathy; decrease performance; and endurance. Interestingly, all these debilitating effects becomes severe with increase altitude. However, it was stated that members of the 1953 expedition were faced with less debilitating effects of altitude as compared to members of the 1951 and 1952 expedition due to the fact that members of the 1953 expedition had prior experience in sojourns to high altitude environment.

The authors of this article also discussed the effects of breathing oxygen supplement at high altitude. The discussion in this article clearly showed that oxygen supplement brings immense benefits to climbers. For instance, oxygen supplement improves performance, endurance, enhance recovery from fatigue, facilitate sound sleep, reduce mental impairment, and improves breathing. Furthermore, it was established that acclimatized men (high altitude native residents) showed better physical performance and are less affected by debilitating effects of altitude as compared to unacclimatized men. For instance, physical examination showed that unacclimatized men experienced hypotension due to extreme exhaustion at high altitude as compared to acclimatized men. Also, apart of oxygen supplement, adequate nutrition plays a major role during ascent to high altitude. It was established that climbers should consume European-type diet which provides high calories during high altitude expeditions. Furthermore, it was stated that climbers should always be physically fit at all times prior to attempting high altitude expeditions. Interestingly, this article state that performance at high altitude as nothing to do with climbers' age.

22. Joels, N. and L. G. Pugh (1958). "The carbon monoxide dissociation curve of human blood." J Physiol 142(1): 63-77.

The purpose of this research study conducted by Pugh (secondary author) and his colleagues was to determine carboxyhemoglobin (COHb) dissociation curve in human blood. Although, a previous study has been done to determine COHb dissociation curve in the blood. However, it was established that the colorimetric methods adopted by the authors of the previous study to determine COHb dissociation curve was observed to be inaccurate. Therefore, Pugh and his colleagues were interested in addressing the limitations of the previous study by using a more reliable and accurate methods called Roughton-Scholander syringe. In this study, COHb dissociation curve was determined at three different CO_2 pressure (pCO_2) [15, 40 and 70 mmHg] and pH (7.50, 7.25 and 7.15) respectively in a deoxygenated blood of 3 subjects who participated in this study. Furthermore, Oxyhemoglobin (O_2Hb) dissociation curve of the 3 subjects was determined at intervals (days to months) and compared with their COHb dissociation curves. In addition, the relative affinity of Hb for CO and O_2 was determined in the 3 subjects.

The results of this study showed that there was no significant difference in the O_2Hb of each of the subjects. Furthermore, the results of this study showed that there were no significant differences in the O_2Hb curves determined at intervals (days to months). For instance, it was stated that the O_2Hb dissociation curve on one of the subjects at a given pCO_2 when repeated after several months showed no significant difference in results. However, significant difference was observed at intervals (days to months) as a result of differences in pH. The results of this study showed that there was no significant difference in the COHb of each of the subjects. Furthermore, the results of this study showed that the relative affinity of Hb for CO and O_2 significantly increases when the pCO_2 decreases. For instance, relative affinity of Hb in one of the subjects was 265 and 223 when pCO_2 was 15 and 70 mmHg respectively.

23. Menier, D. R. and L. G. Pugh (1968). "The relation of oxygen intake and velocity of walking and running, in competition walkers." <u>J Physiol</u> 197(3): 717-721.

This research study was conducted by Pugh (secondary author) and his colleague with the aim of establishing whether there was a relationship between oxygen intake and speed during walking and running and to further make comparison of the observed results between walking and running. The investigators of this study recruited 5 subjects (4 walkers and 1marathon runner). They performed 4-5 mins of walking and running at velocities ranging from (0 km/hr-24 km/hr) on a treadmill at altitude of 1,800 m at separate days of the week. In this study, physiological parameter such as oxygen intake was determined during walking and running.

The findings of this study revealed that there was a positive linear relationship between oxygen intake and running at speed between 8-21 km/hr. Conversely, the findings of this study revealed that at lower velocities (< 8 km/hr) the relationship between oxygen intake and walking speed was nonlinear. However, at higher velocities [> 8 km/hr (8-14.5 km/hr)] there was a linear relationship between oxygen intake and speed of walking. Consequently, when comparison was made between the running and walking, the findings of this study revealed that at higher velocities (8-14.5 km/hr) the slope of walking was steeper as compared to during running i.e., at higher velocities the relationship between oxygen intake and speed of walking was significantly higher than during running. For instance, the mean maximum oxygen intake during walking and running was 60 ml./kg/min and 57.4 ml./kg/min respectively. The investigators attributed the observed results of this study to the fact that it is more efficient to walk rather than to run at lower velocities (< 8 km/hr). whereas, walking is less efficient than running at higher velocities (> 8 km/hr). The investigators stated that these observed results clearly show why during competitive walking, walkers adopt specialized gait patterns which enables then to reach a speed as high as 16 km/hr. The investigators made a conclusion that during walking unlike running, walkers cannot increase their speed much beyond that of their corresponding maximum oxygen intake.

24. Pugh, L. (1969). "Man at High Altitude." <u>J R Coll Physicians Lond</u> 3(4): 385-397.

In this review article, Pugh (primary author) gave a comprehensive overview of how man response to high altitude environment. It is worthy to state that the greatest height humans can permanently inhabit is 17,500 ft (5,540 m). In this article, Pugh gave detailed information about the experience of man at altitudes above 19,000 ft during the 1960-1961 Silver hut expedition where climbers spent a longer period in a prefabricated lab at a great altitude. For instance, it was established that climbers usually show signs of mental deterioration/impairment at altitudes between 18,000 ft-21,000 ft. Also in this review, it was established that barometric pressure, alveolar gas and arterial oxygen saturation decreases as altitude increases. Furthermore, it was established that exercising at high altitude, arterial partial pressure of oxygen (PaO_2) significantly reduces. For instance, in the 960-1961 expedition during muscular exercise, climbers PaO_2 decreases from 67% at rest to 57% at 900 kg m/min work rate. Pugh stated that due to the hypoxic nature of high altitude, there are some physiological compensatory mechanisms that occurs in a man. For instance, increase in lung ventilation, increase in pulmonary diffusing capacity of oxygen, increase in blood oxygen capacity, shift of the arterio-venous points to the steep part of the oxyhemoglobin dissociation curve.

In this review, it was evident that the physiological response of high-altitude native residents (acclimatized men) differs from non-acclimatized men. For instance, it was established that high-altitude native residents have lower sensitivity to hypoxia, reduction in ventilation, significant increase in hemoglobin concentration, higher aerobic capacities and longer delay in experiencing high-altitude diseases as compared to non-acclimatized men. Furthermore, in this review it was also established the incidence of high-altitude diseases depends on the hypoxia, rate of ascent and magnitude of altitude. It was stated that gradual ascent, adequate acclimatization and provision of oxygen supplement could alleviate the symptoms of high-altitude diseases.

25. Sutton, J. R. and L. Pugh (1983). "CLIMBING EVEREST WITHOUT OXYGEN." Seminars in Respiratory Medicine 5(2): 213-215.

This article was written by Pugh (secondary author) and his colleague who gave account of how two men (Peter Habeler and Reinhold Messner) successfully reached the summit of Everest on the 8th of May, 1978 without the aid of oxygen supplement. In this article, Pugh and his colleague clearly stated that the maximum aerobic capacity which is said to be an indicator for cardiorespiratory fitness and endurance of both men decreases with increase in altitude. However, despite the decrease in their maximum aerobic capacity, these two men were able to reach the summit of Everest without using oxygen supplement.

Based on the findings of this article, these two men were able to climb Everest successfully without oxygen supplement owing to: their high level of motivation to achieve the feat at all cost; they had high tolerance to hypoxia; they were able to conserve their energy by reducing the amount of load carried and most importantly, they had mild acclimatization to high altitude prior to the expedition because they are high-altitude native residents. However, despite achieving this giant stride of climbing Everest without oxygen, both men experienced debilitating physiological challenges. For instance, it was documented that about 48 m for them to reach the summit of Everest, they were extremely exhausted and were close to the limit of their function. It was revealed that they collapse into the snow every 10-15 steps taken as they couldn't stand on their feet to rest. The authors of this article concluded that although it is possible to climb Everest without oxygen supplement but it comes with some severe debilitating physiological challenges.

26. Pugh, L. G. C. (1969). "FITNESS FOR HIGH ALTITUDES." <u>Practitioner</u> 202(1210): 593

This article was a note and queries type of article. Pugh (primary author) in this article gave an insightful professional advice on how to adjust to altitude and engage in efficient exercise regimen for a middle-aged patient who had conceived the idea of going to the base camp of Mount Everest next year.

Pugh stated that considering the terrain to the base camp of Mount Everest, the middle-aged patient would definitely go by foot which is said to be a long-distance journey. Having this thought in mind, Pugh believed that the middle-aged patient needs to show some high level of physical fitness prior to the journey. In-order to achieve high level of physical fitness, Pugh recommended 1hr/day of moderate-to-vigorous exercise such as walking, cycling, swimming, hill-walking, running for 3 months. Pugh also recommended that the middle-aged patient should monitor his/her haemoglobin concentration prior to the journey. Furthermore, Pugh stated that age is another important determinant to consider when going for such long-distance journey. It was revealed that an individual who is over 50 years old need to engage in daily physical activity such as long-distance marching which is tailored at strengthening the joints of the legs.

27. Pugh, L. G. C. (1961). "SCIENCE IN HIMALAYA." Nature 191(478): 429.

In this article, Pugh (primary author) gave some detailed summary of some of the findings of the numerous physiological experiments conducted during the 1960-1961 Himalayan Scientific and Mountaineering (Silver Hut) Expedition. In this article, it was documented that batteries of physiological investigations such as determining cardiac output and heart rate during low, moderate and maximum work rate on a bicycle ergometer; determining arterial blood oxygen saturation (SaO_2) at rest and during muscular exercise, maximum oxygen intake (VO_2 max) during exercise, and hematological parameters (e.g., blood volume, haemoglobin concentration) were conducted. It was documented that all these physiological experimental studies were carried out in a prefabricated hut of which Pugh was the leader of the Scientific team, while Sir Edmund Hillary was the expedition leader.

The author of this article revealed some of the findings of the physiological studies that were conducted during the expedition. it was revealed that cardiac output decreases with increase in altitude as compared to sea level at the same maximum work rate. For instance, cardiac output at altitude and sea level was 16-18 l./min and 25-30 l./min respectively. Furthermore, it was revealed that heart rate increases with altitude as compared to sea level at the same low-to-moderate work rate. However, at maximum work rate, heart rate decreases with altitude as compared to sea level. For instance, the maximum heart rate at altitude and sea level was 130-150 beats/min and 180-190 beats/min respectively. In addition, it was revealed that SaO_2 decreases with altitude while at rest as compared to sea level and further decreases during exercise. For instance, while at rest SaO_2 decrease to about 65-70% as compared to sea level and further decrease to about 50-55% during exercise as compared to sea level. Consequently, it was revealed that VO_2 max significantly decreases with altitude during exercise as compared to sea level. For instance, exercising at altitude of 19,000 ft and sea level, VO_2 max was 2.0-2.5 l./min and 3.5-4.0 l./min respectively.

28. Sutton, J. R., N. L. Jones and L. Pugh (1983). "EXERCISE AT ALTITUDE." Annual Review of Physiology 45: 427-437.

The main objectives of this article written by Pugh (one of the secondary authors) and his colleagues was to understand and determine the physiological demands high altitude placed on two men (Peter and Messner) who successfully reached the summit of Everest without using oxygen supplement and to further understand how both men were able to meet the physiological demand despite not using oxygen supplement. However, the authors of this article clearly stated that during that expedition to Everest there were no physiological measurements done on Peter and Messner but the physiological parameters of both men that were discussed in this article were from prior physiological studies done on them. Furthermore, their physiological parameters were compared with climbers who participated in the 1960-1961 Silver hut expedition.

Peter and Messner were able to reach the summit of Everest owing to the following reasons: 1) both men had a significant increase in exercise capacity despite the hypoxic nature of high-altitude as compared to the climbers of the 1960-1961 expedition. For instance, their exercise capacity was said to be 50% (4.9-5.2 l./min) higher than climbers of the 1960-1961 expedition

(0.35-0.50 l./min); 2) both men had high tolerance to hypoxia and thus, showed normal/blunted hypoxic ventilatory response as compared to climbers of the 1960-1961 expedition; 3) both men are high-altitude native residents who had better acclimatization to high-altitude as compared to climbers of the 1960-1961 expedition who are sea-level residents; 4) both men were considered to have significant increase in pulmonary diffusing capacity of oxygen; 5) both men were considered to have significant increase in blood oxygen capacity; 6) with regards to body metabolism, it is assumed that both men used fat as their major source of energy during their final assault. The authors of this article concluded that despite the fact that both men successfully reached the summit of Everest without oxygen supplement, they were still faced with severe physiological challenges. For instance, it was documented that 48 m to the summit of Everest, both men were extremely exhausted and near the limit of their function.

29. Pugh, L. (1983). "MOUNT CHO OYU, 1952, MOUNT EVEREST, 1953." <u>Seminars in Respiratory Medicine</u> 5(2): 109-112.

This was a descriptive article written by Pugh (primary author) who discussed some debilitating physiological problems such as nutrition and fluid imbalance, and deprivation of oxygen which climbers of the 1952 Cho Oyu expedition experienced. Furthermore, solutions on how some of these debilitating physiological problems which led to the success at the 1953 Everest expedition were discussed in this article. For instance, this article discussed the benefits of breathing oxygen supplement at great altitude.

In this article, it was evident that climbers at great altitudes are usually faced with some debilitating factors such as dehydration, loss of appetite (anorexia), severe loss of body weight, deprivation of oxygen. Furthermore, it was clearly evident that climbers are usually faced with inadequate food and fuel supplies, inefficient stove and pressure cooker during high-altitude expeditions. In-order to mitigate the debilitating conditions high-altitude subject climbers to, Pugh recommended that there should be adequate provision of food and fuel supplies, efficient stove and pressure cooker. He recommended that climbers should eat food with adequate calories. For instance, composite ration daily calories intake should be more than 4300 Kcal, while assault ration should not be less than 2500 Kcal. It was evident that the problem of dehydration could be tackled if climbers take 3-5 L of fluid/day with a urine output of 1.2-1.5 L/day. With regards to deprivation of oxygen at high-altitude, Pugh conducted several studies using different flow rates of oxygen (2, 4 and 10 L/min). It was evident that 4 L/min and 1 L/min of oxygen supplement should be used for climbing and sleeping respectively. In this article, the benefit of using oxygen for climbing and sleeping were enormous. For instance, reduction of ventilation and respiratory rate, enhance recovery from fatigue, increase energy, decrease muscle paresis, promote warmth, and induce sound sleep. Lastly, in-order to mitigate the debilitating effects of high-altitude, Pugh recommended adequate acclimatization. He encouraged climbers to climb as high as possible during the day and descend to lower altitude during the night to sleep.

30. Pugh, L. G. C. (1964). "CARDIAC OUTPUT IN MUSCULAR EXERCISE AT 5800 M (19000 FT)." Journal of Applied Physiology 19(3): 441.

The main purpose of this research study which was conducted by Pugh (primary author) was to determine some physiological vital signs parameters such as cardiac output, heart rate, stroke volume during exercise at varying work loads. Furthermore, in this study, Pugh was also interested to determine whether breathing oxygen supplement would influence the observed results of the physiological vital sign parameters. This research study was conducted during the 1960-1961 Himalayan Scientific Mountaineering expedition. It was stated that about 4 members that participated in this expedition acted as subject. The physiological vital signs parameters of the 4 subjects were estimated both at sea level and at 5,800 m (19,000 ft) during exercise on a bicycle ergometer at varying work loads (300, 600, 900, 1,200 and 1,500 kg-m/min).

The results of this study showed that cardiac output decreases with increase in altitude as compared to sea level at the same maximum work load. For instance, the cardiac output at 5,800 m (19,000 ft) and sea level at the same maximum work load was 16 liters/min and 23 liters/min respectively. Furthermore, it was revealed that heart rate increases with altitude as compared to sea level at the same low-to-moderate work load (300 and 600 kg-m/min). However, at maximum load (900 kg-m/min), heart rate decreases with altitude as compared to sea level. For instance, the maximum heart rate at 5,800 m (19,000 ft) and sea level was 130-150 beats/min and 180-196 beats/min respectively. In addition, the results of this study showed that stroke volume decreases with increase in altitude as compared to sea level at the same work load. However, there were changes in the observed results of the physiological vital signs parameters when the 4 subjects breaths oxygen supplement. For instance, it was revealed that cardiac output, stroke volume and maximum heart rate increases. Conversely, the heart rate decreases as compared to sea level at the same low-moderate work load.

31. Pugh, L. (1954). "SCIENTIFIC ASPECTS OF THE EXPEDITION TO MOUNT EVEREST, 1953." <u>Geographical Journal</u> 120: 183-192.

This is a narrative article written by Pugh (primary author) who gave a detailed summary of how he adopted scientific approach to solve the debilitating effects such as loss of appetite, insufficient and adequate diet/nutrition, loss of body weight, lack of acclimatization, inadequate oxygen equipment, poor hygiene, and severe climatic conditions (i.e., hypothermia, frostbite) at high-altitude on man. In this article, it was clearly stated that the scientific approach Pugh adopted during the 1952 Cho Oyu expedition led to the successful ascent of Everest in 1953.

Lack of acclimatization is one of the debilitating effects of high-altitude on man. This narrative article revealed the previously failed expedition to Everest by the Swiss and British was as a result of inadequate acclimatization by the climbers. It was stated that those climbers who participated in the expeditions sudden ascended to high-altitude just after spending few days. According to this article, the scientific approach adopted was that climbers should acclimatize for 3-4 weeks at extreme high altitude. It was stated that 3-4 weeks of acclimatization would significantly improve the physical and health conditions of climbers. Furthermore, it was stated that poor hygiene is also one of the debilitating effects of high-altitude that affects climbers' performance. It was revealed that poor hygiene predisposes climbers to some gastrointestinal diseases such as diarrhoea and upper respiratory infection due to the fact that climbers mingle with local inhabitants who are poorly hygienic. Lack of oxygen supplement or insufficient oxygen supplement is also one of the debilitating effects of high-altitude. It was revealed oxygen supplement was one of the factors that accounted for previously failed Everest expedition due to the fact that climbers weren't convinced about its usefulness. In-order to tackle the problem of insufficient oxygen supplement, it was stated in this article that 4 liters/min and 1 liters/min of open circuit oxygen supplement should be used for climbing at high-altitude above 22,000 and sleeping respectively. Furthermore, inadequate diet/nutrition is also one of the debilitating effects of high-altitude. In this article it was revealed that in-order to tackle the problems of inadequate diet, climbers' diet should be divided into composite (4000-4500 calories) and assault ration (diet consisting of largely of sugar). The composite ration is for general purpose and most especially during approach march and at lower altitudes. However, the assault ration is for extreme high-altitude (≥ 18,000 ft) because of the problems of impaired sensation to thirst climbers experience at such extreme altitude. Dehydration is also one of the debilitating effects of high-altitude. The scientific approach adopted was that climbers should take 3-4 litres of fluid/day. Furthermore, severe climatic condition is another debilitating effect of high-altitude. According to this article, in-order to tackle the problems of severe climatic condition, Pugh designed a protective equipment, clothing and footwears that offered the best thermal insulation and comfort. For instance: a single-cotton nylon fabric clothing and tents which is waterproof and windproof; a light weight special boots with inner and outer covering made up of thin microcellular rubber soles which is water proof; and sleeping bags whose outer and inner compartment are better adapted for - 40°C.

32. **Pugh, L. (1962). "HIMALAYAN SCIENTIFIC AND MOUNTAINEERING EXPEDITION, 1960/61 - THE SCIENTIFIC PROGRAM." Geographical Journal 128(4): 447-456.**

This article was written by Pugh (primary author) who gave an explicit summary of what transpired at the symposium held on the 16th of April 1962 at the Royal Geographical Society with regards to the Himalayan Scientific and Mountaineering expedition to Mount Makalu (5th highest mountain) which took place between 14th of September 1960-June 1961. In this article, it was stated that Sir Edmund Hillary was the leader of this expedition, while Pugh was the leader of the scientific team. According to Pugh, several physiological investigations were carried out in a prefabricated hut situated at 19,000 ft during this expedition. Although, the physiological objectives of this expedition were to contribute to the existing body of physiological knowledge through adoption of new methods of investigation.

In this article, it was established that the meteorological findings during the expedition revealed that the minimum temperature was -27°C during the expedition. The barometric pressure, partial pressure of inspired oxygen and alveolar partial pressure of oxygen at 19,000 ft ("*Silver Hut"*) was 372-383 mmHg, 69 mmHg and 45 mmHg respectively. Furthermore, it was documented that there was a 67% decline in arterial oxygen saturation (SaO_2) at 19,000 ft while climbers were at rest. However, further decline to about 50% was observed while climbers engage in muscular exercise at 19,000 ft. Furthermore, it was established that the maximum oxygen intake of climbers significantly decreases while cycling on a stationary bicycle ergometer at altitude between 15,000-24,4000 ft as compared to sea level. It was also documented that the pulmonary diffusing capacity of oxygen remains unchanged at altitude among the unacclimatized climbers. It was stated that pulmonary diffusing capacity of oxygen is the chief factor that limit exercise at high-altitude and thus, cause decline in SaO_2. In this article, it was documented that as altitude increases from 15,100-24,400 ft climbers of the expedition experienced pulmonary hypertension and right ventricular dysfunction. It was also documented that cardiac output decreases with increase in altitude as compared to sea level at the same maximum work rate. Consequently, heart rate decreases as compared to sea level at the same maximum work rate. It was further established that acclimatized men (*Sherpas*) showed better physical performance than unacclimatized men (sea level residents). For instance, acclimatized men were able to carry 60-Ib of loads up to 19,000 ft at the same climbing speed as compared to unacclimatized men who were without any loads. It was further documented that during the expedition, there were availability of varieties of food. It was stated that during the expedition the average calorie of food taken was between 3000-3200 kcal/man/day. However, despite the adequate diet, all the climbers of the expedition suffered loss of body weights (1-3-Ib) in a week at 19,000 ft. Whereas, climbers body weights were maintained at lower altitude (≤ 15,000 ft). It was further documented that most of the food cooked during the expedition was done on a propane stove. With regards to the medical aspect of the expedition, two climbers suffered from high altitude sickness. For instance, Sir Edmund Hillary and P. Mulgrew suffered from cerebral thrombosis and pulmonary thrombosis respectively.

Cold Physiology Studies

1. **Freeman, J. and L. G. Pugh (1969). "Hypothermia in mountain accidents." Int Anesthesiol Clin 7(4): 997-1007.**

This article gave detailed information about accidental hypothermia during climbing and walking in mountainous regions. Pugh (secondary author) and his colleague in this article expatiated on the signs and symptoms, predisposing factors, prevention and medical management of accidental hypothermia. The authors stated that the symptoms of accidental hypothermia are shivering, aggressiveness, slurred speech, muscle paresis, ataxia, loss of consciousness, rigidity and death. It was also mentioned that the physical signs of accidental hypothermia are absence of peripheral pulses, shallow breathing, pale and clammy skin, decrease core temperature, and pulmonary edema. Furthermore, the authors of this article stated that wearing wet clothing in a windy climatic condition predisposes climbers to accidental hypothermia. Interesting, it was also stated that climbers who are tall and slender are prone to hypothermia.

In this study, emphasis was on the prevention and management of accidental hypothermia. As regards prevention of accidental hypothermia, the authors stated that climbers should avoid getting wet, and seek for warm shelter at all times. The authors of this article stated that care must be taken during the management of climbers who had suffered from accidental hypothermia. For instance, the authors suggested that setting up rescue camps and on-the-spot resuscitation should be adopted for victims who had suffered from accidental hypothermia rather than the conventional transportation/evacuation of victims on stretchers to the hospital. This article highlighted that rescue camps should have equipment and material such as tent, sleeping bags, inflatable mattresses, gas stoves, and plastic bags, that provides the best form of insulation to victims. Furthermore, the authors stated that victims of accidental hypothermia might as well suffer from other injuries such as fractures and head injuries. As such, proper movement of victims are important in the managements of accidental hypothermia. For instance, immobilization with splints should strictly be adhered to for victims who had suffered from fractures. The authors of this article stated that rewarming of victims of accidental hypothermia in the hospital should be taken with caution. For instance, the author stated that some victims experience after drop during rewarming and as such, could predispose them to cardiac arrhythmias or arrest. Interestingly, it was stated that slow and rapid rewarming are effective in the management of accidental hypothermia. The author concluded that during the process of rewarming victims in the hospital, vital signs such as blood pressure, respiration, core temperature (esophageal and rectal temperatures), electrocardiogram (ECG) of victims should be closely monitored.

2. **Pugh, L. G. (1959). The adrenal cortex and winter sports, with a note on other exercise. *Br Med J, 1*(5118), 342-344. doi:10.1136/bmj.1.5118.342**

This research study conducted by Pugh (primary author) revealed how engaging in exercise at high altitude during the winter holiday could affect the stimulation of adrenal cortex. In this study, the author regarded eosinophil count as an indicator of adrenal cortical stimulation. He measured the eosinophil counts of subjects in the morning (before exercise) between 9-10am and evening (after exercise) between 5-6pm for a duration of 6 weeks at an altitude of 3,000 ft. The subjects that participated in this study were classified as either well-trained or untrained depending on how well they have engaged in physical activity (skiing training) prior to this study. It was established that subjects engaged in 1½-4 hours of intense exercise (skiing). Pugh compared the results of this study with already existing data of subjects who participated in different studies.

The results of this study revealed that eosinophil counts decreased significantly with long duration exercise as compared to short duration exercise. For instance, subjects who skied for 4 hours showed significant decrease in eosinophil counts as compared to subjects who skied for 1-2 hours. Furthermore, this study revealed that eosinophil counts decrease significantly in untrained subjects as compared to trained subjects. The author of this study clearly stated that engaging in long duration exercise is associated with low eosinophil counts (eosinopenia). In conclusion, long duration exercise increases the activation of adrenal cortex, which leads to increase secretion of adrenal cortical hormones and thus, decreases eosinophil counts.

3. **Pugh, L. G. (1963). "TOLERANCE TO EXTREME COLD AT ALTITUDE IN A NEPALESE PILGRIM." J Appl Physiol 18: 1234-1238.**

This article describes a 35 years old Nepalese pilgrim who goes by the name Man Bahadur. He was able to tolerate and survive in extreme cold conditions at high altitude between 15,000 ft and 17,500 ft without experiencing any form of associated cold injuries despite not wearing protective clothing or having equipment that would prevent him from cold exposure. Man Bahadur was a resident of a village situated at high altitude 6,000 ft. He was on his way to a pilgrimage when he stopped-by, uninvited at the base camp (15,300 ft) of the 1960-1961 Himalayan Scientific and Mountaineering expedition and thus, requested to stay with them for a month. In this article, Pugh (primary author) stated that Bahadur had on him clothes with poor insulated thermal properties. For instance, it was noted that his clothes were made of cotton materials. Interestingly, it was stated that Bahadur walked bare footed without having boots and gloves that would have prevented him from exposure to the cold climatic conditions.

This article described Bahadur as a thin individual with all his vital signs such as heart rate, respiratory rate, blood pressure, and core temperature were all within the normal physiological range. In this article, it was reported that Bahadur left the base camp just for four days and was able to survive a stormy windy climatic condition between altitude 16,500 ft and 17,500 ft despite lacking food, fluid and protective equipment such as clothes adapted for altitude, and sleeping bag. Owing to the fact that his survival surprised the team of the 1960-1961 expedition, necessitated Captain S.B. Motwani of the Indian Army Medical Service who carried out several physiological experiments such as measuring skin and core temperature, metabolism, fluid and food intake on him. The results of the physiological experiments showed that Bahadur maintained both skin and core temperature due to increased body metabolism. Pugh stated that Bahadur was able to tolerate and survive in extreme cold conditions as a result of adequate acclimatization to cold having been a native of high-altitude environment. Furthermore, it was stated that Bahadur ability to tolerate and survive in extreme cold condition wasn't a function of subcutaneous adipose tissue thickness.

4. **Pugh, L. G. and O. G. Edholm (2004). "The physiology of channel swimmers. 1955." <u>Wilderness Environ Med</u> 15(1): 40-41; discussion 38-49.**

In this research paper, Pugh (primary author) and his colleague clearly highlighted factors that contributed to the endurance and tolerance of some group of people e.g., channel swimmers during extreme cold-water immersion. In the introductory part of this article, it was stated that about 18 channel swimmers participated in a long-distance swimming competition which involved swimming from France to England for about 12-20 hours in extreme cold water (15.5°C). Researchers/Scientists were surprised about the giant strides achieved by those channel swimmers who were able to tolerate and endure the extreme cold-water immersion at that temperature for a long duration because previous studies have shown that during shipwreck in water at 15.5°C, survivors only have 5-6 hours to live before they die as a result of hypothermia. Although, in this article, it was stated that all the channel swimmers who participated in the competition were either obese or stocky. Pugh in this study, reported that channel swimmers were able to maintain their core body temperature for long periods of time owing to the fact that they had significant amount of adipose tissue in their body which enhances body insulation and thus, decreases heat loss. However, in addition to the adipose tissue insulation which was regarded as the chief factor that contributed to increase tolerance and endurance of the channel swimmers, swimmers' somatotypes (body types) were also a contributory factor to their level of tolerance. For instance, it was stated that individual with short trunk and long slender limbs loses heat much faster than those with short limbs and larger trunk. Pugh stated that owing to the significant contribution of adipose tissue which serves as body insulation for the channel swimmers from cold, then the claim by Dr. Sabri who said that "To be fat is good" was valid.

There was an evident argument in this research paper with regards to whether individual should lie still/motionless by clinging to wreckage or swim during shipwreck. One notable researcher by the name Glaser in 1950 claimed that many people would have survived and not died as a result of hypothermia during shipwreck, if they had not cling to wreckage or float on their lifeboat but rather continue to swim hard as long as they can endure. However, Pugh stated that the findings in this study was not in agreement with Glaser claim. It was reported that individuals who remained motionless had a negligible decrease in their core temperature as compared to during swimming. Thus, shivering thermogenesis in water is reduced when motionless/still as compared to during swimming. Therefore, this study affirms the traditional belief that during shipwreck, clinging to wreckage would help individuals to conserve energy rather than wasting energy on swimming.

5. **Pugh, L. G. (1966). "Accidental hypothermia in walkers, climbers, and campers: report to the Medical Commission on Accident Prevention." Br Med J 1(5480): 123-129.**

This research paper conducted by Pugh (primary author) clearly discussed the etiology, signs and symptoms, prevention and treatment of accidental hypothermia among mountain walkers and climbers. What necessitated Pugh to conduct this study was due to the fact that there were many cases of individuals that have died during expeditions to mountainous regions. However, these cases have gone unreported especially in Great Britain. In this study, Pugh critically analyzed the impact of accidental hypothermia on climbers by investigating 23 incidents that occurred in Great Britain between 1951-1965. In this study, the author clearly stated that about 100 mountain climbers and walkers were at risk of accidental hypothermia, 25 victims died, and 18 victims were rescued and received treatment for extreme cold exposure. In all the 23 incidents that were investigated, it was clearly stated that the etiology of accidental hypothermia includes but not limited to: extreme weather conditions such as heavy rain, high wind chill, snow, ambient temperature below or near the freezing point; clothing with lower insulation properties; exhaustion leading to collapse, decrease adipose tissue, gender differences with male more susceptible to accidental hypothermia than female; lack of means of communications such as talkie walkie in cases of emergencies; lack of primus stoves and fuel especially when climbers are caught up with darkness; no prior knowledge and training about high altitude expeditions.

In this study, it was stated that victims who were faced with accidental hypothermia manifested various signs and symptoms which includes but not limited to: numbness; loss of sensation; and paralysis of the extremities; edematous extremities; mental apathy/aberrant behaviors; light headedness; muscle paresis; balance and spatial disorientation; cramps; shallow breathing; collapse; unconsciousness; frequent fall; convulsion; and deaths. Pugh in this study reported that for victims who were able to make it to the hospital, they showed various clinical signs such as generalized muscle rigidity, cold to touch, extreme pallor and pulselessness. In this study, it was clearly stated that accidental hypothermia can be prevented if climbers are adequately prepared for the expedition such as donning waterproof and windproof clothing materials that are resistance to rain and wind, seeking shelter at all times rather than enduring exhaustion, early camping ones there are signs and symptoms of accidental hypothermia, and having significant amounts of adipose tissue in the body. Furthermore, it was clearly stated that victims who survived accidental hypothermia received treatment that would prevent further cooling of their body core temperature. For instance, Pugh advocated for on-the-spot resuscitation rather than the conventional long evacuation on stretcher. He stated that victims of accidental hypothermia immediately respond to treatment administered to them. In this study, victims of accidental hypothermia were treated with various forms of rewarming techniques such as lying-in bed with hot blankets, hot water bottles, and having hot bath.

6. **Pugh, L. G. (1966). "Clothing insulation and accidental hypothermia in youth." Nature 209(5030): 1281-1286.**

This study was conducted by Pugh (primary author) with the aim to improve the body of knowledge by understanding the impact environmental factors have on mountaineers when exposed to extreme cold. This study was of utmost importance to Pugh because he was asked to investigate the cause of deaths of three boys who participated in an annual Four Inn Walk in Britain in March, 1964. Therefore, in order to investigate the cause of deaths of these boys, Pugh conducted some experimental studies by investigating the thermal insulation properties of the typical cloths worn by the participants of the annual event. Furthermore, he investigated the effects exercise, wind speed, and wetting would have on the thermal insulation properties of the cloths. Pugh recruited just one subject for this study. The subject was put in a climatic chamber with a minimum temperature of 10°C and a maximum wind speed of 8-9 m.p.h. While in the chamber, the insulation values of the subject cloths when dry and made wet was determined during rest and exercise on a bicycle ergometer. Furthermore, Pugh investigated the subject work rate and oxygen intake during exercise when cloths was dry and wet.

The results of this study revealed that the insulation values of the cloths worn by the subject decrease during exercise in a wet windy cold climatic condition. it was observed that as the wind speed increases during exercise, the thermal insulation values of the cloths decrease. Consequently, it was also observed that there was a further decrease in the thermal insulation values of the cloths, when cloths were made wet. For instance, the thermal insulation value of the cloth in a dry state was 1.5 Clo. However, the author stated that the insulation value decreases to 0.7 Clo during exercise and increase wind speed and thus, further decreases to 0.4 Clo when cloths was wet. It was also revealed in this study that when subject exercise in a wet windy climatic condition, the work rate and oxygen intake increase as compared to in a dry climatic condition. In conclusion, it was clearly evident that the clothes worn by the Four Inn boys was the main cause of deaths owing to the fact that the cloths lack insulation, waterproof, and windproof properties which would have prevented them from the extreme wet windy cold climatic condition.

7. **Pugh, L. G. (1968). "Isafjordur trawler disaster: medical aspects." <u>Br Med J</u> 1(5595): 826-829.**

This article written by Pugh (primary author) gave account of the incidents that happened in Isafjordur (a town in the northwest Iceland) on the 4^{th}-5^{th} of February 1968 which led to the deaths and injuries of some trawler crew members. In this article, Pugh discussed the circumstances that surrounded the deaths of those crew members and why just one person was able to survive. it was stated that three different incidents happened in which a trawler capsized, and two other trawlers were aground owing to terrible weather conditions. For instance, it was stated that there was an increase in wind velocity, which lead to a horrific storm that was recorded as one of the worst in the history of mankind. For the trawler that capsized, only one man survived out of the 19 crew members on board. Two crew members that were on board in one of the trawlers that was aground sustained cold associated injuries such as frostbite to their extremities. While, all the 6 crew members on board in the last trawler that was aground never survived.

It was clearly stated in this article that the cause of deaths of those crew members can be associated to lack of windproof and waterproof thermal clothing and boots materials which led to hypothermia and frostbite, lack of inflatable lifejackets which led to drowning, panic attack, lack of extra sets of clothes, inadequate self-inflating rafts and bailers, lack of provision of sophisticated emergency talkie walkie which led to delay in rescue operations. It was revealed that the only crew member that survived was wearing clothes with good thermal insulation properties that were resistance to wind and wetting. According to the narration of the only crew member that survived, it is important to always wear dry clothes at all times. Furthermore, this article discussed some recommendations that could prevent trawler crew members from death when faced with unforeseen circumstances. For instance, it was stated that trawler crew members should at all times wear clothes and boots that are windproof and waterproof, be trained on how to prevent and treat hypothermia, use inflatable lifejackets, use sophisticated emergency walkie talkie, adequate self-inflating rafts and bailer.

8. Pugh, L. G. (1957). "Physiological expedition to the Antarctic." Nature 180(4588): 683.

This article by Pugh (primary author) discussed some experimental studies that were to be conducted by a team of an Anglo-American expedition who took part in the operation deep freeze II in order to understand how human acclimatize to cold in the Antarctic. Pugh and his colleagues were part of the team of the expedition who were charged with the responsibilities to conduct batteries of physiological experiments (relating to cold acclimatization) on themselves. It was clearly stated that they were to spend 4 months in the Antarctic during the winter period. It was established that the reason for the mission to the Antarctic was due to the limitation of information about cold acclimatization. This study was also conducted to improve on the inadequacies of previous studies such as lack of efficient and effective methods to measure metabolism and changes in body temperature for extended period of time continuously. It was clearly stated that Pugh and his colleagues made use of a sophisticated apparatus which addressed the inadequacies of previous studies. It is noteworthy to state that the team of the expedition took along with them some equipment such as propane for cooking, plastic bags, ration foods items, and newly designed thermal insulation clothes.

In this article, it was clearly stated that investigating and analyzing human blood and tissue lipid formation is one of the indicators to better understand how well human acclimatize to extreme cold conditions. The author of this article stated that previous studies which have been conducted on animals, revealed that the blood and tissue lipid formation of animals that hibernate during the winter season is quite different from during the summer season. For instance, it was stated that the blood and tissue lipid formation is significantly higher in animals during the winter as compared to during the summer. Interestingly, these results seem to be in agreement with some previous studies done on humans. For instance, a study conducted during the winter on a team of Greenland expedition showed significant deposition of fatty acid in their blood.

9. **Pugh, L. G. and F. A. Chrenko (1966). "The effective area of the human body with respect to direct solar radiation." Ergonomics 9(1): 63-67.**

This study conducted by Pugh (primary author) and his colleague gave an insight on various methods used to determine the effective radiation area of human body that is exposed to direct sunlight. Prior to this study, previous studies have adopted various methods to measure the effective radiation area of men and women who are exposed to direct solar radiation (sunlight). For instance, the photographic method was adopted by Underwood and Ward in 1961, cylinders method was used by Taylor in 1956, and metal models' method was used by Tredre in 1965. However, Pugh noticed some limitations in the previous studies such that the effective radiation areas that was measured were only when the participants were in nudes. Therefore, in this study, the authors adopted the shadow method to investigate the effective radiation area on a participant who was at some point clothed, and in nude.

Pugh and his colleague went further to compare their findings with the results of previous studies. It was established that the findings of this study were in agreement with the results of previous studies. For instance, it was noted that for all the methods used to determine the effective radiation area of human body (either clothed or nudes) exposed to sunlight, the ratio of the effective radiation area to total surface area was directly proportional to the cosine of solar altitude. However, the only difference was that the values of the radiation area obtained by Pugh's shadow method, and Underwood & Ward photographic method were lesser than that of Taylor cylinders methods and Tredre metal models methods.

10. **Pugh, L. G. (1969). "Thermal, metabolic, blood, and circulatory adjustments in prolonged outdoor exercise." Br Med J 2(5658): 657-662.**

The main objectives of this research study conducted by Pugh (primary author) was to understand and determine how individuals respond to prolonged outdoor exercise in warm and cold climatic conditions. Furthermore, the author was also interested in investigating and determining hematological, circulatory, biochemical changes during prolonged exercise upon exposure to extreme cold climatic condition. In this experimental study, six men who had prior experience in hill walking participated in this study. Subjects were divided into three groups (2 men each) and thus, all performed a 28 miles (45-km) self-paced walk during two trial periods [autumn (6-12°C) and cold winter (-2 to 2°C)]. Physiological parameters such as heart rate, skin and core temperature, blood electrolyte, blood volume, lactate. glucose, blood pH and urine samples (ketone) were all measured before, during and 24 hours after each of the trial periods. Furthermore, this study investigated subject heart rate in two different body positions (sitting and lying). This study further investigated cold response between subjects with different body mass (fat vs thin).

The results of this study showed that during the winter trial period, the mean skin temperatures decrease as compared to during the autumn trial period. For instance, the mean skin temperatures were 26.5 to 27.8°C during the winter trial period. Consequently, it was established that core temperature was significantly lowered during the winter trial period (36.7°C) as compared to the autumn trial period (37.9°C). Interestingly, the decrease in core temperature observed during the winter trial period was attributed to the speed of walking and it is independent on cold stress. In this study, it was evident that subjects walking at slow pace would experience decrease core temperature than subjects walking at fast pace. The results of this study showed that the skin temperature of the fat subject was significantly lower (21.3°C) than that of the thin subject (27.5°C). Conversely, the core temperature of the fat subject was significantly higher (38.0°C) than that of a thin subject (36.7°C). Regarding the heart rate findings, the results showed that heart rates were lowered during the winter trail period as compared to during the autumn trial period. The lower heart rate during the winter trial period was attributed to decrease in work rate experienced by subjects during extreme cold climatic conditions. Furthermore, it was evident in this study that heart rate increases during standing as compared to during lying. For the hematological findings, the results showed no significant changes in the hematological parameters except a slight increase in potassium. The urinalysis investigation conducted revealed significant amounts of ketones in all the subjects during both trial periods.

11. Pugh, L. G. (1959). "Carbon monoxide hazard in Antarctica." Br Med J 1(5116): 192-196.

The article described the turns of events that occurred which predisposed the New Zealand and British team to Carbon monoxide (CO) poisoning during the Common Wealth Trans-Antarctic Expedition (TAE). Furthermore, this article clearly highlights the signs and symptoms associated with exposure to co as well as results of some experimental studies in relation to CO exposure which was conducted by the Anglo-America physiological team. In this article, Pugh (primary author) stated that members from the New Zealand and British team were predisposed to CO poisoning owing to the fume coming from the exhaust pipe of the vehicles used for the expedition as well as fumes that came through the primus stoves that were used for cooking during the expedition. For instance, it was revealed that the values of blood CO and % Hemoglobin saturation were significantly increased after vehicles were driven during the expedition as compared to before vehicles were driven. It was stated in this article that the symptoms of CO poisoning started to manifest when members of the expedition were at altitudes between 7,000 – 10,000 ft and as such, the first cardinal signs and symptoms of CO poisoning is headache followed by dizziness, nausea, shortness of breaths, chest tightness, and collapse upon exertion. Pugh noted that the symptoms of CO poisoning is similar to the characteristic's symptoms of altitude sickness.

With regards to the experimental studies conducted during the TAE, the output of CO from Primus stove and rate of absorption of CO from tents during the expedition were all studied. In this article, it was revealed that individuals are easily predisposed to CO poisoning when primus stoves were used for cooking or melting ice as compared to when used for heating purposes. For instance, there was a significant increase in CO concentration when primus stove was used for cooking and melting snow (50-70 ml/min) as compared to when used for heating purposes (2-5 ml/min). In this article, it was revealed that the materials used in constructing expedition tents is of utmost importance when it comes to exposure to CO. For instance, expedition tents made from lightweight nylon cotton reduces the rate at which an individual is exposed to CO poisoning.

12. **Pugh, L. G. and O. G. Edholm (1955). "The physiology of channel swimmers." <u>Lancet</u> 269(6893): 761-768.**

This research study was conducted by Pugh (primary author) and his colleague with the objectives of understanding and determining factors that contributes to how certain individuals (channel swimmers) endures and tolerate extreme cold-water immersion. The authors of this article described how certain individuals (channel swimmers) participated in two different competitions [1) 10½ miles swimming in Lake Windermere and 2) 1954 channel swimming from France to Britain] for prolonged hours in a water temperature of about 15.8°C. Furthermore, the authors of this study clearly described the body types of these channel swimmers. For instance, it was stated that those channel swimmers that participated in the Lake Windermere competition were fat/obese and thin. In this research study, physiological parameters such as skin and core temperature, subcutaneous fat thickness, oxygen consumption, thermal sensation and thermal conductance were all measured. Furthermore, the authors of this study also compared some of the above-mentioned physiological parameters when channel swimmers were swimming and lying in a cold-water bath.

The findings of this study revealed that after swimming the core temperature of a channel swimmer who had a thin body type decreases significantly as compared to the one with a fat/obese body type. Furthermore, it was established that fat/obese channel swimmer was able to maintain core temperature after swimming whereas, during lying-in cold-water bath there was a slight decrease in core temperature. Conversely, for the thin channel swimmer the results showed that there was a significant decrease in core temperature during swimming as compared to during lying in cold-water bath. The results of this study revealed that channel swimmers who had a fat/obese body type showed better thermal comfort than those with thin body type. For instance, the fat/obese channel swimmer showed better thermal comfort when the mean skin temperature was 30-31°C as compared to the thin channel swimmer who showed thermal discomfort at a skin temperature of 32.5°C. In addition, it was revealed that the thermal conductance was significantly lower in fat/obese channel swimmers as compared to thin channel swimmers. Consequently, the results of this study showed that there was an increase in thermal conductance while swimming as compared to laying motionless in cold water immersion. The findings of this study showed that energy expenditure and oxygen consumption was significantly higher in fat/obese channel swimmer as compared to thin channel swimmer. Furthermore, it was established that irrespective of the body type of channel swimmers, energy expenditure and oxygen consumption was significantly higher during swimming as compared to lying motionless in a cold-water bath. These findings suggest that channel swimmer experience higher metabolism during swimming as compared to lying motionless in cold water bath.

13. Pugh, L. G. and F. A. Chrenko (1962). "Observations of the effects of solar radiation on the thermal environment inside tents in Antarctica." <u>Ann Occup Hyg</u> 5: 1-5.

The purpose of this research study which was conducted by Pugh (primary author) and his colleague was to determine the effects of solar radiation on man. According to the authors of this article, this study was conducted during the 1957-1958 Anglo-America expedition to the

Antarctica, when the external air temperature in the summer period was -2 to -3°C. It has been established that man can get warm directly from sunlight when outside in an open air or inside a tent. Therefore, in-order to determine the effects of solar radiation on man considering the cold environment of the Antarctica, two types of tents made from different materials [1) a single-walled lightweight yellow wyncol nylon cotton and 2) a double-walled heavyweight black cotton] were studied. Parameters such as external and internal air temperature, globe temperature, mean radiant temperature, intensity of the solar radiation were all measured. In this study, a radiometer was used to determine the amount of shortwave solar radiation that passes through the walls of the tents (yellow vs black).

The findings of this study showed that the mean globe temperature inside the lightweight yellow tent was significantly higher as compared to the heavyweight black tent. The mean globe temperature inside the lightweight yellow and heavyweight black tent was 28.5°C and 15.8°C respectively. Consequently, the mean radiant temperature from the walls of the lightweight yellow tent was significantly higher as compared to the heavyweight black tent. According to the authors of this article, an increase mean radiant temperature is an indication of heat gain. Therefore, it was evident that the lightweight yellow tent gained significant amounts of heat as compared to the heavyweight black tent. Furthermore, the intensity of radiation passing through the lightweight yellow tent was significantly higher as compared to the heavyweight black tent. The authors in the discussion aspect of this article, stated that the observed findings from the lightweight yellow tent was a better representation of greenhouse effect and as such, the lightweight yellow tent would provide adequate warmth and thermal comfort than the heavyweight black tent.

14. **Pugh, L. G. (1967). "Cold stress and muscular exercise, with special reference to accidental hypothermia." Br Med J 2(5548): 333-337.**

The purpose of this experimental study which was conducted by Pugh (primary author) was to investigate the physiological response to extreme cold exposure during muscular exercise. In-order to determine the physiological response to cold while engaging in exercise, three men who had prior experience in uphill walking participated in this study. All the three subjects performed cycling on a bicycle ergometer at varying work rate (400, 600, 800, 1000 and 1200 kg. m./min) inside a 5°C climatic chamber. According to the author of this study, all the three subjects performed the cycling under two conditions [1) wore dry clothing and were unexposed to wind, and 2) wore wet clothing and were exposed to high wind velocity] at different days. In this study, work rate on the bicycle ergometer were classified into lower (≤ 800 kg. m./min) and higher (≥ 800 kg. m./min). Parameters such as skin and core temperature, oxygen consumption, regional temperature of some body parts such as forehead, hands, feet, upper and lower limbs, were determined. Furthermore, the thermal insulation values of the clothing (dry and wet) worn by the three subjects was determined.

The results of this study showed that when subjects wore the wet clothing during cycling, there was a significant decrease in mean skin temperature as compared to when the dry clothing was worn. For instance, the mean skin temperature when the wet clothing and dry clothing was worn was 18-22°C and 30-32°C respectively. The mean skin temperature difference observed between the two set of clothing doesn't depend on the varying work rate. However, the core temperature difference between the two set of clothing was dependent on the varying work rate. For instance, it was evident that the core temperature when subjects wore both the dry and wet clothing was higher during cycling at higher work rates (≥ 800 kg. m./min) as compared to lower work rates (≤ 800 kg. m./min). Although, the findings of this study showed that core temperature was lower when subjects wore the wet clothing during cycling as compared to when the dry clothing was worn. Furthermore, the results of this study showed that oxygen intake was significantly increased at lower work rates when subjects wore wet clothing as compared to when dry clothing was worn at lower work rates. Conversely, there was no increase in oxygen intake at higher work rates when wet clothing was worn. The results of the regional skin temperature of some body parts showed that when subjects wore wet clothing they are easily predisposed to thermal discomfort as compared to when dry clothing was worn. For instance, the regional skin temperature of the hands and feet when wet and dry clothing was worn was 10.8°C and 31.4°C; 15.9°C and 26.9°C respectively. Furthermore, the results of this study showed that the thermal insulation value of the wet clothing in a windy cold climatic condition was significantly reduced as compared to the dry clothing in a non-windy cold climatic condition. Therefore, all the findings of this study indicate that exercising in a wet windy cold climatic condition would predispose individuals to accidental hypothermia.

15. Pugh, L. G. (1964). "DEATHS FROM EXPOSURE ON FOUR INNS WALKING COMPETITION, MARCH 14-15, 1964." Lancet 1(7344): 1210-1212.

This article was a narrative report written by Pugh (primary author) who gave account of the cause of deaths of 3 boys who were exposure to extreme cold climatic condition during their participation in an annual 45 miles walking competition held on the 14-15 March, 1964 in Britain. Furthermore, the author of this written narrative report gave recommendations on what should have been done to prevent the ugly incident. In this report, it was stated that about 240 youth between the age of 17½-24 years participated in the 1964 annual event. They engaged in 45 miles walk at a lower altitude between 650-2000 ft. However, about 1/3rd of those who participated in the annual event didn't complete the competition. Pugh stated that organizers of the annual event made adequate plans and put structures such as rescue team in place to ensure the smooth run of the event. It was established that participants were well informed about the event prior to the start of the competition. Despite all the preparation and information, 3 boys died during the annual event. The names of the 3 boys are Gordon Withers (19 years old), Butterfield (21 years old) and Welby (21 years old). According to the author of this written narrative report, all the 3 boys experienced exhaustion, collapsed and fell into a state of unconsciousness. This report stated that the 3 boys experienced similar signs and symptoms such as balance and spatial disorientation, slurred speech, and pale. Necropsy examination was conducted on the 3 boys and showed nearly similar findings such as congestion of major body organs (kidney, liver, and lungs), and cardiac hypertrophy.

According to the author of this written report, severe climatic condition, unforeseeable change in the climatic condition (heavy rainfall, severe wind chill), improper clothing, long delay in rescue operations due to improper methods adopted, short interval of time between onset of symptoms and signs to the time of collapse all contributed to the deaths of the 3 boys. For instance, the clothing worn by the boys predisposed them to extreme cold exposure because the clothing wasn't waterproof and windproof and thus, lack adequate thermal insulation. In-order to prevent future occurrence of this ugly incident, Pugh gave some recommendations. It was stated in this written narrative report that the public should be sensitized on the imminent danger of being in a wet windy cold climatic condition. For instance, Pugh recommended that wearing clothing that offer adequate thermal insulation (waterproof and windproof), seeking shelter urgently during early onset of signs and symptoms, adopting proper rescue techniques such as on-the-spot resuscitation and proper warming techniques.

16. **Pugh, L. G., O. G. Edholm, R. H. Fox, H. S. Wolff, G. R. Hervey, W. H. Hammond, J. M. Tanner and R. H. Whitehouse (1960). "A physiological study of channel swimming." <u>Clin Sci</u> 19: 257-273.**

This research study was conducted by Pugh (primary author) and his colleagues with the purpose of understanding and determining the physiological response of long distance (channel) swimmers to cold water immersion. This research study was conducted on 19 subjects (15 men and 4 women) who participated in a long-distance swimming competition from France to Britain in 1955 in a water temperature of 18°C. Parameters such as adipose tissue thickness, total body fat, speed of swimming, core temperature oxygen intake, ventilation, swimmers somatotypes/body types (ectomorphs, endomorphs, and mesomorphs) were all determined prior and during the competition.

The findings of this study showed that majority of the subjects were fatter. For instance, the adipose tissue thickness measurement that was done showed that all the subjects had significant amount of adipose tissue thickness that were above the normal range seen in an average individual. Furthermore, the methods adopted to determine the subjects total body fat showed that all the subject had significant amount of body density and total body fat. Consequently, the results of this study further showed that all the subjects are endomorphs (having significant amount of fat and muscle bulk) and mesomorphs. However, because subjects had varying amount of adipose tissue thickness some were still considered fatter than others. For instance, all the female subjects had significant amount of adipose tissue as compared to the male subjects. The results of this study showed that the oxygen ventilation equivalent of the subjects was within the normal physiological range (18-22 l./l. O_2). The results of this study showed that subjects that had more adipose tissue were able to maintain their core temperature, while those that were considered to have less adipose tissue had a significant reduction in core temperature. Furthermore, with regards to swim speed, it was evident that subjects who were considered to have less adipose tissue were the fastest as compared to those with more adipose tissue. For instance, the winner and runners-up of the competition were those with less adipose tissue. Interestingly, all the findings of this study clearly showed that channel swimmers are able to tolerate and endure long distance swimming in a cold-water temperature owing to the important contribution of having significant amount of adipose tissue which enhance thermal insulation, and reduce thermal conductivity (heat loss).

17. Pugh, L. G. (1972). "The logistics of the polar journeys of Scott, Shackleton and Amundsen." Proc R Soc Med 65(1): 42-47.

This historical article provided insight into the physiological and medical aspect of traveling to the Antarctica. Pugh (primary author) in this article gave a detailed narrative summary of 3 individuals (Scott, Shackleton and Amundsen) who went on different Antarctica expeditions between 1901 and 1912. In this article, Scott and Shackleton were described as individuals who had no prior experience about traveling to extreme cold environment such as Antarctica. Whereas, Amundsen was described as a person who had prior experience traveling to the Antarctica. In-view of this, it was established in this article that Scott and Shackleton encountered difficulties during their expeditions due to poor logistics policies and planning. However, because Amundsen was an experienced explorer, he had good logistics policies and planning.

In this article, it was evident that Scott and Shackleton with their team members experienced mobility/transportation problems due to limited sledge dogs and horses, hunger due to inadequate food supplies, easy fatiguability and decrease performance due to inadequate diet (food with less calorific values), health problems such as vitamins deficiencies, diarrhoea, and loss of body weight. Whereas, Amundsen and his team members were successful in their expedition and never experienced any physical deterioration because they had abundance of food supplies and were able to ration their diet, consumed diet that provided them with the much-needed energy for their expedition, enhanced mobility/transportation means such as taking along with them adequate sledge dogs. For instance, Amundsen and his team members were able to cover longer distance within short periods of time as compared with Scott and Shackleton team. Furthermore, the energy work output of Amundsen sledge dogs was significantly higher than the energy work output of Scott and Shackleton horses and as such, this contributed to a successful expedition for Amundsen and his team. For instance, it was stated that the energy work output of Amundsen sledge dogs were around 6,714 watts as compared to Scott and Shackleton horses with energy work output not more than 1490-2,238 watts.

18. Hatfield, H. S. and L. G. C. Pugh (1951). "THERMAL CONDUCTIVITY OF HUMAN FAT AND MUSCLE." Nature 168(4282): 918-919.

The purpose of this research study which was conducted by Pugh (secondary author) and his colleague was to investigate and compare the thermal conductivity of human muscle tissue and fat. In this study, thermo-electric heat flow disk was used to determine the thermal conductivity of samples of muscle tissue and fat from five dead human beings and 3 dead beef.

The results of this study revealed that thermal conductivity of muscle tissue was significantly greater than that of fat for both humans and beef. For instance, the mean thermal conductivity of the human muscle tissue and fat was 0.00092 cal.cm./em.2sec. °C and 0.000488 cal.cm./em.2sec. °C respectively. Similarly, for beef the mean thermal conductivity of muscle tissue and fat was 0.00067 cal.cm./em.2sec. °C and 0.000489 cal.cm./em.2sec. °C respectively.

Based on the findings of this study, the authors concluded that fat was a better thermal insulator than muscle tissue and as such, a fat individual is better insulated from cold than a thin individual.

19. Chrenko, F. A. and L. G. C. Pugh (1961). "CONTRIBUTION OF SOLAR RADIATION TO THERMAL ENVIRONMENT OF MAN IN ANTARCTICA." <u>Proceedings of the Royal Society Series B-Biological Sciences</u> 155(959): 243.

The purpose of this research study which was conducted by Pugh (secondary author) and his colleagues was to determine the effects of solar radiation on man in the Antarctica. This research study was conducted in the summer at the Scott Base on members who participated in the 1957-1958 Anglo-America Antarctica expedition. In this study, it was established that participants wore a royal-blue cotton-nylon parka over their normal clothing and were instructed to face the sun directly. Parameters such as clothing and skin temperatures were measured using a thermocouple placed on the surface of the cotton-nylon parka, chest and back regions of the participants; the solar radiation was measured. Furthermore, in this article, it was established that after the expedition, a laboratory investigation was carried out in London on one of the members who participated in the expedition. The subject was instructed to wear the same type of clothing worn during the expedition. Parameters such as effective area of clothed body surface exposed to solar radiation was determined; thermal insulation of the clothing was determined.

The findings of this research study at the Scott base revealed that there was a significant increase in skin temperatures of the chest region facing the sun as compared to the back region shaded away from the sun. For instance, the skin temperature at the chest and back region was 34.7°C and 27.1°C respectively. Similarly, there was a significant increase in the clothing-surface temperatures of the chest region as compared to the back region. For instance, the clothing-surface temperatures of the chest and back region was 61°C and 12°C respectively. It was further revealed that at the Scott Base, the areas of clothing exposed to reflected solar radiation was 80% of the total surface area of the clothed body. For instance, it was established that the total surface areas exposed to reflected solar radiation and total surface area of the clothed body was 2.093 m^2 and 2.628 m^2 respectively. Furthermore, the results of the laboratory investigation done in London were compared to those conducted at the Scott Base. It was revealed that the skin and clothing-surface temperatures of the chest region in the laboratory study was significantly lower as compared to those obtained at the Scott Base. Conversely, the skin temperature of the back region was significantly lower as compared to those obtained at the Scott Base.

Exercise Physiology Studies

1. **Pugh, L. G. (1974). "The aerobic capacity of forty British women aged 17-27 years." Ergonomics 17(2): 185-192.**

The main focus of this study was to determine the aerobic capacity or maximum oxygen intake (VO_2 max) in 40 British women who were between 17-27 years of age during 5 min maximum ergometer exercise. Since VO_2 max is an indicator for cardiorespiratory fitness and endurance capacity in exercise performance. Pugh (primary author) conducted this study owing to the fact that little information was available on the VO_2 max of young women in Britain. Apart from measuring the VO_2 max, the author also measured other physiological parameters such as lung ventilation, heart rate, body fat, blood lactate, haematocrit, and haemoglobin concentration during the 5 min maximum ergometer exercise. In this study, 40 women were recruited. 20 out of the 40 were trained skiers, while the other 20 were individuals who lived a sedentary lifestyle.

Pugh measured the VO_2 max and other physiological parameters of the subjects during the first trail and subsequent trials.

He compared the VO_2 max results between the two set of subjects (20 skiers and 20 sedentary individuals), and further looked at the VO_2 max over a short-term period (6-12 weeks) and long-term period (2-6 years). The study revealed VO_2 max increased with subsequent trails and that skier subjects had higher VO_2 max than the sedentary subjects. Pugh also compared the results of this study with results from previous studies conducted by other authors. Thus, giving this study a greater sense of credibility. However, the limitation of this study was that the authors didn't take into consideration how much learning effect on the ergometer could have influenced the VO_2 max results during the subsequent trails.

2. **Brotherhood, J., B. Brozović and L. G. Pugh (1975). "Haematological status of middle- and long-distance runners." <u>Clin Sci Mol Med</u> 48(2): 139-145.**

There was a widespread belief that the physiologic changes induced by exercise in athletes can cause iron deficiency (anaemia), and decrease in oxygen carrying capacity of the blood (haemoglobin concentration). Thus, taking iron supplements could help prevent these anomalies which in turn could enhance exercise performance. Owing to the fact that this widespread belief lacks scientific evidence necessitated Pugh (one of the secondary authors) and his colleagues to conduct this study by investigating the haematological status of middle- and long-distance runners. They recruited 52 subjects for this study. They divided the subjects into two groups [40 male middle- and long-distance runners (experimental group) and 12 non-athletes (control group)]. Some of the subjects in the experimental group had been taking iron and/or folic acid supplements in form of multivitamins for 6 months prior to this study.

The authors compared the haematological parameters such as haemoglobin concentration, packed cell volume, erythrocyte count, total body haemoglobin, serum iron, total iron binding capacity (TIBC), serum iron, 2,3- Diphosphoglycerate concentration of the experimental group and control group. The results of their findings showed a significant increased in blood volume, total body haemoglobin, serum iron concentration, 2,3- Diphosphoglycerate concentration in the experimental group than in the control group. This study was also able to clarify that the use of iron and/or folic acid supplements doesn't affect the hematological parameters because there was no significant difference between runners taking supplements and runners not taking supplements. Interestingly, it is worthy to note that the authors of this study were able to support their discussions with other researchers' perspectives.

3. **Pugh, L. G. (1969). "Blood volume changes in outdoor exercise of 8–10 hours duration." J Physiol 200(2): 345-351.**

Previous studies by other researchers have established their findings on changes in blood volume associated with short term exercise. For instance, previous studies have shown that there was no significant change in red blood volume during short-term exercise, and that plasma volume significantly reduced during short-term exercise. Owing to the available information about blood volume changes during short-term exercise and the dearth of information about the effects of long-term exercise on blood volume, necessitated Pugh (primary author) to conduct this study by investigating the effects of long-term exercise on blood volume and other hematological parameters such as plasma volume, red blood volume, hematocrit, and plasma protein concentration. In this study, six hill walkers were recruited. They performed 28 miles walk which included ascending and descending a height of about 1150 m on two occasions (October and January). While performing this task, subjects had access to food and fluid.

The author measured participants hematological parameters such as blood volume, plasma volume, red cell volume using carbon monoxide rebreathing method before and immediately after the 28 miles walk (exercise) on the two occasions. The study revealed that there was significant increased in blood volume and plasma volume, and a significant decreased in hematocrit immediately after the long-duration walk. However, no significant changes in red cell volume and plasma protein volume were observed. Pugh concluded that during long-term exercise compensatory adjustment of blood volume takes place in the absence of dehydration.

4. **Pugh, L. G., J. L. Corbett and R. H. Johnson (1967). "Rectal temperatures, weight losses, and sweat rates in marathon running." <u>J Appl Physiol</u> 23(3): 347-352.**

The purpose of this study was to investigate body weight, rectal temperature and sweat rates changes among 77 athletes (competitors) who competed in a 42 km marathon race held in Witney, England on June 10, 1966. What spawned Pugh (primary author) and his colleagues to conduct this study was due to the dearth of information on thermal physiological factors such as sweat rate, body temperature limiting performance of athletes in long distance marathon running. Although, before this study was conducted some researchers argued that sweat rate (evaporative heat loss) could be a physiological factor that limits performance during long distance marathon running, but there were no scientific evidence/data available to support their arguments. Some of the parameters measured during this study were: rectal temperature (measured using rectal thermometer) immediately after the race; body weight before and after the race (in order to determine athletes weight loss); urinalysis (pH, albumin and ketones) after the race; O_2 intake; and sweat rates. In this study 63 out of the 77 athletes completed the race. The authors observed that athletes who completed the race had significant weight loss than those who weren't able to complete. The authors keenly observed the rectal temperature, sweat rate, O_2 intake values of the first four athletes who finished the race. The results of the study revealed that the athlete who won the marathon race had the highest values of O_2 intake, rectal temperature, sweat rate, fluid loss as compared to athletes who attained the second, third and fourth position. Pugh and his colleagues stated that despite the fact that successful marathon athletes recorded the highest values of rectal temperature, sweat rate and fluid loss, heat elimination still limit performance in some athletes.

In this study, it was also documented that 4-athlete collapsed 30 min-1 hr after the race. The collapse necessitated Pugh and his colleagues to conduct a hematological investigation such as hematocrit, serum electrolytes, glucose, and urea on them. it was revealed that all the hematological parameters were within the normal range except for blood urea which showed a slightly increased value. The authors of this study couldn't ascertain the exact cause of the collapse. Although, they suggested that fluid loss during prolonged exercise might be a likely factor for the collapse.

5. **Clark, R. P., B. J. Mullan and L. G. Pugh (1977). "Skin temperature during running--a study using infra-red colour thermography." <u>J Physiol</u> 267(1): 53-62.**

This research paper was conducted by Pugh (one of the secondary authors) and his colleagues with the purpose to using a thermographic technique (infra-red colour) to determine skin (cutaneous) temperature during exercise. According to this article, previous studies have been done using the conventional technique (probe thermocouple thermometer) to determine skin temperature. However, Pugh and his colleagues doubted the validity of those previous studies that determined skin temperature with the use of probe thermocouple. In this research study, two subjects were recruited. They were both subjected into two experimental conditions: [1) standing and running on an outdoor track for 1 hour and 15 minutes at 20°C ambient temperature; 2) standing and running on a treadmill for 1 hour and 30 minutes inside a climatic chamber at 11°C both in the presence and absence of wind. Parameters such as overall skin temperatures and regional skin temperatures distributions were all measured before and during the running exercise using both the infra-red colour thermography and probe thermocouple thermometer. In addition, comparison was made between the regional mean skin temperatures measured by the infra-red colour thermography and probe thermocouple thermometer. According to this research study, there are nine different colours shown on the infra-red thermography which signifies different levels of temperatures. However, the black colour signifies the coolest, while the white colour signifies the warmest.

The results of this study in the two experimental conditions revealed that during running (in the presence or absence of wind), the skin temperature distribution was significantly higher over muscles than over other body structures. For instance, the infra-red thermographic colour around the muscle was white, which signifies that the muscle was warmer than other body structures. Furthermore, the results of this study, showed that the skin temperature significantly decreases during running as compared to before running while in a standing position. In addition, the results of this study showed that the skin temperature significantly decreases during running in the presence of wind as compared to in the absence of wind. Most importantly, it was established in this study that there was a reduction in the regional mean skin temperature measured by the infra-red colour thermography as compared to the probe thermocouple thermometer. For instance, the regional mean skin temperature measured by the infra-red colour thermography differed by up to 4°C when compared to the regional mean skin temperature measured by probe thermocouple thermometer.

6. Clark, R. P., B. J. Mullan, L. G. Pugh and N. Toy (1974). "Proceedings: Heat losses from the moving limbs in running: the 'pendulum' effect." J Physiol 240(2): 8p-9p.

The purpose of this research study was to determine what effect does the pendulum motion of the lower limbs has on heat loss during exercise. According to Pugh (one of the secondary authors) and his colleagues, one subject participated in this study. The subject performed three experimental conditions: [1) ran on a treadmill with a speed of 4.5 m/s in the presence of wind; 2) ran on a treadmill with a speed of 4.5 m/s in the absence of wind; 3) stood still (stationary) without running in the presence of 4.5 m/s wind speed. Parameter such as the local heat transfer distribution around the thigh of the subject during the three experimental conditions were determined using a surface plate calorimeter.

The findings of this study revealed that the convective heat transfer coefficient (heat loss) around the thigh during running on the treadmill in the presence of wind was significantly higher as compared to running on the treadmill in the absence of wind. For instance, the heat loss around the thigh during running in the presence of wind and running in the absence of wind was 53.8 $W/m^2°C$ and 21.8 $W/m^2°C$ respectively. Furthermore, the results of this study revealed that local heat loss around the thigh during running in the presence of wind was significantly higher as compared to standing still (stationary) in the presence of wind. For instance, the local heat loss around the thigh was 63 watts and 28 watts during running in the presence of wind and standing still (stationary) in the presence of wind respectively. The authors of this study attributed the significant increased that was observed in the convective heat transfer (heat loss) during running in the presence or absence of wind to the oscillatory (pendulum) motion of the moving limbs (thighs). It was established that extra velocities are needed to move the limbs relative to the trunk during running due to the pendulum effect and as such, this causes a significant increase in local heat loss.

7. **Pugh, L. G. (1971). "The influence of wind resistance in running and walking and the mechanical efficiency of work against horizontal or vertical forces." J Physiol 213(2): 255-276.**

The purpose of this study which was conducted by Pugh (primary author) was to understand and determine the effects of wind velocity during exercise as well as to determine and compare the mechanical efficiency of work against wind (horizontal force) and against gravity (vertical force). In-order to determine the effects of wind velocity during exercise, 4 subjects participated in this study. They were subjected into four experimental conditions inside a climatic chamber: 1) running on a treadmill at various constant speeds in the presence of wind velocities ranging from 1.5-18.5 m/sec; 2) walking on a treadmill at constant speeds in the presence of wind velocities ranging from 0.5-11.5 m/sec; 3) running on a treadmill at various speeds at varying levels of inclination ranging from 2-8%; 4) walking on a treadmill at various speeds at varying levels of inclination ranging from 2-8%. Parameters such as oxygen intake (VO_2), and mechanical efficiency of work [against wind (horizontal force) and against gravity (vertical force)] were all determined during the experimental conditions.

The results of this study shows that VO_2 during running was significantly higher than during walking. Furthermore, it was established that VO_2 increases as wind velocity increases during running and walking. The results of this study showed there was a positive linear relationship between oxygen intake and wind velocity. For instance, during running, the oxygen intake was 3.05 and 4.96 l./min at minimal wind velocity and 18.5 m/sec wind velocity respectively. Similarly, during walking, the oxygen intake was 0.79 and 2.01 l./min at minimal wind and 18.5 m/sec wind velocity respectively. Furthermore, VO_2 increases as work rate increases during running at varying levels of inclination. For instance, it was evident that there was a positive linear relationship between VO_2 and work rate. However, during walking at varying levels of inclination, at higher work rate, there was a positive linear relationship between VO_2 and work rate. Whereas, at lower work rate the relationship between VO_2 and work rate was curvilinear. Furthermore, the results of this study showed that during running and walking, the mechanical efficiency of work against wind (horizontal force) was significantly higher as compared to against gravity (vertical force). For instance, during running the mean mechanical efficiency against wind and gravity was 0.690 and 0.456 respectively. While during running the mean mechanical efficiency against wind and gravity was 0.437 and 0.334 respectively.

8. **Pugh, L. G. (1972). "A modified acetylene method for the determination of cardiac output during muscular exercise." <u>Ergonomics</u> 15(3): 323-335.**

This research study was conducted by Pugh (primary author) with the main objective of understanding the effectiveness of a modified acetylene method for determining cardiac output during exercise at various work rate. Furthermore, this study also compared this modified acetylene method with previously old method that was used to determine cardiac output during exercise. According to the author of this study, the main difference between the modified acetylene method and the previously old method was that in the modified method, acetylene was absorbed through a combustion process. However, for the previously old method, acetylene was absorbed with mercuric chloride. In this article, the procedures for the modified acetylene combustion method were discussed. For instance, in this method, individual rebreathes from a bag containing gas mixture [C_2H_2 (acetylene) and O_2 (oxygen)] of known concentration. After the end of full expiration, the individual opens the tap to the bag in-order to perform inhalation and exhalation by emptying and filling the bag. Thereafter, the two gas samples were drawn at certain time intervals for analysis. Lloyd-Haldane gas apparatus was used to analyzer the gas samples. The Lloyd-Haldane gas analyzer has a combustion pipette which allows acetylene to be absorbed by combustion.

The findings of this study revealed that the modified acetylene combustion method was more sensitive than the previously old method in which acetylene was absorbed with mercuric chloride. The standard deviation of the acetylene analysis by combustion method was significantly lower than acetylene analysis by absorption with mercuric chloride. For instance, the standard deviation for the combustion method and absorption with mercuric chloride was ±0.0137% and ±0.0463% respectively. Furthermore, it was revealed that the modified acetylene combustion method was cost effective as it required lower concentration of acetylene to determine cardiac output during exercise as compared to the absorption with mercuric chloride method. For instance, the percentage of acetylene concentration used by the combustion method and absorption with mercuric chloride method was 3-4% and 10% respectively. Furthermore, despite the lower percentage of acetylene concentration used by the combustion method, there was no significant difference in the degree of accuracy in both methods (combustion and absorption with mercuric chloride) when used to determine cardiac output. Furthermore, it was evident that the findings of this study which adopted the use of the modified acetylene combustion method to determine cardiac output during exercise at various work intensity was in consistent agreement with other previous studies that used the absorption with mercuric chloride method.

9. Pugh, L. G. (1970). "Oxygen intake in track and treadmill running with observations on the effect of air resistance." J Physiol 207(3): 823-835.

The aim of this research study conducted by Pugh (primary author) was to determine and compare the relationship between oxygen intake and speed during track running and treadmill running. Furthermore, Pugh was also interested in determining the influence of wind velocity during exercise (running). In this study, seven athletes acted as subject. They all performed running on a cinder track and all-weather track. Consequently, the results observed during the track running were compared with a set of previously collated data on four athletes running on a treadmill. Furthermore, in-order to determine the influence of wind velocity during exercise, subject ran on a treadmill at constant velocity in the presence of wind of varying velocities. In this study, the only dependent variable measured during the track and treadmill running was oxygen intake.

The findings of this study revealed that during treadmill running there was a positive linear relationship between oxygen intake and speed of running. However, during the track running, the relationship between oxygen intake and speed was nonlinear. Furthermore, it was established that oxygen intake during track running was significantly higher than during treadmill running. For instance, during track and treadmill running at a similar constant speed of 21.5 km/hr, oxygen intake was 74.6 ml./kg. min and 68.3 ml./kg. min respectively. In addition, the slope of the graph during track running was steeper than that of treadmill running. With regards to the influence of wind velocity during exercise, the findings of this study revealed that oxygen intake increases with increase in wind velocity. For instance, running at a constant speed of 15.9 km/hr in the presence of wind velocity (16.2 km/hr) and absence of wind velocity (0 km/hr), the mean oxygen intake was 3.089 l./min and 2.924 l./min.

10. Pugh, L. G. (1974). "The relation of oxygen intake and speed in competition cycling and comparative observations on the bicycle ergometer." J Physiol 241(3): 795-808.

This research study was conducted by Pugh (primary author) with the aim of determining the relationship between oxygen intake (VO_2) and speed during exercise. In this study, 6 people with prior experience in competition cycling acted as subjects. They performed competition cycling (to-and-fro) on a 3 km runway which was timed, as well as cycling on a stationary bicycle ergometer at separate days. Parameter such as oxygen intake was quantified during the cycling activities. In this study, holistic physiological experiments were conducted in-order to: determine the relationship between VO_2 and speed during competition cycling and cycling on bicycle ergometer; relationship between pedal frequencies and speed of cycling; relationship between VO_2 and work rate during ergometer cycling; relationship between mechanical efficiency and work rate at various pedal frequencies; relationship between total resistance to motion (air resistance) and speed of cycling.

The findings of this study revealed that during competition cycling on the runway, there was a curvilinear relationship between VO_2 and speed of cycling. However, VO_2 increase with speed between 12.5-41 km/hr. For instance, at 12.5 and 41 km/hr, VO_2 was 0.88 and 5.12 l./min respectively. Conversely, during ergometer cycling, there was a positive linear relationship between VO_2 and work rate i.e., VO_2 increases as work rate increases. it was also established that there was a positive linear relationship between pedal frequencies and speed of cycling. Furthermore, the findings of this study showed that at higher work rate, mechanical efficiency increases. Whereas, at lower work rate, there was significant decrease in mechanical efficiency. It was also established in this study that there was a positive linear relationship between the net energy cost and cycling speed. For instance, the net energy cost increases as a square of speed. it was established that there was a positive linear relationship between air resistance and cycling speed. For instance, the results showed a strong correlation between air resistance and speed of cycling. Therefore, owing to these findings, Pugh believed that the influence of air resistance on cyclists cannot be overemphasized. It was stated that in the presence of air resistance during cycling, cyclist would ride significantly faster and thus, this would result into increase in cycling speed.