

The Effect of Low Altitude on the Performance of Lung Function in Alaghwar Region, Dead Sea, Jordan

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Abstract

Background: Alaghwar region is the lowest area in the world inhabited by permanent population at the level of the Dead Sea area, which is -420 m (-1,378 ft) below sea level. The reduced barometric pressure, density of air and the degree of acclimatization are associated with the low altitude. These factors are essential for the evaluation of a lung function tests at different altitudes.

Objectives: The main aim of this study was to assess the effect of this unique feature of very low altitude (LA) on the performance of lung function.

Methods: A comparative cross sectional design was chosen as the epidemiological design, and the standard cluster sampling technique was used to select the study population. Study was conducted on 1493 subjects (319 exposed to LA, and 1174 living at HA). Data were collected using predesigned questionnaire on personal and socio-demographic characteristics and smoking habit; as well as measurements of forced spirometry [time-volume curve and flow volume curve], and anthropometric measurements, using standard techniques and equipment. The data was analyzed using SPSS software (IBM, version 22), and multiple regression statistical subroutine, was used. Level of significance for the present study was 0.05.

Results: After allowing for the effect of age, height, gender and smoking habit, people residing in low altitude area had significantly higher lung function indices compared to those residing at high altitude areas. Smoking was found to have significant negative effect on the different indices of lung function mainly of obstructive type.

Conclusions: The increased barometric pressure, decreased density of air and the degree of acclimatization have shown an increment in most pulmonary function indices at low altitude. Basically high altitude may play a role in altering ventilatory function. However, additional factors like smoking should be considered.

Keywords: Alaghwar; Dead sea; Pulmonary function; Low altitude; High altitude; Smoking

Introduction

Studies of people of different ethnic groups have shown a considerable variation in the size of the lungs [1]. Some of the variations are environmental and relate to differences in altitude or level of habitual physical activity. However, after allowing for these factors, material differences remain. They are associated with other differences in body dimensions which are difficult to quantify [2]. Differences between Caucasian and other races have been demonstrated by several studies due to ethnic variation [3-7]. The data that will be involved in this study will meet both the ATS [8] and ECCS [9] recommendations for Spiro-metric testing and equipment.

For the evaluation of a respiratory test at low and high altitude, several factors must be taken into account like the diminished density of air, barometric pressure, and the degree of acclimatization which is related to the altitude and to the length of exposure. Several studies have shown a reduction in forced vital capacity (FVC) at HA area mainly related to an increase in pulmonary blood volume and development of interstitial edema.

Among these two different study locations namely Alaghwar (LA) vs. Alkarak (HA) in Jordan given the higher atmospheric pressure below sea level as in Alaghwar region; the air has slightly higher oxygen content (3.3% in summer to 4.8% in winter) as compared to oxygen concentration at sea level [10]. Barometric pressures at the Dead Sea were measured between 1061 and 1065 hPa and clinically likened with health effects at different altitude (below, at and above sea level).

The Dead Sea area characterized by having the highest barometric pressure worldwide; where it is located about 420 m below sea level;

the Dead Sea has the world's highest recorded barometric pressure about (800 mmHg). The oxygen-rich air along the Dead Sea contains 6-8% more molecules per cubic meter compared to sea level as shown by Kramer et al. [11,12]. However, Alkarak region (HA) is situated on a hilltop about 1,000 m (3,300 ft) above sea level and recorded a barometric pressure about 678 mmHg [13,14].

Facts on lung volumes and variations in flow-volume spirometry at high altitude are scarce and do not offer comprehensive assessment of the occurring changes. With increasing altitude FVC and FEV₁ were reduced by up to 25% (74.8% /74.6% of baseline) and MEF₂₅ was reduced to 81.5% of baseline values. As many studies conclude that living in at high altitude leads to increased pulmonary restriction [15].

A study done by Sliman NA revealed that arithmetic mean test presented significant difference for FVC only among boys; while the variance test showed significance in the FVC, FEV₁, and FMF (25-75%), and the values of the LA area participants were lower than HA area. However, when the data were analyzed for girls there were no statistically significant differences between the two groups (LA vs. HA), even though there was a minor apparent difference in all values, with

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the LA area girls having higher figures (FVC, FMF25-75%), and FEV₁ [16].

In a study done by Ziaee et al. [17] showed that a significant decrease in forced vital capacity (FVC) while ascending to different levels (2850, 4150 m) compared to baseline level (1150 m), and FVC significantly decreased with increasing altitude from baseline level. However, FVC was significantly less than baseline level at the sea level.

The reduced barometric pressure, the density of air and the degree of acclimatization are correlated inversely with the high altitude, in addition to the length of exposure; these factors are essential for the evaluation of a lung function tests at high altitude. A reduction in forced vital capacity (FVC) at high altitude was mentioned in several studies which are related chiefly to an increase in pulmonary blood volume and development of interstitial edema. In same study; these detected changes (forced expiration curves) are temporary and return to baseline value after returning to sea level [18].

Elevated barometric pressure at low altitude is a simple means of increasing the quantity of inspired oxygen. Increasing barometric pressure at low altitude (or pressurized wards) can help as a simple way to increase arterial oxygenation in hypoxemic patients and to improve exercise performance as stated by Kramer et al. [12] in which these conditions may improve pulmonary rehabilitation of hypoxemic patients with COPD, in the same study Maximum oxygen consumption (VO₂ max) rose from 901 ± 257 mL/min (baseline: Jerusalem 800 m above sea level) to 1,099 ± 255 and 1,063 ± 250 mL/min (p=0.01) (low altitude: Dead Sea 402 m below sea level).

Aim of the Work

The main objective of this study is to investigate the effect of low and high altitude on values of lung function tests.

Subjects and Methods

A cross sectional design was chosen as the epidemiological design. This study was conducted at Alkarak governorate. The index sample comprised 1500 subjects, of Jordanian ethnic origin, residing in Alkarak governorate (Alkarak region: HA, and Alaghwar region: LA). Their age ranges from 13-88 years.

In order to meet the pre-established criteria for reference individuals, selected subjects had to be healthy and without any evidence of cardio-pulmonary or systemic diseases. Also, pregnant and menstruating women were excluded; in addition to current or previous history of high risk occupations, chronic cough, wheezes, rhinitis, respiratory or cardiovascular diseases, thoraco-abdominal wall deformities and recent upper or lower respiratory tract infections up to 3 weeks [9].

Sampling

The standard cluster sampling technique was used to select the study population. This technique allows relative small numbers of the target population to be sampled while providing data which are statistically valid [19]. Within each cluster a stratified random sampling technique with random allocation was adopted to select proportional numbers from different age groups.

Sources and methods of data collection: Data were collected on the selected subjects by:

Questionnaires: MRC questionnaire on respiratory symptoms and smoking habits.

Anthropometric measurements: Body measurements were made,

using standard equipment and procedures [20-23]. Equipment: Standard weighing machines, and Harpenden stadiometer. Measurements: Height (cm), Weight of the body (kg).

Measurement of lung function: Measurement of lung function was conducted according to the ATS and ECCS recommendations for maneuver of Spiro-metric testing and equipment [8,9].

Equipment:

1. Portable spirometer: A completely self-contained automated spirometer combines a micro-computer, and an integral thermal printer.
2. Disposable mouth pieces.

Lung function indices: The Following lung function indices were obtained: Forced vital capacity (FVC), forced expiratory volume in one second (FEV₁), and it's percent from FVC (FEV₁%), peak expiratory flow rate (PEFR), forced mid-expiratory flow rate between 25% and 75% of FVC (FMF_{25-75%}), maximum voluntary ventilation (MVV), and Maximum flow rate at different forced vital capacities (FEF₂₅, FEF₅₀, and FEF₇₅) were determined with a portable spirometer (Autospiro AZ-505).

Maneuver: Each subject was instructed on how to perform the test correctly before performing it. All subjects performed the test in a standing position. Any tight clothes were released, and the subject stood in a comfortable position. Each subject had to breath normally for three times, then was asked to breath in maximally till his lung is really full of air; then the subject was asked to blow air out as fast as possible, and in an explosive way till he empties his chest. Then the subject was asked to breath in fully again. Each subject performed the test maneuver, at least three times.

Complete physical examination: All subjects included in the study were subjected to complete physical examination to exclude any subject suffering from chest wall deformity, any lung or heart diseases. Normal subjects included for the estimation of lung function were individuals with the following criteria:

1. No symptoms of lung or heart diseases or any other systemic disease.
2. Asymptomatic smokers.
3. Normal physical examination of the heart and lung, and chest wall.

Institutional review board approval was obtained from Mutah University Scientific Research Committee (NO-3/2017) and Mutah University Ethics Committee (NO- 20177) for this study, and informed consent was obtained from all study participants.

Statistical design

Data were checked for transmission errors, and to detect outliers. Data were analyzed using the SPSS statistical package where descriptive as well as analytical statistical methods were used. Multiple Regression analysis methods were used to determine the explanatory variables affecting lung function indices. The level of significance for the present study was 0.05.

Results

The total number of studied subjects was 1466; 689 males (47%), and 777 females (53%). Mean age of the studied subject was 31.1 years (standard deviation=15.76). Of the studied subjects, 319 (21.8%) were

from Low altitude area, while 1147 (78.2%) were from high altitude area.

Table 1 shows prediction equations for the slow vital capacity (VC), tidal volume (T_v), and inspiratory reserve volume (IRV). The only significant determinant of slow VC was smoking, where mean value of VC was significantly lower in the smokers (by 3.180 L), compared to the non-smokers. Although the overall models were significant for T_v ($F=3.556$, $p=0.001$), and IRV ($F=5.842$, $p=0.000$), the only significant

determinant was gender, where T_v increased in males compared to females, while females had larger IRV compared to males ($\beta = -0.41$, and 0.56 respectively).

Table 2 shows prediction equations for the expiratory reserve volume (ERV), inspiratory capacity (IC) and forced vital capacity (FVC). ERV was significantly increased with gender (females) and decreased in smokers ($p=0.01$). FVC was higher in males ($\beta = -0.55$), and increased with increased weight and height ($\beta = 0.01$, and 0.03

Variables	VC			T_v			IRV		
	β	t-test	p-value	β	t-test	p-value	β	t-test	p-value
(Constant)	19.566	1.181	0.238	2.16	2.58	0.01	-1.262	-1.24	0.216
Sex	1.38	0.78	0.44	-0.41	-4.58	<0.001	0.56	5.1	0
Age	-0.79	-1.08	0.28	0.02	0.51	0.61	-0.01	-0.12	0.907
Weight	0.08	1.24	0.22	0	-0.17	0.87	0.01	1.36	0.173
Height	-0.06	-0.63	0.53	0	-0.44	0.66	0.01	1.11	0.266
Smoking	-3.18	-2.17	0.03	-0.07	-0.91	0.36	0.05	0.61	0.54
Altitude	0.96	0.53	0.6	0.42	0.59	0.56	-0.76	-0.88	0.378

VC: Slow Vital Capacity; T_v : Tidal Volume; IRV: Inspiratory Reserve Volume

Table 1: Correlation regression relationship between SVC, T_v , and IRV with residence in low altitude Dead Sea area, and other variables among Jordanian population at Alkarak region.

Variables	ERV			IC			FVC		
	β	t-test	p-value	β	t-test	p-value	β	t-test	p-value
(Constant)	0	-0.01	0.99	0.87	1.64	0.1	-3.48	-9.62	<0.001
Sex	0.15	2.83	0.01	0.14	2.48	0.01	-0.55	-14.45	<0.001
Age	0.04	1.79	0.08	0.02	0.76	0.45	0.16	9.98	<0.001
Weight	0	1.02	0.31	0.01	2.26	0.02	0.01	5.93	<0.001
Height	0.01	1.56	0.12	0.01	1.48	0.14	0.03	14.2	<0.001
Smoking	-0.11	-2.49	0.01	-0.01	-0.19	0.85	-0.08	-2.44	0.015
Altitude	0.06	0.14	0.89	-0.35	-0.78	0.44	0.46	11.37	<0.001

ERV: Expiratory Reserve Volume; IC: Inspiratory Capacity; FVC: Forced Vital Capacity

Table 2: Correlation regression relationship between ERV, IC, and FVC with residence in low altitude Dead Sea area, and other variables among Jordanian population at Alkarak region.

Variables	FEV ₁			FEV ₁ %			PEFR		
	β	t-test	p-value	β	t-test	p-value	β	t-test	p-value
(Constant)	-3.23	-9.55	<0.001	-211.79	-1.08	0.28	-2.25	-2.31	0.021
Sex	-0.54	-15.08	<0.001	-22.9	-1.11	0.27	-1.96	-19.03	<0.001
Age	0.16	10.62	<0.001	1.01	0.12	0.91	0.26	6.01	<0.001
Weight	0.01	4.34	<0.001	-0.35	-0.46	0.65	0.01	3.32	<0.001
Height	0.03	14.65	<0.001	1.99	1.67	0.1	0.05	8.07	<0.001
Smoking	-0.1	-3.17	<0.001	12.17	0.7	0.48	-0.07	-0.8	0.424
Altitude	0.48	12.63	<0.001	-13.1	-0.6	0.55	0.58	5.3	<0.001

FEV₁: Forced Expiratory Volume in One Second; FEV₁%: FEV1 Percent Vital Capacity; PEFR: Peak Expiratory Flow Rate.

Table 3: Correlation regression relationship between FEV₁, FEV₁%, and PEFR with residence in low altitude Dead Sea area, and other variables among Jordanian population at Alkarak region.

Variables	FEF _{25%}			FEF _{50%}			FEF _{75%}		
	β	t-test	p-value	β	t-test	p-value	β	t-test	p-value
(Constant)	-1	-2.09	0.04	-2.43	-3.16	<0.001	-2.23	-2.27	0.023
Sex	-0.35	-6.88	<0.001	-0.93	-11.41	<0.001	-1.77	-17.06	<0.001
Age	0.11	5.29	<0.001	0.22	6.41	<0.001	0.27	6.13	<0.001
Weight	0	0.39	0.7	0.01	2.18	0.03	0.01	2.53	0.011
Height	0.02	6.73	<0.001	0.04	7.94	<0.001	0.05	7.47	<0.001
Smoking	-0.09	-2.03	0.04	-0.14	-1.99	0.05	-0.06	-0.63	0.527
Altitude	0.38	7.1	<0.001	0.52	6.1	<0.001	0.49	4.49	<0.001

FEF_{25%}, FEF_{50%}, and FEF_{75%}: Maximum flow rate at different forced vital capacities.

Table 4: Correlation regression relationship between FEF_{25%}, FEF_{50%}, and FEF_{75%} with residence in low altitude Dead Sea area, and other variables among Jordanian population at Alkarak region.

Variables	FMF _{25-75%}			MVV		
	β	t-test	p-value	β	t-test	p-value
(Constant)	-2.31	-3.33	<0.001	172.33	10.25	<0.001
Sex	-0.82	-11.11	<0.001	-1.02	-0.57	0.568
Age	0.19	6.26	<0.001	-2.16	-2.92	0.004
Weight	0.01	1.69	0.09	0.09	1.32	0.186
Height	0.04	8.52	<0.001	-0.3	-2.94	0.003
Smoking	-0.1	-1.64	0.1	1.26	0.85	0.394
Altitude	0.52	6.73	<0.001	33.26	17.99	<0.001

FMF_{25-75%}: Forced mid-expiratory flow rate between 25% and 75% of FVC; MVV: Maximum Voluntary Ventilation

Table 5: Correlation regression relationship between FMF_{25-75%} and MVV with residence in low altitude Dead Sea area, and other variables among Jordanian population at Alkarak region.

respectively). Smoking decrease the FVC of the lung, while residing in low altitude, increases the FVC ($\beta = -0.08$, and 0.46 respectively). P values were <0.05 for all the independent variables.

Table 3 shows prediction equations for the forced expiratory volume in one second (FEV₁), FEV₁ percent vital capacity (FEV₁%), and peak expiratory flow rate (PEFR). FEV₁ and PEFR were higher in males ($\beta = -0.540$, and -1.96 respectively), and increased with increased weight and height ($p < 0.05$). The relationship of FEV₁ and PEFR with age is curvilinear, where it increases with age in the young ages and then flattened and decline with advanced ages. Smoking decreased the FEV₁ ($p < 0.05$), while residing in low altitude, increases FEV₁ and PEFR ($\beta = 0.48$, and 0.58 respectively).

Table 4 shows prediction equations for the flow volume curves indices FEF₂₅, FEF₅₀ and FEF₇₅. All these lung function indices revealed relationships similar to FEV₁, and those who lived in low altitude regions had higher values ($p < 0.05$).

Table 5 shows prediction equations for the forced mid expiratory flow rate (FMF_{25-75%}), and maximum voluntary ventilation (MVV). MVV and FME_{25-57%} were higher in males. Its relationship with age is curvilinear, where it increases with age in the young ages and then flattened and decline with advanced ages. Residing in low altitude, increase MVV and FMF_{25-75%} ($p < 0.001$).

Discussion

Smoking reduced the capacity of the lungs to function; especially the vital capacity (VC) of the lungs, and this reduction in vital capacity ($\beta = -3.18$, $p = 0.03$) has many adverse health effects. Previous studies have found that smoking reduces the VC of the lungs [24]. Smoking has an extensive effect on the respiratory function and it has been really implicated in the etiology of respiratory disease like chronic bronchitis, emphysema and bronchial carcinoma. A study results showed significantly lower vital capacities among smokers compared to nonsmokers.

The study proposed that the decrease in vital capacity occurred even in young people who have only been smoking for a short time [25]. In the present study it was found that, the only significant determinant of slow VC was smoking, where mean value of VC was significantly lower in the smokers (by 3.180 L), which is more than another related study which shows that VC decreased by 1.5 L when compared to normal people [26]. However, the present study results revealed that smoking decrease the FVC of the lung by 0.078 L, while residing in low altitude, increases the FVC by 0.46 L. Also, smoking was significantly associated with reduction in ERV, FEV₁/FVC, FEF_{25%} and FEF_{50%} ($p < 0.05$); which is consistent with another study findings on the effect of the paternal smoking on the pulmonary functions of adolescent males [27].

Regarding low altitude; FVC, FEV₁ and PEFR were significantly higher than high altitude measurements ($\beta = 0.46$, 0.48 and 0.58 respectively), where $p < 0.001$. These findings were highly comparable to previous study done by Fischer et al. [26]. However, a study done by Sliman revealed that only among boys; the values of the LA area participants were lower than HA area in terms of FVC, FEV₁, and FMF_{25-75%} [16,17].

A reduction in forced expiration curves at high altitude was noticed and mentioned in several studies. The reduced barometric pressure, the density of air and the degree of acclimatization, in addition to the length of exposure may explain these variations and the significant inverse correlation with HA values [18].

Other factors such as environmental factors and altitude (high vs. low) may have an effect on pulmonary function test (PFT) results but the degree of effect on PFT is not clearly understood at this time [28]. Results of the present study showed that all values of FEF_{25%}, FEF_{50%}, FEF_{75%}, FEF_{25-75%} and MVV among LA participants were significantly higher than HA participants ($p < 0.001$), these significant variations support the hypothesis that at HA the respiratory function can be affected by the presence of an increased blood volume in the pulmonary circulation or the development of interstitial edema [18]. So, living in an environment of hypobaric hypoxia and exposure to low oxygen tension leads to a series of important physiologic responses that allow individuals to tolerate these hypoxic conditions [29].

All values of FEF_{25%}, FEF_{50%}, FEF_{75%}, FEF_{25-75%} and MVV among HA participants were significantly lower than LA participants which generally attributed to the physiologic responses that occur at high altitude and as a result the inhabitants of such high altitude have to acclimatize and tolerate these hypobaric hypoxic conditions [30].

Conclusion

Evaluation of the forced pulmonary function test results at high altitudes with a portable spirometer is a useful method reflecting the right field situation, also may provide clinically related indicator (forthcoming pulmonary edema). These data suggest that, although altitude may play a role in modifying ventilatory function, other factors should be considered. Also, the occupants and their children of the Dead Sea area (LA) are actively involved in agriculture while the children of HA have few exercise facilities available, which may be considered to explain these value differences. Our results yielded that there was a significant difference in the vital capacities of smoking and nonsmoking participants. This assessment may initiate further studies on the probable health benefits for patients with underlying chronic respiratory diseases like COPD, emphysema, pulmonary hypertension, or obstructive sleep apnea to be treated and managed in such a unique lowest area in the world.

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