Trabajos Originales

Voluntary breath holding time (VBHT) is shortened at high altitude. How and why?

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SUMMARY

OBJECTIVES: To review five papers of author's own works on shortness of Voluntary Breath Holding Time (VBHT) at high altitude, since 1970, when he joined Japanese Mt. Everest Expedition. After that, he repeated the same observation on himself and some other Himalayan climbers to whom he asked to re-examine it. **METHODS:** The breath holding time means the time span between the start and the breaking point, and it was observed at sitting and full inspiratory (TLC) position using the subject's wristwatch. The data obtained were analyzed on the view point of relationship between VBHT% and altitude (atmospheric pressure), here, VBHT% = VBHT at altitude / VBHT at sea level x100. **RESULTS:** The common tendency observed among Himalayan climbers was that VBHT decreased straightly with increasing of altitude, and the relationship between VBHT% and altitude was revealed as a not continuous but discontinuous line. All of these lines were interrupted abruptly at some altitude, then, shifted rightward on the graph drawing new straight lines. **CONCLUSIONS:** This phenomenon could be hypothesized that respiratory alkalosis induced by hyperventilation could be corrected by intermittent excretion of alkali reserve through kidneys.

Key words: Voluntary Breath Holding Time (VBHT), shortened VBHT%, High altitude.

RESUMEN

OBJETIVOS: Revisar 5 artículos propios del autor sobre la reducción del tiempo de reserva voluntaria respiratoria (VBHT) en la altura, desde el año 1970, cuando viajó en la expedición japonesa al monte Everest. Después repitió la misma observación en sí mismo y también en escaladores del Himalaya. **MÉTODOS:** El tiempo de reserva respiratoria significa el espacio de tiempo entre el inicio y el punto de interrupción de la reserva respiratoria, lo que fue observado en posición sentada y luego de una inspiración completa (TLC), usando un reloj de muñeca. Estos datos fueron analizados en su relación entre VBHT% y la altura (presión atmosférica), VBHT% = VBHT en altura / VBHT a nivel del mar x 100. **RESULTADOS:** La tendencia común observada entre los escaladores del Himalaya fue que el VBHT disminuyó directamente con el incremento de la altura. La relación entre VBHT% y la altura mostró una línea discontinua. Las líneas fueron interrumpidas abruptamente en alguna elevación y luego desviadas hacia la derecha y continuaron como nuevas líneas rectas. **CONCLUSIONES:** Hipotéticamente, este fenómeno podría ser explicado como que la alcalosis respiratoria inducida por la hiperventilación podría ser corregida por la excreción intermitente de la reserva alcalina por el riñón.

Palabras clave: Tiempo de reserva voluntaria respiratoria (VBHT), VBHT% reducido, altura.

INTRODUCTION

When a man holds his breath voluntarily, the time-limit to be able to tolerate is called 'the breaking point (BP) of breath holding' and the time span between the start and BP is called 'the voluntary breath holding time (VBHT)'. It is a well known phenomenon in respiratory physiology that VBHT is shortened at high altitude[1,2]. The author was interested in this phenomenon and wanted to know how and, if possible, why such a phenomenon is observed at high altitude. Moreover, it was thought that it might be one of the keys to clarify acclimatization. Observation and measurement of voluntary breath holding time at high altitude (VBHT-HA) by himself started in 1970, when he joined the Japanese Mount Everest Expedition. Since then until now he has repeated the same observation on himself or colleagues of Himalayan expeditions with him, whenever he had the chance. The observations on the following five expeditions are reviewed in this present paper:

1) Japanese Mt. Everest (8848 m) Expedition in 1970 (JMEE'70).
2) Kyoto University Medical Research Expedition to Xixabangma (8 027 m) in 1990 (KUMREX'90)[3].
3) Kyoto University Pamir (up to ca. 5 400 m) Scientific Expedition in 1993 (KUPSE'93)[4].
4) Japanese Mt. Bhagirathi (6 856 m) Expedition in 1994 (JMBE'94)[5].
5) Bus trip on the Atacama High-Land (ca. 4 000 m) in Chile in 2000 (CHILE)[6].

In general, breath holding is a very hard or unbearable performance and it is indistinct whether the data obtained is really reliable or not. So, only readings to be thought as reasonably reliable, e.g. not average but the largest values on each subject, were collected.

The most important but difficult matter of this investigation was to get the climber's understanding and their willing cooperation, especially in such thin air environment. First of all, it is a very emotional matter to hold their breath voluntarily and it can be influenced and then discontinued easily by the subject's mind status. So, it needs a very strong will and hard efforts to hold their breath as long as possible (up to the real breaking point). Therefore, the studies started every time from giving them a lecture to teach the significance of this investigation for mountain medicine. It was emphasized that only genuine readings of VBHT are useful for that purpose. Because of above mentioned reason, the main subject was the author himself through these 5 expeditions.

METHODS

The breath holding time was measured by the subject's own wristwatch. The breath holding started at sitting and TLC (total lung capacity = full inspiratory) position. The VBHT tests had been repeated until to get constant value by all of the subjects at home (sea level) before starting the expeditions. The constant values obtained were used as the standard. Then, the percentage of obtained value at altitude to standard was calculated and recorded as 'VBHT%'.

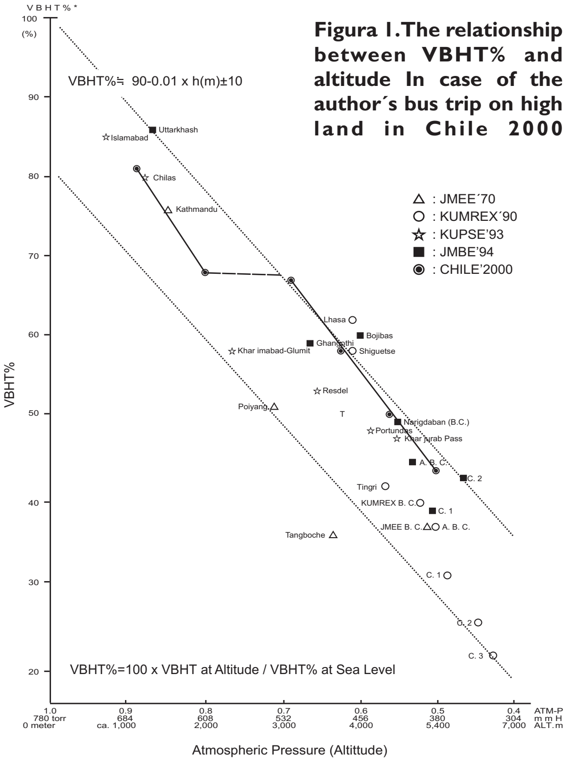
Here: VBHT% = VBHT at altitude / VBHT at home (standard) x100

RESULTS

All dots on graph revealing the relationship between VBHT% and altitude (atmospheric pressure) were scattered within a limited range (Figure 1)[6]. The range limitation was revealed with the following formula: VBHT% = 90 - (0.01 x h) ± 10 (h=altitud / m)

On Figure 1, we can easily see the remarkable tendency of relationship between VBHT% and altitude. On a bus trip through Atacama High-Land in Chile, the author observed VBHT% - altitude graphs were not curved continuous lines but sequential discontinuous straight lines. That is, the line was straight from sea level to altitude ca. 2,000 meter above sea level (masl), where the VBHT% was about 68% and the line discontinued abruptly. Then, VBHT% at ca. 3,000 masl was also about 68% in spite of 1 000 m higher elevation. After that, VBHT% decreased to about 58% at ca. 3,500 m asl and to about 50% at ca. 5,000 masl. The VBHT% - altitude line also revealed straight line on the graph. It means that on one sequential observation of VBHT from sea level to ca. 5,000 masl, two discontinuous straight lines were observed. The first one was between sea level and ca. 2,000 masl and the second one was between ca. 3,000 masl and ca. 5,000 masl. These two lines were discontinued between ca. 2,000 and 3,000 masl, just like shifted rightward from the first (low altitude) line to the second (high altitude) line.

Figura 1. The relationship between VBHT% and altitude In case of the author´s bus trip on high land in Chile 2000

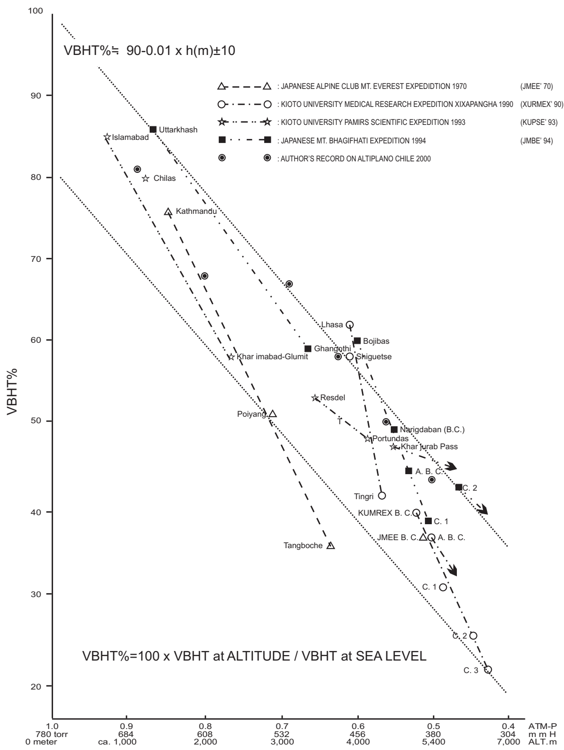


All dots observed in these 5 occasions reveal the relationship beween VBHT% and atmospheric pressure (altitude). They are scattered withing the area revealed by the formula: VBHT%=VBHT%HA/Standard VBHT%

In case of author´s bus trip, the relationship could be revealed by 2 discontinued strait lines. The first line was interlapted suddenly at altitude ca 2,000m and shifted to righward, then, the second line started at ca 3,000m.

The phenomena with same tendency were commonly observed in all other occasions, although occasions or circumstances were quite different. In Figure 2[6] we can see the same sort of discontinuities between Tangboche (3,800 m) and Base Camp (5,400 m) (JMEE70), Tingri (4,342 m) and ABC (5,640 m) (KUMREX'90), Kharimabad-Glumit (2,300 m) and Rasdal (3,200 m) (KUPSE'93), Gangotri (3,150 m) and Bojibas (3,792 m) (MBE'94) respectively.

Figura 2. VBHT% - Altitude relationship observed among Himalayan climbers



In spite of these are average figures of climbers of each expedition, they revealed the same tendency with that of author´s observation on bus trip in Fig. 1. The same tendency was observed commonly among all of the other occasions, though, the measuring occasions or circumstances were quite different respectively. On Fig. 2, we can see the same sort of discontinuities beween Tangboche (3,800m) and Base Camp (5,400m) (JMEE70), Tingri (4,342m) and ABC (5,640m) (KUMREX´90), Kharimabad-Glumid (2,300m) and Rasdal (3,200m) (KUPSE93), then, Gangotri (3,150m) and Bojibas (3,792m) (MBE´94) respectively.

DISCUSSION

The VBHT is shortened according to the increasing of altitude. The relationship between VBHT and altitude can be revealed as the straight line on the graph. However, these lines on the graph were not revealed as simply continuous lines throughout but sequentially discontinuous plural lines which were interrupted in route (Figure 1). The reason of this discontinuity could be explained as follows.

Concerning with VBHT-HA, factors regulating BP are mainly PaO_2, $PaCO_2$, and the subjects' strong will to complete the performance. The importance of the examinie´s will has already been explained. On the view point of life-threatening factor, O_2 lack is more serious than Co_2 accumulation for us. In other words, it is safer for us to be more sensitive to CO_2 accumulation than to be sensitive to O_2 lack. When the respiratory center in brain caught this signal, Go-sign would be sent to the respiratory muscles, and the breath-holding would be interrupted at this point, and ventilation would be resumed. This is the 'BP of VBHT'. Thus, the key to interrupt breath holding might be the CO_2 sensor in brain.

Masuda[7,8] and Honda[9] suggested that, under the condition of hypocapnia + hypoxia, the ventilatory response of the respiratory center to $PaCO_2$ becomes more sensitive. If so, it sounds like, at altitude, the sensitivity threshold to $PaCO_2$ becomes lower; then, breath-holding becomes harder, as a result, breath holding time becomes shorter and shorter with increasing altitude.

On the other side, Yokoi et al.[10] argued that the initiative of BP is not on CO_2 but O_2. As the discussion whether initiative of BP is on CO_2 or O_2 might need more investigation, we leave this discussion to physiologists, and proceed to the next theme, the discontinuity of VBHT%- altitude lines. This phenomenon was observed in all expeditions without exception, not only with acute but also subacute exposure to altitude, as far as the author's experiences.

Such sort of discontinuity was also observed on the other physiological studies in KUMREX'90. The SpO_2 of climbers of KUMREX'90 was routinely recorded during mountaineering. The mountaineering of this time was composed of three strategic stages to obtain acclimatization. The first stage was climbing up and down between BC (Base Camp: 5,020 m) and C3 (Camp 3: 6,970 m), then took a rest for several days at BC. The second stage was of positioning with altitude sojourn, could be explained as "acclimatization". Moreover, similar discontinuities on SPO_2 – altitude lines like VBHT% – altitude lines were also observed between ABC (Advanced Base Camp: 5,640 m) and C1 (5,850 m) through all 3 stages.

The shortness of VBHT and discontinuity (rightward shift) of the VBHT% –altitude lines as well as the discontinuity of SpO_2– altitude lines are thought to have a common root. That is, it could be explained by acid-base balance theory, which may connect with the explanation of high altitude acclimatization. At high altitude, a sequential physiological change may be considered in the human body as follows: high altitude → hypoxia → hyperventilation → hypocapnia → respiratory alkalosis → excretion of alkali reserve from kidney → metabolic correction of respiratory alkalosis, then, high altitude acclimatization may be acquired. However, as this phenomenon was observed during only one hour or so bus trip, it might be not a matter of acclimatization, but a matter of some other physiological quick reactions of the respiratory center against hyperventilation. Possibly on this physiological sequence induced by hyperventilation, acute hypocapnia with hypoxia at high altitude may be a result to higher sensitivity of the respiratory center to CO_2 accumulation. That could explain why VBHT is shortened at altitude so quickly.

The once shortened VBHT could be recovered during high altitude sojourn. This recovery could be brought by metabolic correction of the respiratory alkalosis induced by hyperventilation. The metabolic correction might be done through kidneys intermittently, so, as the result, discontinuity (rightward shift) of VBHT%-altitude line would be followed. To confirm this speculation, the more detailed laboratory observation to check change of arterial and urinary pH during breath-holding should be performed in the future.

CONCLUSIONS

When a man climbs up to some extent of elevation as 2,000 m or more, his breath holding time may be shortened. The reason for this shortening may be due to increasing of sensitivity of brain respiratory center to CO_2 accumulation which may come from hyperventilation alkalosis.

In the relationship between VBHT% and altitude, the mode of this shortening is revealed as straight lines on the graph. However, it is not continuous all the way through, but discontinued abruptly at some altitude, where the sequence of VBHT% - altitude line at low altitude shifts to rightward, then, appeared as the new sequence of line, at high altitude. This sudden rightward shift of the VBHT% - altitude line could be explained by intermittent excretion of alkali reserve through kidneys.

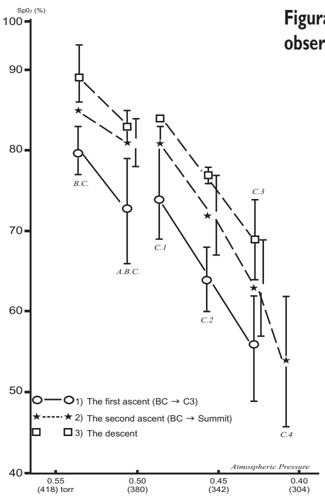


Figura 3. SPO2 - Altitude Relationship observed on KUMREX´90

On KUMREX ´90, the mountaineering stages were composed of 3 stages, 1): ascent fron BC to C3,2): re-ascent fron BC to summit after rest al BC, then 3): descent. Though, the Sp02 had decreased straightly with ascent, the Sp02-altitude line increase stepwise by the stages. This stepwise increase of lines could be explained as "acclimatization". And also, discontinuities (rigtward shift) of these lines of each stage were observed between ABC (Advanced Base Camp) and C1 (Camp 1) through all these 3 stages.

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