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REVIEW PAPER

Supplemental Oxygen for Paratroopers and Sky Divers

V.N. Jha

Defence Bioengineering and Electromedical Laboratory, Bengaluru – 560 093, India
E-mail: *drjhavn@gmail.com*

ABSTRACT

Parajumping and sky diving in Armed Forces are used for rapid and strategic troop's deployments. In the combat free fall (CFF), the troops are paradropped from high altitudes in excess of 30,000 ft above mean sea level (AMSL) when they glide to a great distance, often within the enemy lines. Physiology of parajumping necessitates supplemental oxygen above 15,000 ft AMSL. Possibility of serious hypoxia and decompression sickness mandate the usage of supplemental oxygen through dedicated equipment. Other considerations such as effects of hypoxia on tissue oxygenation, physical and mental performance, neuronal functions, night vision, and prevailing anxiety factors, etc. also assume significance. Factors like intermittent hypoxic exposures, free fall, effects of posture during fall, and possible microgravity become mitigating factors. Owing to limited oxygen supply being carried by the paratroopers, using dilution method in providing the breathing gas too assumes importance at times as a trade-off between requirements and supply. This paper reviews the literatures to extent possible and recommends certain concepts for an optimal oxygen usage during the high altitude parajumps.

Keywords: Parajumping, sky diving, high altitude jumps, hypoxia, decompression sickness, night vision, jump anxiety, oxygen jumps

1. INTRODUCTION

Parajumping and sky diving from aerial vehicles are undertaken for various reasons. Among civilians, it is mostly an adventure sport whereas the military uses it for strategic rapid deployment. Traditionally, parajumping is undertaken below 8,000 ft above mean sea level (AMSL). In a routine low altitude military training paratroopers are dropped from 4,000 ft to 8,000 ft AMSL over the drop zone (DZ) when parachute opens immediately after jumping. However, during high altitude jumps, there are options of high altitude high opening (HAHO) by deploying the chute within seconds of the jump or high altitude low opening (HALO) when one continues falling freely and the chute deployment is delayed till a few thousands of feet (usually 2,000 ft – 4,000 ft) above ground level, the minimum opening height[1]. The strategic military HAHO jumps usually conducted from about 30,000 ft especially under night and limited visibility operations, offer greater surprise on enemy and less vulnerability to enemy fire[2]. One can glide as much as 20-40 km away from the drop point and remain suspended in air for a very long time. Such prolonged exposures to above 20,000 ft AMSL need support with supplemental oxygen and protection against other environmental extremes that can incapacitate the jumpers.

Supplemental oxygen undoubtedly is a necessity for preventing hypoxia at high altitudes. During an exposure to sustained high altitude, one may become hypoxic and continue to deteriorate with every passing moment. On the other hand, parajumpers even if hypoxic, will become better and better with the passing time due to decreasing altitude whether under free fall or deployed canopy. US parachute association[3] classification of the jump altitudes is largely followed by the parachutists the world over. The jump altitudes are categorised as Low (<15,000 ft), intermediate (15,000 ft – 20, 000 ft), high (20,000 ft – 40,000 ft) and extremely high (> 40,000ft). The intermediate and high altitudes are also known as physiologically deficient zones. This categorisation is largely from oxygen usage point. No oxygen usage is contemplated in low altitude jumps whereas on-board usage of oxygen while ascending in the aerial vehicle, is advised prior to intermediate altitude jumps and a supplemental personal bail out oxygen system (PBOS) usage becomes essential in addition to the on-board usage for the high altitude jumps.

An unacclimatised human will be vulnerable to moderate hypoxia over 10,000 ft AMSL if without supplemental oxygen. For a paradrop from above 15,000 ft (but below 20,000 ft) AMSL, either HALO or HAHO, it is customary to be on 100 per cent O_2 while ascending to the jump altitude in the aerial vehicle. It is also customary to place the paratroopers on 100 per cent pre-breathing with oxygen with on-board aircraft oxygen system for 30-45 min to prevent decompression sickness (DCS) if exposure to above 18,000 ft is contemplated[4]. The pre-breathing is continued till 1-2 min before the actual jump. On the other hand, for the jumps from above 20,000 ft, the jumpers carry a PBOS that assists them to descend through the higher altitudes to below 12,000 ft.

Paratroopers are always faced with variety of challenges. Whether sport or profession, it is always fraught with danger. The dangers exist in the form of incapacitation due to hypoxia, DCS, life threatening low temperatures. In addition, possibility of non-deployment of parachute, apprehension of being blown

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over enemy lines and being fired upon or captured as well as vulnerability to the landing injuries etc are ever existing. Hence, though the sport may seem glamorous, the profession in itself has inherent unpredictability and dangers.

Although paradrops from high altitudes are routine, yet very few dedicated life support technologies have been developed exclusively for the paratroopers. Most of these technologies have been adapted from aviators in an ad-hoc measure. It is essentially because there have been very few dedicated studies on the understanding of their physiological needs. Although most of the para organisations have some basic safety guidelines, US Air Force adopts a policy[5] of physiology technician (who monitors and helps the jumpers on-board aircraft).

This paper is an effort to look in to all aspects in the profession of the parajumping that influence their physiological needs during the actual operations.

2. OPERATIONAL REQUIREMENTS OF PARATROOPERS' OXYGEN SYSTEM

The parajumpers/sky divers have the following operational requirements of the life support with reference to oxygen system during the event of high altitude paradrop or sky diving:

- One should descend down safely through the physiologically deficient zone under HALO or HAHO as a routine, at times with some calculated risks.
- They should achieve the strategic advantage of a safe long gliding endurance at high altitude in a combat zone that may not be safe for overhead paradrop.
- Post jump, the troops should be in a good physical/ physiological state of combat effectiveness. This implies that they should not suffer from the effects of decompression sickness (DCS), significant Hypoxia and if possible, even from minor limitations such as loss of night vision etc.
- Their landings should be safe with the carried loads within limits.

In nutshell, the oxygen management for the paratroopers should provide adequate breathing gas that protects them against hypoxia (through a PBOS) and also protect against the DCS (through a separate pre-breather console mounted in the aerial vehicle). The PBOS must be light weight to enable maximum glide time under HAHO and also lessen vulnerability to landing injuries.

3. PHYSIOLOGY OF PARAJUMPING

Paratroops undertake jumps from varying altitudes. Their physiological status pertaining to oxygenation and other issues need special consideration. Jumps below 10,000 ft AMSL do not have much physiological concerns. Jumps above this height expose one to physiologically deficient zone of atmosphere with the following concerns:

3.1 The Altitude Factor

The jump altitudes for a paratrooper are dictated by the operational requirements as well as the availability of the life support system that can sustain them to descend through physiologically deficient zone. There are historical instances of show jumping by daredevils from as high as 1,00,000 ft. Whereas in strategic military operations paratroopers have been dropped from above 30,000 ft AMSL including under night conditions. Although, most of the life support gears for the paratroopers with 100 per cent oxygen breathing are capable of protecting them against hypoxia up to 40,000 ft AMSL of paradrop, the other challenges such as DCS and the extreme environments also need to be addressed.

3.2 The Tissue Oxygenation

At sea level breathing air yields an alveolar pAO_2 of 103 mm of *Hg* that provides approx 98 per cent of blood O_2 saturation which is optimum for tissue oxygenation. Variation of blood O_2 saturation with alveolar pAO_2 at different altitudes, is depicted in Fig. 1. From the graph it is evident that raising pAO_2 >103 mm of *Hg* by breathing O_2 rich gas (Fig. 2) even at higher altitudes, is a waste of precious little O_2 gas carried by the jumpers in preventing hypoxia. The physiological goal of oxygenation in preventing hypoxic hypoxia should essentially be aimed at maintaining alveolar pAO_2 of 103 mm of *Hg*. This can be achieved by gradually increasing the concentration of O_2 from sea level upwards, achieving 100 per cent at 33,000ft and thereafter, supplying 100 per cent O_2 under increasing pressure with increasing altitudes.

At sea level, arterial blood oxygen tension (paO_2) of

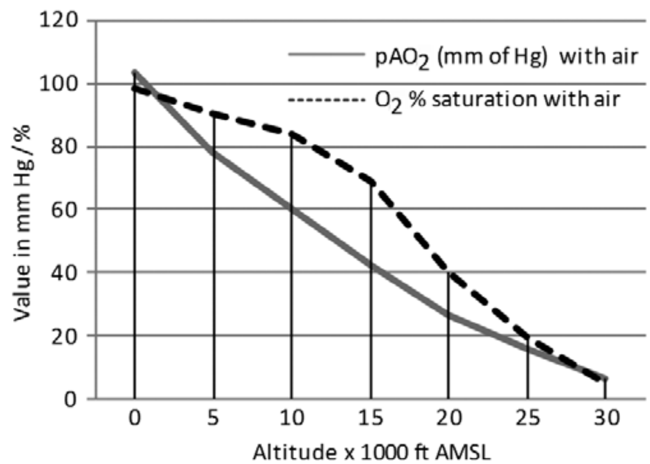

Figure 1. pAO_2 and blood O_2 saturations at various altitudes while breathing air.

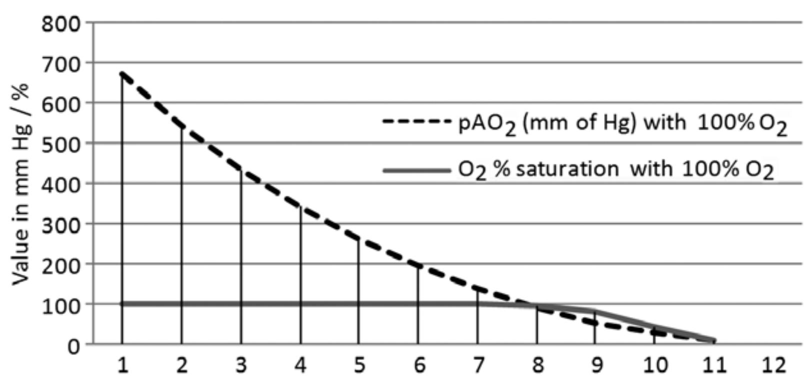

Figure 2. Relation of pAO_2 and blood O_2 saturations at various altitudes.

approx 95 mm of *Hg* distributes the oxygen to the tissues through capillaries and interstitial fluid, where the actual O_2 partial pressure of the tissue cells vary from 40 mm to 5 mm *Hg* (averaging 23.5 mm) depending upon the cellular distance from the vascular bed and the status of cellular metabolism of that tissue. Human connective tissues can work till very low intracellular O_2 tension (0.5 to 3 mm *Hg*) that is required for the mitochondria to perform oxidation[6]. The brain tissues on the other hand, have limitations of a very small O_2 reserve in them. In addition, its inability to utilise anaerobic pathway of metabolism makes it vulnerable to hypoxia. Although, such minimum levels of oxygen are mostly available in the blood even under Hypoxia routinely encountered in parajumping, it is mostly the interruption or cessation of the blood flow to the brain tissue that leads to problems. In fact, the brain tissues at rest, are known to have surplus oxygen that usually diffuses back to the capillaries[7]. It is the intracellular requirements of even such low level of oxygen which has to be met through effective O_2 pressure gradients across the cellular membranes as well as by maintaining a rich blood flow around the tissues. Human tissues have vast capabilities of homeostatic adjustments for tissue oxygenation.

3.3 Physical and Mental Performance

The alveolar pAO_2 of 103 mm *Hg* at sea level, becomes 60 mm at 10,000 ft, 42 mm at 15,000 ft and 26 mm at 20,000 ft AMSL while breathing air. Numerous high altitude physiological research have rendered unambiguous conclusion that human performance above 10,000 ft altitude has distinct limitations. Performance of unacclimatised person without supplemental oxygen shows significant lowering of the skilled task performance and potentiates one to errors. Performances on cognitive and psychomotor tasks as well as mood changes are known to get affected at or above this altitude[8]. While staying above 10,000 ft beyond certain time (usually in minutes) and breathing air, recall of the memory (short/long term) is adversely affected by about 25 per cent at 15,000 ft AMSL. At this altitude, time taken to complete the previously learnt simple coding task is increased by 10-15 per cent and psychomotor task performance is adversely affected[9]. Consciousness is usually lost if the pAO_2 is <30 mm of *Hg* for a period of time. Some other studies have shown that vigilance task performance remained unaffected at 15,000 ft but when studied by Batholomew, *et al.* readbacks of high memory load recall got affected[10]. The P-300 waveform studies at 4 km, 5 km, and 6 km altitudes have shown that performance of some individual may get affected at 4 km AMSL while others may not get affected even at 6 km following exposure of 45 min. It is noteworthy that most of these studies indicate the effects of continued hypoxic exposures at those altitudes beyond 30 min which is not the case of relevance for the parajumpers in whom the altitudes of exposure invariably keeps on decreasing following the jump.

3.4 The Neuronal Functions

In the brain tissues, severe Hypoxia (pAO_2 of 20-35 mm of *Hg*) or a flow dependant interruption of O_2 supply for > 3 s to 5 s (mostly vaso-vagal), causes loss of consciousness. Hence, for continuation of cerebral function, continuation of blood supply is absolutely essential. If the nervous system has to retain the capability to exercise its complete ability of critical cortical functions (sensing, analyses and control as required in aviation tasks), a comparatively higher state of cerebration called time for useful consciousness (TUC) or effective performance time (EPT) becomes the matter of relevant. TUC is a state under which an individual having near sea level blood oxygen is suddenly deprived of the oxygen either by removal of the supplemental O_2 source or an acute drop in surrounding atmospheric pressure. The TUC permits them to remain 'effective' for some time the duration of which depends on the prevailing altitude, rate of ascent and the physical activities[6,9]. This available time permits one to initiate corrective actions to descend to safer altitude (below 15,000 ft). The mean TUC at different altitudes[6] are shown in Fig. 3. Although no study has been done to find out the TUC and the paO_2 without bail out supplemental oxygen during free fall or assisted fall, it is assumed that TUC among the jumpers will be approx 30-50 per cent below that of a rested person owing to their heightened anxiety and physical activities involved prior to the jump. A probable TUC among the paratroopers is also shown in Fig. 3. The tissue oxygen saturation towards the end of the TUC has been found to vary from 52-58 per cent (range 42-74 per cent) while breathing nitrogenated air akin to 25,000 ft AMSL[11]. While applying this logic to the paratroopers, it permits them to jump from 20,000 ft AMSL without supplemental oxygen. Under such circumstances, their pAO_2 level will constantly keep on increasing as they continue descent. Further, with the decreasing altitudes, the TUC will keep on increasing.

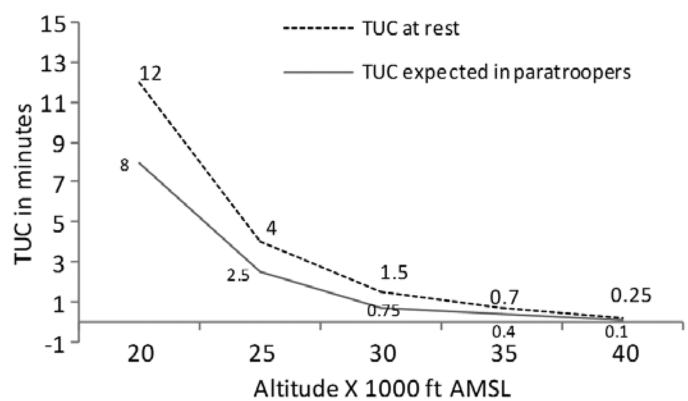

Figure 3. Depicts the mean TUC in a rested and a paratrooper subject.

3.5 Decompression Sickness

Decompression sickness (DCS) is a possibility during exposures to altitudes >18,000 ft while breathing N_2 mixed gas. It is likely to occur if the exposure to such altitudes are >5 min and N_2 gas is dissolved in blood and tissues. The DCS is more common among the jump masters moving around and the jumpers having had diving/hyperbaric exposures on preceding day. The DCS can largely be prevented by removing the dissolved N_2 by undertaking pre-breathing of 100 per cent O_2 for 30-60 min depending upon the exposure altitude[5,6,9]. Though, theoretically possible above 18,000 ft AMSL, DCS is not a major threat below 22,000 ft AMSL. The occurrence of DCS is seldom seen among altitude acclimatised personnel owing to lesser dissolved N_2 in tissues.

3.6 Night Vision

The loss of night visual functions under Hypoxia among the aviators is well researched. It is known that they suffer from partial loss of visual acuity as well as dark adaptation. The losses amount to 10-20 per cent at 5,000 to 7,000 ft AMSL. In a retrospective study, 2-6 per cent helicopter aircrew reported of symptoms related to deterioration of visual function[12]. However, in a recent study of 12 h exposure to 10,000 ft, unaided night vision performance was found not to have been adversely affected significantly under mesopic (such as moonlit) light condition[13] whereas the colour vision in the same range does get affected[14]. Though these losses may seem minimal, it may have significant effect on the aviators for their ground vision of navigation and target detection. The loss of dark adaptation has some residual effect before recovery at lower altitudes. As a result, it is customary for the military fighter/bomber aviators to use supplemental oxygen from the ground level during night flying. It is also a common practice among the transport/airliner pilots not to use supplemental oxygen as a routine wherein the cabin altitude is at 4,000 ft to 8,000 ft AMSL. Paratroopers on the other hand, also need their night vision akin to mesopic conditions so as to maneuver themselves to the landing area especially for precision landing. Although most of the military paratroopers are dropped in the DZ, the combat troops dropped from high altitudes have to maneuver themselves much inside the enemy lines, at times under reasonably dark conditions owing to operational compulsions. They need to retain their night vision even if provided with an NVG. As such while the NVGs are adequate to view the underneath DZ, it gives no depth perception. Hence, the landing will have to be through naked eyes in the last few feet of descent. This is a very specific task for which it will be desirable to keep the pAO_2 level akin to an altitude corresponding to approx. 6,000 ft AMSL at all times of the jump. Table 1 specifies the oxygen concentration required in breathing gas to maintain pAO_2 of either optimum sea level condition (103 mm *Hg*) or an acceptable trade-off to preserve the night vision for a parajumper (to 75 mm of *Hg*) akin to 6,000 ft AMSL.

3.7 Effects of Intermittent Hypoxic Exposures

It is known that the intermittent hypoxic exposures (IHE)[15] increases the chemosensitivity induced ventilatory response of the body for better oxygen utilisation. This hyperventilation acts to partly offset the effects of altitude on PaO_2 by helping to restore normal O_2 delivery to tissues. IHE is also known to facilitate both transport of O_2 across the cell membrane and also utilization by the mitochondria[16]. How much of these effects are of relevance to the paratroopers, is not known. But it is assumed that some beneficial effect of IHE does play part in attenuating the effects of acute hypoxic symptoms or on manifestation of the performance decreament.

Table 1. Requirement of O_2 per cent in breathing gas at various altitudes

Altitude in ft X 1000	per cent O_2 for pAO_2=103	per cent O_2 for pAO_2=75
5	25	17
10	30	24
15	38	30
20	47	38
25	57	50
30	80	64
33.7	100	70
37	100^+	100

$^+$ denotes breathing of 100% O_2 at positive pressure

3.8 The Jump Anxiety (A-Factor)

Anxiety level among the parajumpers and sky divers are known to be high before and during jump. These stresses bring in additional catecholamine in the blood that prepares one to fight or flight[17,18]. The ensuing rise in the heart rate, blood pressure and cardiac output increase the tissue perfusion and also increase in the rate and depth of pulmonary ventilation. These effects in ventilation and perfusion, seem to improve oxygenation akin to the compensatory Hypoxic phase adaptation. However, if the response is disproportionate, the concurrent overwhelming autonomic overflow will compromise with overall performance of the jumper and the hypocapnoea following hyperventilation, will be a problem that will produce symptoms and also, reduce the CBF owing to vasoconstriction of the cerebral vessels.

3.9 The '*g*' factor of Para Descent

The often ignored dynamic phenomena of parajump, is the varying '*g*' during free fall. On one hand, it causes microgravity during the initial stages of free fall and on the other, it exposes to high '*g*' of the parachute opening shock (POS). Microgravity is transient during initial stage of free fall till terminal velocity is achieved. If a body falls unhindered without wind drag, it will be almost a zero '*g*' condition. But that is not the case with the parajumpers because wind drag creates the buoyancy proportionate with the descent rate. No sooner they attain the terminal velocity, the '*g*' component goes back to 'near 1g'. POS imposes high '*g*' load depending upon the altitude and opening speed. Higher the altitude or speed of parachute opening (such as HAHO[19]), greater the 'g' load of the POS on the subject.

4. THE DYNAMICS OF TISSUE OXYGENATION IN PARATROOPERS

It is known that the flow of blood with even lesser oxygen saturation is equally important to keep the brain and/or other tissues perfused and oxygenated. In rapidly descending subjects such as paratroopers, the dynamics of the free falling body makes their condition different from an aviator or the others. Two important dynamic phenomena occur during the stage of free fall. Firstly, the altitudes keep decreasing rapidly to lessen the hypoxic stressor and secondly, the free fall itself has certain effects on the vascular system.

4.1 Decreasing Altitudes

During jumps, the altitude keeps decreasing, more rapidly during free fall than during canopy descent. The rate of descend can be as much as 10500 fpm to as low as 1200 fpm

Table 2. Summary of the usage of the supplemental oxygen

Jump altitudes	Aircraft oxygen			Pre-oxygenation	PBOS for the jumpers
	Aircrew	Jump master	Para-jumper		
Below 10,000 ft	Nil	Nil	Nil	No	Nil
10,000 ft to 12,000 ft					
Exposure not exceeding 2 hrs	Yes^{*+}	Nil	Nil	No	Nil
Exposure exceeding 2 hrs	Yes^{*+}	Yes^{+}	Nil	No	Nil
>12,000 ft to 15,000 ft	Yes^{*+}	Yes^{+}	Nil	No	Nil
>15,000 ft to 20,000 ft	Yes^{**+}	100 per cent	100 per cent	30 min	Nil
>20,000 ft to <30,000 ft	Yes^{**+}	100 per cent	100 per cent	45 min	Yes^{+}
>30,000 ft to <40,000 ft	Yes^{**+}	100 per cent	100 per cent	60 min	Yes^{+}

* In Unpressurised cabin; ** These flights are recommended in pressurized cabin only; $^{+}$ In dilution mode. of oxygen.

with deployments. With this, the partial pressure of oxygen in the alveoli keeps on increasing with every moment of fall and is translated into an improved blood oxygenation. Hence, even if an individual had been towards the dwindling end of one's TUC at the time of the initiating jump, his condition will keep on improving with every moment of falling and it is most likely that one would come out of the hypoxic phase fully safe and sound.

Thus, as long as a parajumper initiates the jump within the period of TUC, there is not much concern for hypoxia under a HALO jump from intermediate altitudes. HAHO may take 5 min to 7 min before the jumper descends below 15,000 ft AMSL at which level, hypoxia per se does not have much impact on a paratrooper (vide supra). Since, the TUC at 20,000 ft is of the order of 10 min, continuously increasing in the next 2 min of descent to 25-30 min, the jumper is reasonably safe against hypoxia as a disturbing element.

4.2 Circulation in Falling Body

The microgravity increases the cerebral blood flow (CBF) due to reduction of blood pooling in the dependent part and at the same time, reducing the pressure gradient in the column of blood above the heart level. Also, horizontal posture of free fall reduces the inequality of ventilation perfusion ratio due to microgravity/horizontal posture, reduces blood pooling thus increases the CBF. But, hypoxia/anxiety induced hyperventilation reduces the $pACO_2$, causes cerebral vasoconstriction, decreasing CBF.

Thus, the microgravity induced increase in the CBF, even if minimal, can be of significant protective value in minimising the hyperventilation induced reduction in the CBF and sustain them even with a lesser O_2 concentration. As such, under hypoxia with arterial oxygen tension of 30-40 mm *Hg*, interstitial oxygen tension decreases to 15 mm *Hg* even with the increased cerebral blood flow[20]. Hence, if the above mechanisms are able to yield a better O_2 supply to the brain and other tissues, it is going to be a better oxygenation status for the paratroopers. Towards the end of free fall however, the POS increases the blood pooling below heart level and at times, combined with the reduced $pACO_2$ of hyperventilation, can dangerously compromise the CBF.

5. OXYGEN CONCENTRATION OF THE BREATHING GAS FOR PARATROOPERS

The concentration of oxygen in the breathing gas of the oxygen system for high altitude parajumps will be influenced by the following considerations:

5.1 Who are the Jumpers?

If the bravehearts, they may prefer to take calculated risks to create records. The trainee jumpers on the other hand, may well be within their limits of safety and adhere to the laid down norms. Military combat troops would prefer full combat effectiveness even during the descent part of the jumps by keeping their oxygenation status to uncompromised level.

5.2 Supplemental Oxygen Requirement

For the aircrew in pressurised cabin, there is no requirement of supplemental O_2. However, in unpressurised cabin, supplemental O_2 is required as below. The jump master(s) on the other hand, moving up and down to instruct and monitor the parajumpers need to be protected against both hypoxia and DCS. It is even advisable for him to have a personal oxygen system that can supply O_2 in dilution mode or 100 per cent till the jumps are completed and cabin is repressurised. Thus keeping in view the total scenario, the need for oxygen for all (jump master & parajumpers) has been summarised in Table 2 including the need for pre-oxygenation and PBOS. Many literatures mandate 30 min of pre-oxygenation to be completed before the cabin altitude rises above 8,000 ft to 10,000 ft AMSL.

5.3 Continuous Flow or Demand Type of Breathing

The continuous flow type of breathing system is invariably 100 per cent oxygen, at a predetermined flow rate esp. when either there is no dearth of the gas source or the time of exposure is very short. Continuous flow rate of 10 lpm to 15 lpm is the routine requirement and such oxygen apparatus have the advantage of a simple design. The demand type on the other hand, has a more complex design in which the breathing gas flow commences following inspiratory effort. The breathing gas could be 100 per cent oxygen or air diluted oxygen. The air dilution can either be of a fixed proportion or a variable type in which the required concentration of O_2 is provided as per the prevailing altitude.

5.4 Concentration of Oxygen in Breathing Gas

The sea level oxygenation (pAO_2 = 103 mm of *Hg*) is the optimum level of oxygen for optimum performance by a human. With a minimal acceptable compromise, even the aviators are permitted to fly up to 10,000 ft AMSL without supplemental oxygen and up to 12000 ft AMSL if the duration of exposure is less than 20 min. It must be remembered that the aviators during their operations usually 'maintain' or slowly increase/ decrease their flight level whereas the paratroopers get into a state of descent during their jump whether under free fall or under canopy descent. For the paratroopers, it may be prudent to assume that their oxygen status of 10,000 ft equivalent will be adequate to have a trade-off between requirement and supply. But, keeping the night vision requirement in view, it is recommended to keep the oxygen status equivalent to 6,000 ft (pAO_2 of 75mm of *Hg*) minima by providing supplemental oxygen concentration as per Table 1.

5.5 Low Altitude Parajumping (<15,000 ft AMSL)

Jumping from 15,000 ft (pAO_2 = 40 mm of *Hg*) without supplemental O_2 is routine among the paratroopers and is considered medically safe[3,21] although American Military advocate its usage above 13,000 ft AMSL[22]. Australian Parachutist Federation have kept this altitude to 14,000 ft AMSL[23] These jumpers ascend to the drop altitudes in an aerial vehicle and then initiate their jump under HAHO or HALO (actually a misnomer below 20,000 ft of altitude) profile. Seldom is any difficulty related to hypoxia is experienced in jumps from these altitudes. Under these circumstances, breathing atmospheric air is considered adequate. Even under HAHO, the subject will be below 7,000 ft AMSL within 8 min during which ones' performance is expected to be well within the TUC.

5.6 Intermediate Altitude Jumps (>15,000 ft to <20,000 ft)

For these jums, the jumpers' oxygenation status will be compromised if not supplemented with oxygen. There is a concern for DCS beyond 18,000 ft AMSL. Hence, for all jumps beyond 18,000ft AMSL, they are put on 100 per cent oxygen pre-breathing for 30-60 min duration[24] during the ascent to the jump altitude. Such oxygenation is usually started at 4,000 ft to 8,000 ft AMSL[3] and atleast 30 min of pre-breathing is completed before ascent to above 10,000 ft cabin altitude. Often differently pre-breathing protocols are followed for jumps from different altitudes. The supplemented oxygenation washes out enough N_2 from the tissues to prevent DCS and imparts almost 100 per cent blood oxygen saturation prior to the jump so that they could sustain descent to below 13,000 ft AMSL[21] even under HAHO while still within the TUC. However, their night vision capabilities could be compromised to some extent under HAHO if they remain above 6,000 ft AMSL with pAO_2 <75mm of *Hg*. If jumping under HALO, they will descend below 5,000 ft AMSL in about 90 s thus escaping any significant night vision deterioration. Hence, for the military para operations from intermediate altitudes in the night, it will be advisable to either exercise HALO or have a personal oxygen system if HAHO is planned. The breathing gas mixture in such case should maintain pAO_2 of 75 mm of *Hg* or above in order to prevent deterioration of night vision. In this case, the quantity of O_2 gas in the PBOS should be adequate to bring them to altitude below 6,000 ft AMSL.

5.7 High Altitude Parajumping (>20,000 ft AMSL)

For these jumps, the requirement of 100 per cent oxygen pre-breathing for 30-45 min prior to the depressurisation (or opening up of the ramp) of the cabin is essential to minimise the risk of decompression sickness (DCS). This pre-breathing requirement is over and above a personal bail out system that is mandatory for the jump. Although the daredevil sky divers have often undertaken the HALO jumps without personal oxygen system from altitudes up to 24,000 ft[25,26], a PBOS is considered necessary. Such PBOS may have either air diluted oxygen to maintain pAO_2 of 75 mm of *Hg* or provide 100 per cent oxygen, either in continuous flow or in demand mode.

6. CONCLUSIONS

Para jumping and sky diving are unique exercises that have come to stay as a profession. In addition, high altitude Combat Free Fall has a special strategic importance for the military. Very few concerted scientific studies have been undertaken specific to their physiological needs. Mostly, there is a tendency to apply the applied knowledge of aviation physiology of the aviators to the requirements of the paratroopers as well. However, there is a significant difference in the dynamics of operational environment of the paratroopers from those of the aviators. The risks of Hypoxia, physical, and mental performance decreament, DCS, loss of night vision in the two categories are somewhat different owing to the dynamics of falling body (with or without parachute).

Exposure to altitudes in excess of 10000 ft AMSL , without supplemental oxygen compromises the oxygenation status of an individual. In the profession of parajumping, it is customary to avoid supplemental oxygen for the jumps from upto 15,000 ft AMSL. Jumps from intermediate altitudes (15,000 ft – 20,000 ft) are usually considered safe without personal supplemental oxygen system if the jumpers were kept on 100 per cent O_2 prior to initiating the jump. However, under HAHO jumps from the intermediate altitudes, if the night vision is to be kept unaffected, it is advisable to use a PBOS during the jump. For the jumps above 20,000 ft AMSL, requirement of a PBOS is considered mandatory for the safety of the paratroopers in order to keep their performance uncompromised from oxygenation point of view. Since there is a common PBOS for day/night jumps, the concentration of O_2 in the breathing gas ought to be such that keeps the pAO_2 to $\geq$75 mm of Hg. Further, the endurance of the PBOS should enable the paratroopers to descend below 6,000 ft AMSL to prevent deterioration of night visual functions.

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Contributor

Dr V.N. Jha completed his MBBS in 1979, AMD in 1984, and MD (Aerospace Medicine) in 1990 from AFMC, Pune. He has published more than 30 research papers in various national journals and was conferred with Fellowship of Indian Society of Aerospace Medicine in 2005. Presently working as Scientist 'F' and Head, Aeromedicine Evaluation & Technique Facility Group at Defence Bioengineering and Electromedical Laboratory (DEBEL), Bangalore. His team has developed a helicopter oxygen system for *Cheetah/Chetak* aircraft of IAF. His interest area includes; Aircrew life support technologies.