THE EFFECT OF BODY POSITION ON LUNG FUNCTION
IN OLDER HEALTHY INDIVIDUALS

by
FIONA MANNING

BSc (PT), The University of British Columbia, 1986

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENT FOR THE DEGREE OF
MASTER OF SCIENCE
in
THE FACULTY OF GRADUATE STUDIES
[INTERDISCIPLINARY STUDIES]

Departments of Medicine, Physical Education and Physiology

We accept this thesis as conforming
to the required standard

------------------

THE UNIVERSITY OF BRITISH COLUMBIA
September, 1992
© Fiona Manning, 1992
ABSTRACT

The purpose of this study was to investigate the interrelationships between postural change and indices of lung function in healthy older individuals. Nineteen nonsmoking subjects (mean age 62.8 ± 6.8 years) with no known history of pulmonary disease were tested over two sessions; on one session the test positions were sitting and left side lying and on the other the positions were sitting and right side lying. In each of the three positions, tests of forced expiration [forced vital capacity (FVC), forced expiratory volume in one second (FEV1), and forced expiratory flow during 25 to 75% of the vital capacity (FEF25-75%)], a single-breath test of pulmonary diffusing capacity for carbon monoxide (DLCO), and the single-breath nitrogen test [slope of Phase III (DN2%/L)] were conducted using the SensorMedics 2200 Pulmonary Function Laboratory (SensorMedics, Anaheim, CA). Standards and procedures of the American Thoracic Society and the National Heart and Lung Institute were followed for all tests.

On the basis of 95th percent confidence intervals, the individual subject results were generally normal; in the sitting position, results for both spirometry and DLCO were above the lower limit of normal (with the exception of three subjects who fell below this limit for FEF25-75%) and results for DN2%/L were below the upper limit of normal. Repeated measures within subjects were reproducible and were comparable to those in the literature. Specifically, the coefficients of variation for all dependent variables, with the exception of DN2%/L, were less than 10%. With reference to the sitting position, the effects of side lying on the dependent variables were: (i) a decrease in FVC, FEV1, and FEF25-75% in both left and right side lying; (ii) a decrease in FEV1/FVC from sitting to left side lying only; (iii) an increase in DN2%/L from sitting to left side lying only; and (iv) no change in DLCO or DLCO/VA (diffusing capacity corrected for alveolar volume) in left or right side lying. The degree to which age contributes to these position-related phenomena is unknown; however, certain aspects of aging, for example, a decrease in
elastic recoil of the lung and an increase in the weight and volume of the heart, are likely
to have a significant role. A further contribution to these phenomena is the effect of
recumbency, for example, external compression of the chest wall and impingement of the
abdominal contents on the diaphragm, on respiratory mechanics. With regard to the
interrelationships between dependent variables, there was a positive correlation for FVC
versus DLCO, reflecting the volume-dependence of DLCO. The results of this study
support the differential effects of body positioning on aspects of lung function which are
reflective of oxygen transport. Further investigation of these effects in younger and older
individuals and of their underlying mechanisms are required. With a greater
understanding of the complexities of position-related phenomena in a variety of age
groups and in the presence or absence of cardiopulmonary disease, the effects of body
positioning can be exploited therapeutically and potential negative effects can be
minimized.
TABLE OF CONTENTS

Abstract ii
List of Tables vii
List of Figures viii

Introduction

General Purpose 1
Background 1

1. Body Positioning 2
2. Positioning and Spirometric Variables 2
3. Positioning and the Distribution of Ventilation 6
   i. Slope of the alveolar plateau as an index of the homogeneity of ventilation 7
   ii. Effect of body position on the slope of the alveolar plateau 9
   iii. Other techniques used to study the effect of body position on the distribution of ventilation 11

4. Position and Pulmonary Diffusing Capacity 14

5. Studies reporting various relationships between spirometric measures, measures of the distribution of ventilation, and pulmonary diffusing capacity 18
   i. Epidemiological studies 18
   ii. Studies based on models of the lung 21
   iii. Studies examining the effects of body position 21

Rationale for this Study 25
Specific Objectives of this Study 28

Methods 30
Research Design 30
Subjects 30
Procedures

General Procedures

Specific Procedures

1. Independent Variable: Body Position

2. Dependent Variables

i. Measurement by the SensorMedics 2200 System

ii. Performance of spirometric tests

iii. Performance of the SBN2 test

iv. Performance of the DLCO test

Data Analysis

Results

Subject Characteristics

Characteristics of Group Performance

Interrelationships Between the Dependent Variables

Reproducibility Within and Between Test Sessions

Discussion

Comparison of Lung Function Indices Obtained With the SensorMedics System and Norms

Reproducibility

The Effect of a Position Change From Sitting to Side Lying on Each Dependent Variable

1. Spirometric Variables

2. DN2%/L

3. Diffusing Capacity Variables

Comparison of the Effect of Side Lying on Each Dependent Variable

Interrelationships Between the Dependent Variables
LIST OF TABLES

I. A. Descriptive Statistics for the Dependent Variables
   in Test Session A for Sitting and Left Side Lying

B. Descriptive Statistics for the Dependent Variables
   in Test Session B for Sitting and Right Side Lying

II. Interrelationship Between Variables in Each Test Position: Pearson Product-Moment Correlation Coefficients

III. Reproducibility of the Dependent Variables: Coefficients of Variation [SD/Mean %]
     Within Subjects [n=19] for the Two Sitting Positions

IV. Reproducibility of Variables Within and Between the Two Sessions for Sitting:
    Paired t-Tests and Pearson Product-Moment Correlation Coefficients
LIST OF FIGURES

1. General Experimental Procedure

2. SensorMedics 2200 Tracing of the Single-breath Nitrogen Test

3. SensorMedics 2200 Tracing of the Test of Diffusing Capacity for Carbon Monoxide
INTRODUCTION

GENERAL PURPOSE

The purpose of this study was to investigate the interrelationships between body position and indices of lung function in healthy older individuals. A battery of tests was conducted using a computerized system (the SensorMedics 2200 Pulmonary Function Laboratory) in each of three positions, namely sitting, left side lying and right side lying. The tests included spirometry (tests of forced expiratory volume and forced expiratory flow), the slope of Phase III of the single-breath nitrogen test (a noninvasive measure of ventilation homogeneity), and pulmonary diffusing capacity for carbon monoxide (reflective of gas transfer "across the lung"). Although it is well-known that these tests are position-dependent, the majority of previous position-related studies have focused on young subjects and on changes between upright positions and supine rather than lateral positions. Furthermore, few investigators have examined the various aspects of gas exchange with these tests in combination.

BACKGROUND

The background literature relevant to the present study will be discussed first with respect to body positioning in general, and second with respect to the use of specific tests (spirometric tests, tests assessing the distribution of ventilation, and tests of pulmonary diffusing capacity) which have been examined in studies of the effect of body position on lung function. Finally, the few studies which have used a similar combination of tests (in a single test position) as those used in the present study will be discussed.
1. Body Positioning

The significance of gravity as a determinant of cardiopulmonary function has been documented throughout this century. With the remarkable advance of biomedical technology over the past several decades, there has been increasing recognition of the complex role that gravity plays in determining lung function. This complexity is reflected by the diversity of studies relating gravity and positional change to both pulmonary physiology and pathophysiology. For example, investigators have studied the effect of a change in body position on lung compliance (Navajas et al, 1988), airway resistance (Behrakis et al, 1983), airway impedance (Navajas et al, 1988), work of breathing (Liu et al, 1991), alterations in respiratory muscle function (Xie et al, 1991), dyspnea (Barach et al, 1974; O'Neill and McCarthy, 1983), ventilation to perfusion ratios (Clauss et al, 1968), fluid volume redistribution (Tenney et al, 1959), maximal oxygen uptake (Ray et al, 1991), and partial pressure of oxygen in arterial blood (Russell et al, 1981; Marti and Ulmer, 1982). In addition, many studies have focused on the position-induced changes in either spirometry, the slope of Phase III (DN2%/L) of the single-breath nitrogen test (SBN2), or pulmonary diffusing capacity for carbon monoxide (DLCO), the dependent variables of the present study. Few investigators have used the combination of these tests in a single study to compare and contrast the effect of body position on aspects of lung function that affect gas exchange.

2. Positioning and Spirometric Variables

Documentation of position-related changes in spirometric variables dates back to 1846 when Hutchinson reported a decrease in vital capacity (VC) in supine relative to an
erect posture. This effect has been confirmed by other investigators. Craig et al (1960) reported a decrease in VC from sitting to supine in a group of 16 young men. Hunt and Green (1985) determined the upper 95% confidence limit for a change in forced vital capacity (FVC) from standing to supine as being 18.9% for a group of 50 subjects with a mean age of 44.7 years. Furthermore, Svanberg (1957) examined right and left lungs separately and found that the VC of each side was greater in sitting than supine. In the same study, it was shown that the VC of the right lung was somewhat larger than that of the left lung (the latter accounting for 47% of the total VC) regardless of position.

Not all studies have reported the same directional change in VC when position is changed from sitting to supine. In a later study by Craig et al (1971) of 10 subjects, 28 to 53 years of age, there was no significant decrease in VC from sitting to supine. A similar result was reported by Behrakis et al (1983) in a study of 10 subjects with a mean age of 31.4 years.

Other investigators have approached the topic by studying the effect of factors such as age and smoking history. Parot et al (1970) reported that a stand-supine VC decrease (estimated at 6% for a group of 25-35 year-olds) is observed only in individuals under the age of 60 years; for subjects 60 to 70 years of age there was a nonsignificant decrease in VC; and for subjects older than 70 years the VC did not change between standing and supine. They explained their results in terms of positional changes in expiratory and inspiratory reserve volumes (ERV and IRV, respectively), suggesting that in older individuals a decrease in ERV in the change from standing to sitting is compensated for by an increase in IRV. Also, Michels et al (1991) reported an age-related
reduction in the decrease of VC in the recumbent versus upright postures. This trend was reported to be more marked in men than women and in smokers than non-smokers.

Although most studies of change in VC compare an erect posture with supine, some include an examination of lateral postures. Results obtained for lateral positions are conflicting. For example, Svanberg (1957) reported that VC increased in lateral versus supine positions whereas Blair and Hickman (1955) reported the opposite.

The literature regarding the change in various lung volumes between different body positions has been much more extensive than that regarding the change in VC. Of the major pulmonary subdivisions, the functional residual capacity (FRC) is known to show the greatest variation with postural change. Agostini and Hyatt (1986) explain the well-known decrease in FRC that accompanies a change from sitting to supine by an analysis of volume-pressure curves for the respiratory system. The shape of this curve is determined by elastic, surface, and gravitational forces acting on the lungs and the chest wall. A significant gravitationally-induced factor to consider is the hydrostatic pressure of the abdominal contents. For example, the increase in abdominal pressure in horizontal positions causes cephalad displacement of the diaphragm, thereby contributing to the decrease in FRC. Another contributing factor to the decrease in FRC is the increase in both intrapulmonary and extrapulmonary blood volume that accompanies a shift to a recumbent posture. The increase in thoracic blood volume (and possibly an increase in abdominal blood volume, contributing to the cephalad displacement of the diaphragm) acts as a mechanical constraint on the intrathoracic gas volume. This is reflected by decreases in both ERV and residual volume (RV) (which together comprise FRC), although the reduction in FRC is primarily due to a reduction in ERV (Blair and
Hickman, 1955; Agostini and Hyatt, 1986). Behrakis et al (1983) calculated a 50% reduction in ERV for the change from sitting to supine and 22% for the change from sitting to a lateral position.

The postural change in FRC has been studied in some detail with respect to airway closure, a phenomenon attributed to collapse and closure of small airways in dependent lung zones. If the volume at which airway closure occurs is within the range of volumes encompassed by tidal breathing, ventilation to perfusion ratios in dependent regions may be reduced, resulting in impairment of gas exchange (Leblanc et al, 1970; Craig et al, 1971b). Therefore, the relationship between FRC and closing volume, the volume at which the onset of airway closure occurs, is critical. Craig et al (1971a) identified the ages at which closing volume exceeds FRC as being 49 years for sitting and 36 years for supine, reflecting the large decrease in FRC from sitting to supine. These figures reflect the importance of body position as a factor affecting the onset of airway closure and thus gas exchange.

The study of static lung volumes in relation to positional change is somewhat limited in its extension to lateral postures (the most commonly-reported position change again being sitting to supine), however, there seems to be general agreement that FRC increases from supine to a lateral position (Svanberg, 1957; Hazlett and Watson, 1971, Agostini and Hyatt, 1986). The increase is attributed to changes in position of the diaphragm, mediastinum and abdominal contents, resulting in alteration of the distribution of pressures between the rib cage, lung, diaphragm and abdomen. Shifts in blood flow may also contribute to the increase in FRC, although the blood volume change between these positions is recognized as being small (Hazlett and Watson, 1971).
There are very few studies which look at the effects of changes in body position on the flow-volume aspects of spirometry. Castile et al (1979) compared maximum expiratory flow-volume (MEFV) curves obtained in standing, supine, and lateral positions by (1) plotting slope ratios (defined as the slope of a given flow-volume point divided by the slope of a line drawn from that point to RV) vs. volume, a method thought to magnify the details of the flow-volume configuration, and (2) analyzing the curves in increments of 0.1 L/s. Although the resulting patterns were described as being unpredictable and difficult to describe objectively, the investigators were able to conclude that MEFV curve configurations undergo significant changes with posture in most healthy adults. Pyszczynski et al (1985) studied the effect of gravitational stress on MEFV curves by exposing seated subjects to +1Gz, +2Gz, and +3Gz with a centrifuge. The results suggested that changes in gravitational stress were not associated with a change in the MEFV curve and were explained in terms of the uniformity of lung emptying. The investigators proposed that the stiffness of the lung at total lung capacity (TLC) offsets gravitational stress on the lungs. A major effect of this would be an enhancement of the uniformity of regional mechanical properties, in turn resulting in a uniformity of regional emptying through at least 50-60% of the FVC maneuver.

3. Positioning and the Distribution of Ventilation

The effect of body position on the distribution of ventilation has been a focus of study for more than 150 years. However, many questions regarding this topic remain unanswered. Furthermore, it is not only position change (i.e. difference between positions) which continues to be a source of questions; much has yet to be learned about the regional distribution of ventilation within a single position. This complex topic has
been explored in a variety of ways, many of which have incorporated a change of body position as an essential methodological component.

i. Slope of the alveolar plateau as an index of the homogeneity of ventilation

The single-breath nitrogen test (SBN2) is one of the techniques used to assess the homogeneity of gas distribution in the lungs. In the characteristic 4-phase SBN2 plot that is produced in this test, Phase III is representative of the gas expired from the alveolar portion of the lung. The magnitude of the slope of the Phase III (the "alveolar plateau"), expressed as the per cent change in concentration of expired nitrogen per unit of lung volume expired (DN2%/L), is taken as a measure of the homogeneity of alveolar ventilation. The steeper the slope, and thus the greater the value of DN2%/L, the greater the degree of alveolar gas inhomogeneity. Since its inception in 1949 by Fowler, the SBN2, in various modified forms, has been a commonly-used research tool for both clinical and epidemiological purposes.

In many studies that include the slope of the alveolar plateau as a dependent variable, including those that look at the effect of body position on DN2%/L, the primary research interest is focused on attempting to determine the slope-producing mechanisms. Controversies concerning the nature of these mechanisms have flourished over several decades and theories continue to evolve. In 1956, Otis et al put forth a theory of mechanical dependence of the distribution of ventilation which was based on differences in pressure-volume relations between parallel lung units. They suggested that differences in airway compliance and resistance (i.e. differences in time constants between different lung regions) are the basis of a pattern of sequential filling and emptying, which in turn
produces regional inhomogeneity and a sloping alveolar plateau. Through the 1960's and 1970's the emptying sequences of lung units with different gas concentrations was a commonly quoted mechanism to account for DN2%/L. Various investigators proposed that the existence of gas concentration differences is largely due to either interregional inhomogeneity, which is mainly influenced by convection and mechanical factors, or intraregional inhomogeneity, which is mainly influenced by diffusion (Engel, 1986). It is now generally recognized that non-gravity dependent intraregional inhomogeneity is the major determinant of the alveolar slope of the SBN2 (Engel et al, 1974; Engel, 1985). Significant evidence leading to this conclusion came from a study by Michels and West (1978) who showed that DN2%/L did not change under conditions of weightlessness simulated by parabolic flight paths, which presumably abolished the topographical inhomogeneity of ventilation. Further evidence was contributed by Anthonisen et al (1970) and Marcq and Minette (1980) and is discussed under section ii.

More recently, Paiva et al (1981, 1982) proposed a mechanism for the slope of the alveolar plateau which is not based on sequential changes in bulk flow. From calculations based on a "two trumpet model" (consisting of two trumpet-shaped lung units with variable lengths and volumes and a common "airway" to a branch point) they simulated inhomogeneity in alveolar gas concentrations by introducing airway asymmetry at the alveolar duct level. In this model, the more proximal the branch point of the asymmetric pathways, the more significant the contribution to the slope of the alveolar plateau. They explained their results as being a consequence of a complex interaction between convection and diffusion at branch points which subtend units (trumpets) of unequal volume. The significance of convective and diffusive gas transport
in the lung continues to be under study (Parks et al., 1985; Schrikker et al., 1989; Schulz et al., 1992).

ii. Effect of body position on the slope of the alveolar plateau

Many studies examining the effect of body position on DN2%/L have been designed to investigate possible mechanisms responsible for the alveolar slope. Clarke et al. (1969) used a modified technique, which involved inhaling a bolus of nitrogen from RV post nitrogen washout with a mixture of 80% argon and 20% oxygen, to study three healthy subjects 31 to 34 years of age. The test procedure was carried out using a combination of various postures (upright, supine, prone and inverted) for inspiration and expiration. A major finding was that the alveolar slope for expired nitrogen was markedly affected by body position, the pattern being a positive slope with lower lobes dependent and no slope or a negative slope with upper lobes dependent. These results were attributed to (1) the observed pattern of the nitrogen bolus entering the uppermost part of the lung first in all positions, and (2) the dependency of sequential lung emptying on the gravitational force (for example the dependent lung zones emptied first in all positions).

Another position-related study looking at the gravity-dependence of sequential emptying was performed by Anthonisen et al. in 1970. In order to determine the effect, if any, of a reversal of the gravitational field on the alveolar plateau, they changed a subject's test position from right to left lateral (four subjects) and from inverted to erect (two subjects) between inspiration and expiration. Alveolar plateaus for both nitrogen and radioactive xenon (Xe) were obtained and compared for (1) lateral and lateral with
180 degree pivot and (2) erect and inverted with 180 degree pivot to erect. It was found that at flow rates less than 1 L/sec, the Xe tracings were mirror images for each of these pairs of test conditions. For example, in the inverted position the Xe was inspired and distributed to the non-dependent base; in expiration in the erect position Xe was expired first from the base, now dependent. As a result, the Xe concentration at the mouth decreased over the course of expiration as the apex increased its contribution to the expirate (resulting in a negative alveolar slope versus the positive slope obtained from a test with both inspiration and expiration in the erect position). These results, reflecting the interregional inhomogeneity of a Xe bolus, were in contrast to the results of the SBN2 test. In comparison to the alveolar slope for Xe, DN2%/L changed little when the SBN2 was performed with the invert-upright technique. This was interpreted as further evidence for the significant contribution of intraregional alveolar gas inhomogeneity to the slope of the alveolar plateau for nitrogen.

Marcq and Minette (1980) performed a similar study with nine healthy subjects with a mean age of 43.5 years (including a smoking group which consisted of three ex-smokers and two smokers, mean 6.7 pack years). They studied the effect of gravity reversal on the slope of the alveolar plateau by comparing results of the SBN2 test (and a helium bolus washout technique) performed with (1) both inspiration and expiration in an erect posture and (2) inspiration in the inverted and expiration in the erect posture. For both nonsmoking and smoking groups, DN2%/L did not change significantly between these two test conditions. The investigators concluded that their results, which suggested that DN2%/L is largely independent of gravity, provided strong evidence for the proposal that the alveolar slope for nitrogen is primarily determined by intraregional inhomogeneity.
iii. Other techniques used to study the effect of body position on the distribution of ventilation

Much that is known about the distribution of ventilation in various body positions has been extracted from studies which have used techniques other than the SBN2. A variety of positions have been studied, including the lateral position to a significant degree (in contrast to the study of other aspects of pulmonary function, for which the lateral position is seldom selected). Early bronchspirometric studies of the lateral position showed a higher overall ventilation-perfusion ratio in the dependent vs. nondependent lung (Bjorkman, 1934) and an increased oxygen uptake in the dependent lung (Svanberg, 1957). These findings were supported by radiologic examination of x-rays taken in the lateral position during inspiration from FRC to TLC; a greater degree of expansion of the dependent vs. nondependent lung was observed (Wade and Gilson, 1951).

The gravity-dependence of the distribution of ventilation was further confirmed by Kaneko et al in 1966. In this classic study of the regional distribution of ventilation, radioactive Xe was inhaled as a tracer gas in a variety of positions. External scintillation counts in the lateral position indicated that the dependent regions received a greater proportion of the inspired volume than the upper zones (at lung volumes greater than FRC). This effect was also observed in supine and prone but to a lesser degree, and was attributed to the smaller overall vertical lung distance in these positions compared to lateral positions. Glaister (1967) confirmed the observation. Specifically, he reported a nonsignificant difference between upright and inverted for the ratio of dependent-to-nondependent lung ventilation, and a near one-to-one ratio for the supine position (from radioactive Xe studies). In comparison of upright and lateral positions, Anthonisen et al (1970) reported a greater range of radioactive Xe concentrations in the lateral position (a
10- to 15-fold variation in concentration in the tenth intercostal space from top-to-bottom of the lung vs. a 5- to 10-fold apex-to-base concentration gradient in upright. In agreement with Milic-Emili et al (1966), who studied subjects in the sitting position, the investigators suggested that the primary factor influencing the regional distribution of inspired gas is a vertical gradient of intrapleural pressure (which increases at an estimated rate of 0.2 cm per cm of lung height). As a result of this static pressure gradient, lung units would be expected to have differing trans-pulmonary pressures, depending on their topographical location, and thereby different effective compliances as determined by their representative location on the non-linear pressure-volume curve for the lung.

Various investigators in the 1970's further studied the distribution of ventilation in the lateral position by having subjects, who were trained with biofeedback procedures, change their pattern of respiratory muscle contraction during either expiration or inspiration. Roussos et al (1976) used a single-breath helium washout technique to compare two expiratory maneuvers (both performed at constant flow of less than 0.4 L/sec): "relaxed" expiration through an external resistance, and expiration with voluntary diaphragmatic contraction. At lung volumes greater than 70% of VC, the expired helium concentration was significantly greater during voluntary diaphragmatic contraction, which was interpreted as being indicative of a greater contribution to the expirate from helium-rich nondependent zones (i.e. a lesser degree of sequential emptying was demonstrated with voluntary diaphragmatic contraction than with "relaxed" expiration). More direct evidence of this pattern was contributed by a follow-up study (Roussos et al, 1977b) which involved inspiration of radioactive Xe. [This study also revealed an alinear and discontinuous gradient of regional volume in the lateral position which the investigators could not explain (the gradient was accentuated at mid-lung volumes and at
low transdiaphragmatic pressures; the middle region of both lungs was most expanded and the discontinuity was at the level of the mediastinum). A proposed decrease in the vertical gradient of intrapleural pressure, due to the diaphragmatic contraction during expiration, was thought to contribute to the observed emptying pattern. The possible mechanisms proposed for this pattern included (1) a decreased influence of the weight of the abdominal contents on the intrapleural pressure gradient (i.e. a rigid vs. compliant diaphragm "isolating" the thoracic cavity from the hydrostatic abdominal pressure gradient), and (2) a decrease in applied pressure by the mediastinum on the dependent lung (due to an observed elevation of the mediastinum with diaphragmatic contraction). These conclusions contrast with the classical description of the distribution of ventilation in which a constant intrapleural pressure gradient leads to differences in regional compliance.

Further studies of "voluntary" changes in ventilation distribution in the lateral position were done by Roussos et al (1977a) and by Chevrolet et al (1979). Both groups of investigators trained their subjects with biofeedback procedures to breathe selectively with three types of inspiration defined as: (1) natural, (2) preferential use of intercostal and accessory muscles (minimizing contraction of the diaphragm), and (3) enhanced motion of diaphragm and abdomen. By inference from helium bolus washouts (performed with inspiration from FRC in the lateral position), Roussos et al (1977a) reported a preferential distribution of inspired gas to dependent regions when abdominal breathing was used and to nondependent regions (or no preferential distribution) with the intercostal pattern. Similar conclusions were obtained by Chevrolet et al (1979) from analysis of nitrogen and Xe multiple breath washouts performed in the right lateral position. Both groups of investigators proposed that voluntarily-induced changes in the
shape of the chest wall produce regional changes in pleural pressure, thereby altering the
distribution of ventilation. It must be recognized that all studies of "voluntary" changes
in ventilation distribution have used subjects who have been trained extensively with
biofeedback procedures; it is not anticipated that untrained subjects would produce
similar results.

4. Positioning and Pulmonary Diffusing Capacity

The study of the effect of body position on pulmonary diffusing capacity dates
back to the development of the test of pulmonary diffusing capacity for carbon monoxide
(DLCO). In Bates' and Pearce's comparison of methods of measurement of DLCO
(1956), reference is made to the finding that DLCO in supine was increased by an average
of 3 ml/min/mmHg compared to sitting (for both single-breath and steady-state methods
applied to 6 healthy subjects ranging from 23 to 41 years of age). In another early
description of methods of measurement of DLCO and their standardization, Ogilvie et al
(1957) reported a significant increase in DLCO in supine vs. sitting for a group of 7
healthy subjects (age not reported). Later studies vary in statements regarding the
magnitude of this postural change, but there is general agreement among investigators
that DLCO increases from sitting to supine in normal subjects (Jebavy et al, 1971; Stokes
and Nadel, 1981; Crapo and Forster, 1989). The relationship persists for the specific
diffusing capacity (DLCO/VA), which is an expression of DLCO as a function of
alveolar volume (VA), for values of VA between 50 and 100% of TLC (Stam et al, 1991).
(DLCO/VA is used to standardize for lung volume and is frequently preferred over
DLCO for comparison of test results under conditions in which alveolar volume may
change and for interpreting intersubject variability.) It is noted that the majority of studies
which focus on the effects of position on DLCO have compared sitting and supine positions. Little is known about the changes occurring in DLCO from sitting to side lying despite the fact that lateral positions are commonly assumed by patients in hospital and are used as therapeutic positions for individuals with cardiopulmonary compromise.

In attempting to determine the mechanisms of the postural-dependence of DLCO, the effects of age, smoking, and hemodynamic status on the sit-supine DLCO response have been examined by various investigators. In a group of 18 young subjects (mean age 26.4 years), Jebavy et al (1971) found no correlation between the position-dependent change in DLCO (expressed per square meter) and age. However, in a group with a larger age range of 16 to 79 years, Stam et al (1991) found that the positional responses for both DLCO and DLCO/VA decreased in older subjects. Both of these variables were larger in supine than sitting in subjects up to 50 years of age, but for subjects older than 50 years there was no significant positional change (with lung volume at 100% of TLC). This discrepancy was thought to reflect a more uniform distribution of pulmonary blood flow, resulting from an increase in mean pulmonary arterial pressure, in older seated individuals. As a result, it would be expected that a change from sitting to supine would result in a lesser change in pulmonary capillary blood volume, and hence DLCO, in older than in younger individuals.

Hyland et al (1978) had also reported a correlation between age and the change of DLCO/VA between supine and sitting, and in addition found that the positional change was less in smokers than non-smokers (the subject group consisted of 41 non-smokers, mean age 39.3 years, and 32 smokers, mean pack-years 18 and mean age 37.5 years). The effect of smoking was confirmed in 1981 by McClean et al, who reported an 18.5%
increase in DLCO/VA (from sitting to supine) in non-smokers compared to a 3.5% increase in smokers. A possible explanation for these results is that smoking-related thickening of the walls of the pulmonary vasculature (primarily apical) limits the position-related increase in apical blood flow (and thereby limits the increase in DLCO on moving to the supine position).

With regard to the effect of hemodynamic variables, Jebavy et al (1971) reported that the postural change in DLCO (supine-sitting) correlated significantly with mean left atrial pressure, pulmonary vascular resistance, and mean pulmonary artery pressure. The strength of the latter correlation led to one of the major conclusions of the study, which was stated, "postural changes of DLCO are the indicators of the level of the pulmonary arterial pressure". As an overall conclusion, the authors suggest that the mechanisms underlying the postural change in DLCO are complex and are affiliated with not only the change in pulmonary capillary blood volume but also the area of perfused alveoli. The effect of a graded increase in intravascular pressure on DLCO was studied by Daly et al (1965) in one of the few studies looking at positions other than sitting and supine. The test procedure involved measuring DLCO in 20 healthy subjects (21 to 36 years of age) at different degrees of body tilt through the range of 60 degrees head up to 60 degrees head down. Right atrial pressure, used as a measure of central vascular pressure, varied with position (increasing progressively from head up to head down); in a smaller group of six subjects changes in right atrial pressure were obtained by an increase in external body pressure (imposed with a body suit) or the use of thigh tourniquets. The overall result was that DLCO reached a maximum with relatively small changes in central vascular pressure (obtained by either gravity, suit inflation or tourniquets). For example, increasing downwards tilt past 15 degrees produced no further increase in DLCO. The
interpretation of these results is that there is a limit to the passive enlargement of the pulmonary capillary bed by pressure changes. The investigators suggested that this is a consequence of either a limited number of pulmonary capillaries (resulting in limitation of recruitment with a pressure increase) or a limited dilatation of previously "open" capillaries as pressure is increased.

Equally important to the search for physiological mechanisms underlying the positional changes in DLCO is the study of changes in the components of diffusing capacity. Specifically, the relative contributions of Dm (the diffusing capacity of the alveolar capillary membrane) and Vc (the pulmonary capillary blood volume) to DLCO are of interest. An increase in either Dm or Vc theoretically increases overall diffusing capacity. Early studies found no significant change in Dm with a change from sitting to supine (Lewis et al, 1958) and no consistent change between a variety of postures including standing, sitting, supine and inverted (Newman, 1962). In a more recent study, Dm was reported to be smaller in supine compared to sitting in an unspecified proportion of 37 healthy subjects. Although significant variability of individual results was noted, the implication is that a decrease in diffusion surface in supine favors a decrease in DLCO (Stam et al, 1991). With regard to Vc, many studies have shown a significant and consistent change with a change in position. Lewis et al (1958) reported an increase in Vc from 59.2 ml in sitting to 85.9 ml in supine (mean values for four subjects) and in a following study (Lewis et al, 1960) a decrease in Vc (that was abolished by norepinephrine) from supine to 45 degree head-up tilt. Studies by Newman (1962) and Fournier et al (1979) provide further evidence for variation in Vc with postural change. However, Hirasuna and Gorin's study (1981) in particular is a reminder of the complexity of the topic. They found that for 19 healthy subjects (18 to 41 years of age) a change
from sitting to supine was accompanied by an initial increase in Vc (over a five-minute period), followed by a decrease in Vc (over a 90-minute period). They suggest that the latter may be due to a redistribution of pulmonary capillary blood into capacitance vessels with prolonged recumbency.

5. Studies reporting various relationships between spirometric measures, measures of the distribution of ventilation, and pulmonary diffusing capacity

Over the last several decades, the combination of spirometric measures, measures of the distribution of ventilation, and estimates of pulmonary diffusing capacity have been studied to elucidate the effect of body position on lung function. In general, studies which include these dependent variables can be grouped into three categories: (1) epidemiological and occupational field studies, in which various tests are used to detect structural and functional impairment, (2) model-based studies which are focused on describing distributional patterns and their causes, and (3) studies in which a change of body position is utilized as a means of characterizing lung function and of exploring possible physiological mechanisms of the changes observed. The last of these categories is most directly relevant to the present study in that the effect of body position is highlighted. Studies in the first two categories contribute pertinent information in that they provide reference data for the interrelationships of the dependent variables in the sitting position.

i. Epidemiological studies

Spirometric measures (for example the ratio of FEV1 to FVC which is a conventional measure of airway obstruction) and SBN2 parameters (for example DN2%/L and the ratio of closing capacity to total lung capacity, both considered as tests
of small airway function) have been common components of epidemiologic surveys. Many of these surveys have been concerned with detecting the effects of smoking on the lungs, however, the ability of a single test or a group of tests to predict which smoker will develop irreversible airflow has been questioned (Buist et al, 1979, 1988).

The usefulness of the SBN2 as a detector of abnormalities in small airways has been controversial with respect to several of its parameters, notably the measure of closing volume. However, the DN2%/L, has been found by many investigators to be a sensitive measure of small airway abnormality in adults. In a study of 50 and 60 year olds, Oxhoj et al (1977) reported that DN2%/L was more sensitive than either spirometric measures or closing volume in the detection of small airway abnormalities in smokers. This was based on the finding that 40-60% of the smoking group had an abnormal DN2%/L whereas only 10-30% of the same group had an abnormal FEV1 or closing volume measure. Sterk et al (1981) also singled out DN2%/L from other SBN2 parameters as a useful detector of functional abnormalities associated with smoking. In their survey of 1141 individuals, they reported that the DN2%/L was larger in smokers than non-smokers and that it was larger in symptomatic smokers than asymptomatic smokers. Dosman et al (1981) reported a high sensitivity of DN2%/L in smokers (63% of male smokers who had an abnormal FEV1/FVC% also had an abnormal DN2%/L), and in addition reported the test to have a relatively high specificity (79% of subjects with a normal FEV1/FVC% also had a normal DN2%/L). DN2%/L has also been found to be more strongly correlated with mortality than FEV1, DLCO or closing volume (Menkes et al, 1985). However, this finding was unexplained as subject deaths were largely from nonpulmonary disease.
While the use of DN2%/L as a detector of small airways disease is generally promoted, its usefulness as a predictor of the development of chronic airflow limitation in smokers and nonsmokers is controversial. Buist et al (1979) addressed this question (and the usefulness of other parameters of the SBN2) in a study of asymptomatic smokers and nonsmokers (25 to 54 years of age), taken as random samples from three North American cities. Of interest was their finding of only a weak concordance between FEV1/FVC and any of the SBN2 parameters, including DN2%/L (determined on the basis of the prevalence of abnormality of the two tests in combination). In a later study by Buist et al (1988), which involved a nine to eleven year follow-up of two cohorts, the SBN2 was again questioned regarding its predictive usefulness in smokers. The investigators reported that in this regard the SBN2 (specifically the components of closing volume, closing capacity and DN2%/L) offered "little advantage" over either FEV1 or FEV1/FVC. In contrast, other investigators have promoted DN2%/L as a predictor of the rate of decline of FEV1. For example, Olofsson et al (1986) reported that the magnitude of DN2%/L on initial assessment was related to the rate of decline of FEV1 over a seven-year period.

In a small number of epidemiological and occupational field studies, the ability of DLCO to detect functional impairment in the early stages of disease has been a focus of attention. Becklake et al (1970), in a study of asbestos workers, reported that a greater degree of radiologic abnormality was required for there to be a decrease in DLCO vs a decrease in FVC. However, in a sample of 1,612 individuals from the general population (20 years of age and older), it was reported that symptomatic smokers could be distinguished from asymptomatic smokers on the basis of DLCO (Viegi et al, 1990). The investigators recommended the inclusion of DLCO in epidemiologic surveys.
ii. Studies based on models of the lung

In attempting to characterize the distributions of ventilation and diffusing capacity in the lung, some investigators have applied subject data to a lung model. For example, Lewis et al (1981) measured both DLCO (via a multibreath technique) and the distribution of ventilation (from washout of argon) in 32 subjects (18 to 70 years of age; 16 subjects had varying degrees of chronic obstructive lung disease). When the data was fitted to a two-compartment lung model (with compartments in parallel), the well-ventilated areas of the lung had the greatest diffusing capacity. (Note: this approach is in contrast to the conventional test of DLCO which gives a single number that is the "average" diffusing capacity for the whole lung). Prabhu et al (1990) also used a two-compartment lung model in interpreting data collected from seven nonsmokers (mean age 37 years). To study the influence of a deep breath on gas mixing and diffusion in the lung, they measured DLCO (using a 3-equation method) and ventilation inhomogeneity (using the alveolar slope obtained from a helium washout technique) during a submaximal single-breath maneuver performed immediately after a deep breath. Both DLCO and ventilation inhomogeneity were found to be greater than the corresponding values obtained from a maneuver performed after tidal breathing. On the basis of lung model characteristics, the increase of DLCO was attributed to overall increases in carbon monoxide conductance throughout the lung.

iii. Studies examining the effects of body position

As with position-related studies that restrict their focus to one principal variable, studies which examine the effect of body position on a combination of variables most commonly compare the sitting and supine positions. Norreggard et al (1989) measured a
variety of lung function parameters including FEV1, maximum expiratory flow at 50% of FVC (FEF50), and DLCO in these two positions in 39 women (mean age 29 years; 30 pregnant women, 10 in each trimester, and nine women post partum). Following a change from sitting to supine, FEV1 decreased significantly only in the group of third-trimester women, whereas no significant changes were observed for FEF50 or DLCO in any of the groups. The investigators suggest that for women in late pregnancy there may be some degree of large airway obstruction associated with the supine position.

Sundstrom (1975) also used sitting and supine in a study of the influence of body position on younger (mean age 25 years) and older (mean age 60 years) men. The data collection included the regional distribution of ventilation and perfusion (via radiospirometry using Xe) and DLCO (using a steady-state method). Significant differences between age groups were observed: in the younger group DLCO was not significantly different in sitting and supine whereas in the older group DLCO was significantly greater in sitting (which was recognized as an uncommon finding). In part, this age-related difference was attributed to ventilation-perfusion disturbances in the older group (for example, an age-related increase in perfusion uniformity resulting in similar basal ventilation-perfusion ratios for supine and sitting in the older group). Pistelli et al (1991) reported the commonly-observed increase in DLCO/VA from sitting to supine in a group of 12 nonsmokers (26 to 40 years of age). In addition, they measured postural changes in the distribution of ventilation by evaluating SBN2 tracings and found no significant difference in DN2%/L (or closing volume) between sitting and supine. Furthermore, it was observed that specific membrane diffusing capacity (Dm/VA) increased significantly from sitting to supine whereas specific pulmonary capillary blood volume (Vc/VA) did not. These findings led the investigators to conclude that the increase in DLCO in supine
could be explained by an increased homogeneity of the distribution of ventilation with respect to diffusion surface in this position versus sitting.

Positions other than sitting and supine in which changes in several indices of lung function have been studied during a single test session include squatting and lateral positions. Hamosh and Luchsinger (1970) examined lung volumes, maximum expiratory flows, and DLCO (using a single-breath technique) in nine healthy subjects (23 to 42 years of age) in sitting and squatting. They reported a decrease in VC and an increase in maximum expiratory flow and DLCO in squatting versus sitting. The change in VC was explained by the upward displacement of the diaphragm, the mechanism causing a change in maximum expiratory flow was unknown, and the change in DLCO was postulated as being largely due to increased perfusion of the lung in squatting since VC was also shown to increase in this position. Of particular relevance to the present study is the work of Denison et al (1980) which examined sitting and right and left lateral positions. In five healthy subjects (29 to 45 years of age) the distribution of ventilation was measured with fiberoptic bronchoscopy, and DLCO was measured with a modified single-breath technique (referred to as a "single exhalation technique" with no breath hold) and by a rebreathing method (the results of the two methods were highly correlated). Although sitting and lateral positions were not directly compared, ventilation per unit alveolar volume and DLCO/VA were greatest in dependent regions (as was regional perfusion, for which the vertical gradient was the steepest; perfusion was estimated by the rate of uptake of radioactive tracer gases). These results were obtained by positioning the bronchoscope in the right and left main stem bronchi in the lateral positions (giving a comparison between the upper and lower lung) and in lobar bronchi in sitting (giving a comparison of the right upper, middle and lower lobes and the left upper
lobe, lingula, and lower lobe). In contrast, additional "whole lung" (versus regional) measures made at the mouth (versus in a bronchus) showed no significant difference between DLCO values (or perfusion) in any of the three positions. The investigators concluded that the procedures they described could provide a useful adjunct in the clinical evaluation of lobar and segmental lung function.
RATIONALE FOR THIS STUDY

The relationship between body position and lung function is of considerable physiologic interest and in addition has important clinical implications. For example, specific body positioning is well recognized as a primary means of enhancing oxygen transport in patients with cardiopulmonary dysfunction (Remolina et al, 1981; Sonnenblick, 1983; Norton and Conforti, 1985; Ross and Dean, 1989). However, there continue to be many gaps in our knowledge of prescribing body positioning to maximize clinical efficacy. The present study, therefore, was conducted to replicate and extend the existing body of knowledge pertaining to the normal relationship between body positioning and lung function. We examined the relationship between a variety of body positions and several indices of lung function in older healthy individuals.

First, we chose to study an older age group as the majority of position-related studies to date have examined a young adult population. The results of these studies cannot be extrapolated to an older population due to the significant effect of aging on lung structure and function. For example, it is well-known that the bony structure of the thorax, the ventilatory muscles, the lung parenchyma and the pulmonary vasculature are affected by the aging process (Zadai, 1985; Knudson, 1991). The interrelated changes in these structural aspects result in a gradual decline in lung function with aging that is distinguishable from the more profound loss of function that occurs as a result of disease. Although the changes accompanying the normal aging process may be relatively subtle, they are reflected by characteristic changes in certain indices of lung function. The influence of aging on indices of lung function is documented in the literature (Georges et al, 1978; Zadai, 1985; Knudson, 1991), however it is generally recognized that the
complexities affiliated with the aging process require further study. Thus, the present study was designed to augment our understanding of normal age-related changes in lung function, to further our understanding of changes in lung function when disease is superimposed upon aging, and to establish the effect of changes in body position on the lung function of older people.

Second, in addition to the reference position of sitting, we selected left and right side lying positions for the present study. The side lying positions were selected because their physiologic effects have not been studied in detail previously. In addition, the effects of these positions are of considerable clinical interest given the profound effects of body position on lung function. Not only are these positions used therapeutically, for example to improve ventilation and perfusion matching and for postural drainage, but also they are frequently spontaneously assumed by hospitalized patients.

Third, we studied the following combination of dependent variables: VC, FEV1, FEF50, FEF25-75%, DN2%/L, and DLCO/VA in the different body positions. The spirometric variables were included for the purposes of screening for airway obstruction, setting a baseline for acceptability of the DLCO test (which requires the subject to inhale a minimum of 90% of his or her VC), and evaluating changes in airway resistance between different positions. The DN2%/L and DLCO/VA provide valuable information with respect to the function of the lung as a gas exchanger. The DN2%/L focuses on the process of ventilation, hence, the movement of inspired gas from the atmosphere to the alveoli; and DLCO/VA focuses on the process of diffusion involving the transport of gases across the alveolar-capillary membrane. Specifically, the distribution of ventilation, in combination with the distribution of pulmonary perfusion, is a determinant
of the efficiency of gas exchange. Various ventilation-to-perfusion abnormalities, classically described by a "three compartment model" which includes areas of alveolar deadspace (high ventilation-to-perfusion ratios) and areas of physiological shunt (low ventilation-to-perfusion ratios), result in a decreased efficiency of gas exchange. The relevance of diffusing capacity to gas exchange is more direct in that it evaluates one of the four defined steps (or "conductances") of the oxygen transport system as described by Otis (1956). Specifically, it refers to the conductance (more precisely the reciprocal conductance) between the alveolar gas and the capillary blood. At this point in the oxygen transport pathway, oxygen must diffuse from the alveolar space across the alveolar-capillary membrane and into the blood where it combines with hemoglobin. Disruption of this process results in reduced gas transfer, which is significant clinically in that it is a cause of reduced partial pressure of oxygen in arterial blood.

A greater understanding of the relationship of body position and lung function in health is prerequisite to (1) improving our understanding of this relationship when pathophysiology is superimposed and (2) applying body position as a primary intervention to maintain or improve overall gas exchange in hospitalized individuals who present with cardiopulmonary dysfunction.
SPECIFIC OBJECTIVES OF THIS STUDY

This study was designed to replicate and extend previous studies on the relationships between body position and indices of lung function. Specifically, we were interested in characterizing the lung function of older individuals when exposed to three body positions, namely sitting, left side lying and right side lying. The indices of lung function that were of specific interest included spirometric variables, i.e. forced vital capacity and forced expiratory flows (FVC, FEV1, and FEF25-75%), the homogeneity of ventilation (DN2%/L), and the pulmonary diffusing capacity (DLCO/VA).

To establish the quality of our results, we first wished to confirm:

1. that the SensorMedics 2200 provided measures of spirometry, DN2%/L, and DLCO/VA consistent with established norms for healthy older adults,

2. that test-retest reproducibility of the dependent variables was consistent with those of other laboratories,

3. that spirometric variables decrease in the side lying positions compared with sitting, and

4. that DN2%/L increases in the side lying positions compared with sitting.

Further, we wished to answer the following questions:

1. Is there a difference in the spirometric variables between left side lying and right side lying?
2. Is there a difference in DN2%/L between left side lying and right side lying?

3. Is there a difference in DLCO/VA between left side lying and right side lying?

4. Does DLCO/VA increase in side lying positions compared with the sitting position?

5. Are the spirometric variables correlated with DLCO/VA and DN2%/L in the sitting and side lying positions?

6. Is DLCO/VA correlated with DN2%/L in the sitting and side lying positions?
METHODS

RESEARCH DESIGN

A within subject experimental design was used to examine the interrelationship between indices of lung function and body position in nineteen healthy subjects. Subjects were tested over two sessions, within one week, over a five-month interval. In each session, lung function tests were performed in two body positions, namely the reference position of sitting and one side lying position. The selection of left or right side lying on the first visit was alternated for subsequent subjects. The tester was constant throughout the study. The lung function tests included spirometric tests of volumes and flows (FVC, FEV1, FEF25-75%), the single-breath nitrogen test to determine the homogeneity of ventilation (as indicated by DN2%/L), and a single-breath test of DLCO to determine the diffusing capacity. In each position, spirometric tests were conducted first to provide a reference value of VC for the test of DLCO. The test of DLCO was conducted before the SBN2 as the latter involved inhaling 100% oxygen (which potentially could influence the DLCO test). Each session lasted approximately two-and-a-half hours. Subjects rested between tests and between repeated trials of each test.

SUBJECTS

Subjects (mean age 62.8 ± 6.8 years) ranged from 50 to 74 years of age and included 11 females and 8 males. Seventeen subjects were Caucasian; one subject was Philippino and one was a North American native. There were 9 lifetime nonsmokers and 10 ex-smokers (only two of whom could be described as previously heavy smokers). All subjects confirmed that they were healthy and had no known history of pulmonary disease. One subject may have had a myocardial infarct several years ago and another was being investigated for atherosclerotic heart disease; otherwise subjects did not
present with any known history of cardiac disease. Nine subjects were taking some form of regular medication, for example for arthritis, thyroid disease or high blood pressure. All subjects were independently mobile and most participated in some form of regular exercise as determined by a questionnaire of general activity level. The group was recruited from the UBC community through a publicity statement.

PROCEDURES

General Procedures:

All subjects refrained from vigorous exercise prior to testing on the day of the test session. They were also requested to avoid eating a heavy meal within two hours of the test and to wear comfortable non-restrictive clothing.

A flow chart of the general experimental procedure is presented in Figure 1. The protocol for Session A was randomly selected for the first subject on the first visit (with the protocol for Session B used in the second visit). For successive subjects, the two protocols were alternately ordered. On arrival at the laboratory for the first session, the test procedures were explained to the subjects who then gave written consent to participate. The time taken for this discussion and for the determination of individual heights and weights allowed for a rest period prior to testing. It also allowed for familiarization with the environment and the tester, who was constant throughout the study to control for experimenter effects. In both sessions, the first test position was sitting and the second test position was either left or right side lying. With this protocol, all subjects were tested in all four test positions, namely sitting and left side lying in Session A, and sitting and right side lying in Session B. The order of lung function tests, as shown in Figure 1, was the same for each visit, as necessitated by spirometric
Figure 1. General Experimental Procedure

<table>
<thead>
<tr>
<th>SESSION A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation of procedures</td>
</tr>
<tr>
<td>Signing of consent form</td>
</tr>
<tr>
<td>Measure of height and weight</td>
</tr>
</tbody>
</table>

| POSITION: Sitting |
| TESTS: Spirometry |
| DLCO (post 15 min in sitting) |

| POSITION: Left side lying |
| TESTS: Spirometry |
| DLCO (post 15 min in side lying) |

| POSITION: Sitting |
| TEST: SBN2 (post 15 min in sitting) |

| POSITION: Left side lying |
| TEST: SBN2 (post 15 min in side lying) |

<table>
<thead>
<tr>
<th>SESSION B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion of questionnaire</td>
</tr>
</tbody>
</table>

| POSITION: Sitting |
| TESTS: Spirometry |
| DLCO (post 15 min in sitting) |

| POSITION: Right side lying |
| TESTS: Spirometry |
| DLCO (post 15 min in side lying) |

| POSITION: Sitting |
| TEST: SBN2 (post 15 min in sitting) |

| POSITION: Right side lying |
| TEST: SBN2 (post 15 min in side lying) |

* Session A and Session B were alternated for successive subjects
prerequisites for DLCO and the potential for the 100% oxygen inhaled during SBN2 to interfere with the DLCO test. Each session was completed in approximately two-and-a-half hours, and included three- to five-minute rest periods between trials and a minimum of 15 minutes in each position prior to testing. In the rest periods between tests and at the beginning of the second session, subjects completed a brief questionnaire regarding general medical history and activity level (see Appendix 1).

Specific Procedures:

1. Independent Variable: Body Position

   For the sitting position, subjects were seated in a firm high-backed chair. During the tests in sitting, the tester ensured that they maintained an upright position. For the side lying positions, subjects lay on a flat stretcher with one pillow under the head, one pillow behind the back and against the stretcher rail, and one pillow between the knees. The tester observed the subject throughout the rest periods and the test maneuvers to ensure the maintenance of a full side lying position with the head in line with the torso.

   Subjects assumed the test position 15 minutes prior to the first trial of either the DLCO test or the SBN2 test in each position. This rest period was included to accommodate the effects of position change on the pulmonary circulation, notably the pulmonary capillary blood volume, which are known to be time-dependent (Lewis and Christanson, 1978; Hirasuna et al, 1981). Although the time course and duration of position-related changes in the pulmonary circulation are not well-defined in the literature, various studies of the effect of position change on DLCO have used rest periods of 15 minutes or less (Malmberg, 1966; Norregard et al, 1989; Pistelli et al, 1991).
2. Dependent Variables

i. Measurement by the SensorMedics 2200 System

Data for all dependent variables measured in this study were collected from a semi-automated, computerized system, the SensorMedics 2200 (SensorMedics Corporation, Anaheim, CA). The technology on which this unit is based is relatively new and enables investigators to measure several parameters with one piece of instrumentation. Volume and flow measurements with SensorMedics 2200 are made from a mass flow sensor (Rauterkaus and Kittinger, 1989). Mass flow is the number of molecules moving past the point of measurement, which in this case is a pair of heated stainless steel wires, over a given time period. The two wires are electrically heated to different temperatures (180 and 240 degrees Celsius) and are part of a Wheatstone bridge circuit. When a laminarized gas flow (obtained by channelling the gas through a tapered Venturi tube) crosses the wires, the hotter wire loses heat more rapidly than the colder wire. This results in an electrical current change to keep the bridge circuit balanced. The amount of heat lost, and therefore the amount of current required, is proportional to the mass flow of the gas. Flow rates are measured directly whereas volumetric measurements are obtained by an electronic integration of flow signals. Mass flow measurements determined in this way are independent of humidity and of the temperature of the gas.

The SensorMedics 2200 system has both a nitrogen analyzer, which is used in the single breath nitrogen test, and a Rapid Response Multi-gas Analyzer, which is used in the test of DLCO (SensorMedics Manual, 1989). For measuring the nitrogen concentration of expired gas during the SBN2 test, a needle valve is mounted into a mouthpiece adaptor. The valve is connected to a fast response nitrogen analyzer which
includes an ionization chamber. Maximum nitrogen ionization is achieved by an optimum negative pressure (created by a vacuum pump) in the analyzer. When nitrogen ionizes, it emits ultraviolet light, the intensity of which is directly related to the concentration of nitrogen. The light energy is converted into an electric signal which is translated by the computer into a concentration. The response time for this analysis is given as less than 50 milliseconds. A different method is used for measuring the carbon monoxide concentration of expired gas during the single-breath DLCO test. In this case, the measuring principle is the "Non-Dispersive Infrared Absorption" technique. The expired gas is exposed to a beam of infrared energy and absorbs a certain amount of this energy, depending on the partial pressure of the gas (which in turn is dependent on the concentration of the gas). The infrared absorption is measured and converted to an electric signal which is relayed to the computer.

Calibration for flow and volume measurements was done prior to each session and according to the procedure outlined in the SensorMedics 2200 Operator's Manual (1989). This involved using a 3.0 liter calibration syringe to deliver room air into the system. Calibration of the nitrogen analyzer was performed at least once a week as per the terms outlined in the operator's manual. This involved "peaking the needle" by opening or closing the needle valve (to allow more or less gas flow into the analyzer) to obtain the maximum percent nitrogen reading on room air. The vacuum pump was turned on a minimum of 20 minutes prior to calibration, as per the specified calibration procedure. A linearity check of the nitrogen analyzer was performed at the onset of the study and twice during the study. This involved exposing the SensorMedics 2200 to five different concentrations of nitrogen (ranging from 0.00% to 49.8%) for analysis.

Depending on the specific test selected from the computer menu, a valve automatically switched the subject, who was connected to the system by a breathing tube
and mouthpiece, between room air, 100% oxygen or a multi-gas mixture. Throughout a
test, tracings on the computer screen provided visual feedback for the subject and
coeaching cues for the tester. Computer messages regarding the subject's performance
(for example, "Exhalation Not Complete; Exhale Longer", as based on American
Thoracic Society standards) were used as an aid for coaching and for the determination of
the acceptability of each trial. Results of each test, in both graphic and numerical form,
were available immediately after the completion of each trial and were compared with
previous trials which were stored in the computer's memory. In addition, "best" results
for spirometric tests (as per ATS standards) and averages for DN2%/L and DLCO were
displayed, as were the values expressed as a per cent of predicted. For this study,
prediction equations were those of Crapo et al. (1981) for volume measurements,
Knudson (1983) for flow measurements, Buist and Ross (1973) for DN2%/L, and Miller
(1983) for diffusion measurements.

ii. Performance of Spirometric Tests

The maximum expiratory flow maneuver, from which spirometric measures were
taken, was conducted according to American Thoracic Society (ATS) standards (1987).
Positioned in either sitting or side lying, the subject was monitored throughout the test to
prevent alterations in body position. Following a detailed explanation of the test, the
subject was connected to the mouthpiece with the noseclip in place. After several tidal
breaths, the subject was coached through the maximal forced expiration procedure. The
end of the test, as defined by ATS criteria of no change in volume for at least two
seconds following an exhalation time of at least six seconds, was indicated by a computer
message displayed on the screen. Also displayed immediately following the test was the
extrapolated volume, which was obtained from the back extrapolation method used to
determine "time zero" (as per ATS standards). The extrapolation volume was defined as
less than five per cent of the FVC for an acceptable test. The subject was coached to expire with maximal expiratory effort until three acceptable tracings were recorded (which involved a maximum of six trials). In accordance with ATS recommendations for test reproducibility, the two largest FVC's (taken from acceptable curves) varied by less than five per cent of the largest FVC. Similar reproducibility criteria were applied to FEV1.

From the accepted trials, the largest FVC and the largest FEV1 were selected for data analysis. The measure of FEF25-75% selected for data analysis was from the single "best" expiratory maneuver, which is defined by the ATS as the test which gives the largest sum of FVC and FEV1. The selected spirometric values were compared by the computer to reference values and were presented as a per cent of predicted.

iii. Performance of the SBN2 Test

The SBN2 tests were conducted according to the National Heart and Lung Institute standards (Martin and Macklem, 1973). Following a detailed explanation of the maneuver, the subject was connected to the mouthpiece with a noseclip in place. After several tidal breaths, the subject inhaled two slow deep breaths and then exhaled completely. From residual volume, which is recognized by the computer as the point at which there is no expiratory flow for one-half second, the subject inhaled a slow VC breath of oxygen (automatically delivered by the computer). The flow rate of the subsequent slow exhalation was maintained between 0.3 and 0.6 L/sec for as long as possible. To assist the subject in maintaining a flow rate in this range, the flow rate was displayed on the computer screen during exhalation, along with two horizontal dotted target lines which represented the upper and lower limits of the flow rate range. (See Figure 2 for a SensorMedics 2200 tracing of the SBN2 test including a record of flow
Figure 2. SensorMedics 2200 tracing of the single-breath nitrogen test. The subject was a healthy 29-year-old female who was not part of the data set for this study. The test position was sitting.
rate throughout the test.) In addition, resistance to expiratory flow was increased, thereby making the flow rate easier to control, by narrowing the diameter of the expiratory port. This was done with an insert specifically designed for the test by the SensorMedics Corporation.

In each test position, the SBN2 test was repeated until three acceptable tracings were obtained. Rest periods of approximately five minutes were given between trials to provide time for washout of excess oxygen and thus the restoration of the normal nitrogen gradient in expired air. As per National Heart and Lung Institute standards (1973), an acceptable test was one in which the mean expiratory flow (not including the first 500 ml of expirate), was less than or equal to 0.5 L/sec (as determined by visual inspection of the expiratory flow rate tracing), the difference in inspired VC and expired VC (the latter measured manually from computer tracings) was less than five per cent, and there were no step changes in the N2 concentration of the expire. The DN2%/L was calculated by the computer from analysis of the final expire (using the increase in N2 concentration over one liter of the expired volume, between 750 ml, representing the complete deadspace washout, and 1750 ml). The average of DN2%/L from three acceptable tests was used for data analysis, expressed as a percent of predicted.

iv. Performance of the DLCO Test

The DLCO tests were conducted according to ATS standards (1987) for a single breath test. As with the other tests, the subject was connected to the mouthpiece with a noseclip in place for a short period of tidal breathing before the test maneuver. On cue from the tester, the subject exhaled to residual volume and then quickly inhaled a vital capacity of the test gas, which contained 0.302% carbon monoxide, 0.301% methane, 0.300% acetylene, 20.95% oxygen, and the balance N2. (Methane was used as an inert
tracer gas for determination of lung volume. The acetylene was incorporated in the gas mixture to measure pulmonary capillary blood flow from a test of DLCO which involved no breathhold; however, this measurement was not made with the single-breath test of DLCO used in the present study.) On the basis of previous forced expiratory maneuvers which gave a measure of VC in the same position, the computer displayed the minimum acceptable volume (at least 90% of the subject’s VC) by a horizontal target line which the subject could see while inhaling. The subject was coached to breath-hold at total lung capacity for ten seconds, during which time he or she was encouraged to relax against the closed valve of the unit. The end of the breathhold was signalled by the crossing of the volume versus time tracing over a vertical time line, after which the expiratory valve automatically opened and the subject was coached to exhale rapidly and completely. (See Figure 3 for a SensorMedics 2200 tracing of the single breath DLCO test, including a plot of carbon monoxide concentration at the mouth during expiration.) The precise breathhold time was calculated by the computer using the Jones and Meade (1961) technique (approved by the ATS) of including 0.7 of the inspiratory time and 0.5 of the expiratory time. The mean concentrations of methane and carbon monoxide were calculated by the computer over a 1000 ml alveolar sample volume (from 750 to 1750 ml of the expired volume). This sample volume was manually adjusted according to recommended procedures after the test was completed such that the sample was taken from plateaus of the gas concentration versus volume lines and from as close to the deadspace clearing interval as possible. The sample collection volume was not adjusted larger than 1000 ml.

In each test position, the DLCO test was repeated until at least two acceptable tracings were obtained. At least four minutes were given as a rest time between trials to allow the test gas to wash out from the subject’s lungs. Before each trial, an automated procedure was initiated in which methane and carbon monoxide concentration readings
Figure 3. SensorMedics 2200 tracing of the test of diffusing capacity for carbon monoxide. The subject was a healthy 29-year-old female who was not part of the data set for this study. The test position was sitting.
were zeroed with room air. The two tests from which an average DLCO/VA was calculated were within 10% of each other, in accordance with ATS recommendations. The average DLCO/VA was expressed as a per cent of predicted for data analysis. Although an adjustment for hemoglobin is desirable in the calculation of DLCO, it is not considered mandatory by the ATS for generally healthy subjects and was not made in this study. Also, as noted by Pistelli et al (1991), it is assumed that for every subject the hemoglobin concentration was constant through the study. Because the two test sessions were conducted within one week for eighteen subjects (for one subject the test interval was 36 days) the effect of normal fluctuations in hemoglobin or DLCO was presumably minimized. Thus, we were confident that hemoglobin changes did not confound DLCO when different positions were studied.

DATA ANALYSIS

Results for spirometry, the single-breath nitrogen test, and the test of diffusing capacity were determined by the computer in the SensorMedics 2200 system and thus involved no hand calculations.

There were six steps involved in the data analysis. All statistical tests were performed on data expressed as a percent of the predicted value. A significance level of p less than 0.05 was selected for all statistical tests.

First, descriptive statistics were calculated for age, height, and weight of the female and male subjects. Descriptive statistics were also calculated for the five dependent variables, namely FVC, FEV1, FEF25-75%, DN2%/L, and DLCO. These variables were expressed as observed values
for the presentation of individual subject test results (Appendix 2) and as both observed values and percentage of the predicted values for the presentation of group data.

Second, individual subject test results were compared with norms to establish normality or abnormality of the data set. For each subject, the observed value was compared to the lowest acceptable normal limit (for the spirometric variables and for DLCO) or the highest acceptable normal limit (for DN2%/L). The limits of normal were obtained by subtracting (for the lowest limit) or adding (for the highest limit) the 95th percent confidence interval (1.65 x SEE) (see Methods for references for reference values) from the predicted value for each subject.

Third, to establish the reproducibility of the data, coefficients of variation were calculated using the three repeated measures of the spirometric variables and DN2%/L and the two repeated measures of DLCO for each subject. Paired t-tests and Pearson product-moment correlation coefficients were also calculated within each variable between the two sitting positions (Sit-A and Sit-B).

Fourth, the effect of a change from sitting to side lying on each dependent variable was determined by using paired t-tests. Comparisons were made between Sit-A and left side lying and Sit-B and right side lying.

Fifth, the effect of the side lying position on each dependent variable was determined by using paired t-tests. Comparisons were made between left and right side lying.

And sixth, the interrelationships between (i) the spirometric variables and DLCO (DLCO/VA), (ii) the spirometric variables and DN2%/L, and (iii) DLCO (DLCO/VA)
and DN2%/L, were examined using Pearson product-moment correlation coefficients. The interrelationships were examined for Sit-A, left side lying, Sit-B and right side lying.
RESULTS

SUBJECT CHARACTERISTICS

Nineteen subjects were included in the study. Of these, 11 were female (mean age 63.6 ± 5.5 years) and eight were male (mean age 61.8 ± 8.1 years). Overall, the mean age was 62.8 ± 6.8 years. The average height of females was 159 ± 6 cm and that of males was 176 ± 8 cm. The average weight of females was 56.6 ± 8.2 kg and that of males was 72.0 ± 11.0 kg. With the exception of one Philippino subject and one North American native subject, all were Caucasian.

Appendix B is a compilation of individual subject data for all tests in each of the three test positions (with two sets of data for the sitting position, which was used on each of the two visits; see Figure 1). A table of individual subject characteristics including gender, ethnicity, age, smoking history, height and weight is also included in Appendix B.

Predicted values and the 95% confidence intervals for spirometric variables (given by Crapo et al, 1981) and DLCO (given by Miller et al, 1983) were used to calculate the lower limits of normal for each subject in the sitting position. Three subjects (number 6, 8, and 11) fell below this limit for FEF25-75%; otherwise all subjects were above the lower limits of normal for the variables observed in the sitting position. The upper limits of normal for DN2%/L were calculated for each subject using the 95th percent confidence interval given by Buist and Ross (1973); all subjects fell below this limit for the DN2%/L observed in the sitting position.
CHARACTERISTICS OF GROUP PERFORMANCE

All subjects who participated in the study completed both test sessions. The interval between test sessions ranged from one day to 36 days (one subject), with most subjects completing both sessions within one week. In 18 subjects, three acceptable spirometric tracings, three acceptable SBN2 tracings and two acceptable DLCO tracings were obtained in each test position. Due to equipment problems, one subject was limited to two SBN2 tracings for left side lying and for one of the sitting positions (Sit-B). In these instances, an average value was taken from the two successfully completed SBN2 trials for data analysis.

The descriptive statistics for spirometric variables (FVC, FEV1, FEV1/FVC, and FEF25-75%), DN2%/L and DLCO test variables (DLCO, and DLCO/VA) for each of the test positions are summarized in Table I. From Sit-A to left side lying (Table I, Panel A), there were statistically significant decreases in percent predicted values for FVC, FEV1, FEF25-75% and FEV1/FVC (p<0.01), and there was a significant increase in the percent predicted value for DN2%/L (p<0.05). From Sit-B to right side lying (Table I, Panel B), there were significant decreases in percent predicted values for FVC, FEV1, and FEF25-75% (p<0.01). Diffusing capacity variables were not significantly different between sitting and either left side lying or right side lying (p>0.05).

When the two side lying positions were compared, there were no statistically significant differences for any of the variables (p>0.05).
TABLE I

DESCRIPTIVE STATISTICS FOR THE DEPENDENT VARIABLES IN TEST SESSION A FOR SITTING AND LEFT SIDELYING [n=19]

POSITION: SIT-A

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>OBSERVED VALUE</th>
<th>SD</th>
<th>%PREDICTED† VALUE</th>
<th>SD</th>
<th>RANGE %PREDICTED MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC</td>
<td>3.97</td>
<td>0.87</td>
<td>113</td>
<td>13</td>
<td>87</td>
<td>143</td>
</tr>
<tr>
<td>FEV1</td>
<td>2.76</td>
<td>0.68</td>
<td>101</td>
<td>18</td>
<td>57</td>
<td>132</td>
</tr>
<tr>
<td>FEF25-75%</td>
<td>1.97</td>
<td>0.86</td>
<td>74</td>
<td>28</td>
<td>38</td>
<td>136</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>69.79</td>
<td>7.55</td>
<td>90</td>
<td>10</td>
<td>61</td>
<td>103</td>
</tr>
<tr>
<td>DLCO</td>
<td>23.59</td>
<td>4.92</td>
<td>100</td>
<td>15</td>
<td>73</td>
<td>121</td>
</tr>
<tr>
<td>DLCO/VA</td>
<td>4.29</td>
<td>0.85</td>
<td>98</td>
<td>15</td>
<td>76</td>
<td>143</td>
</tr>
<tr>
<td>DN2%/L</td>
<td>2.07</td>
<td>0.87</td>
<td>135</td>
<td>70</td>
<td>47</td>
<td>307</td>
</tr>
</tbody>
</table>

POSITION: LEFT SIDELYING

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>OBSERVED VALUE</th>
<th>SD</th>
<th>%PREDICTED† VALUE</th>
<th>SD</th>
<th>RANGE %PREDICTED MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC</td>
<td>3.84</td>
<td>0.85</td>
<td>110</td>
<td>13</td>
<td>81</td>
<td>140</td>
</tr>
<tr>
<td>FEV1</td>
<td>2.59</td>
<td>0.65</td>
<td>95</td>
<td>17</td>
<td>47</td>
<td>126</td>
</tr>
<tr>
<td>FEF25-75%</td>
<td>1.66</td>
<td>0.75</td>
<td>63</td>
<td>21</td>
<td>23</td>
<td>97</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>67.58</td>
<td>8.84</td>
<td>86</td>
<td>11</td>
<td>47</td>
<td>100</td>
</tr>
<tr>
<td>DLCO</td>
<td>22.77</td>
<td>4.65</td>
<td>97</td>
<td>15</td>
<td>79</td>
<td>131</td>
</tr>
<tr>
<td>DLCO/VA</td>
<td>4.16</td>
<td>0.74</td>
<td>95</td>
<td>13</td>
<td>79</td>
<td>133</td>
</tr>
<tr>
<td>DN2%/L</td>
<td>2.59</td>
<td>1.41</td>
<td>168</td>
<td>99</td>
<td>12</td>
<td>421</td>
</tr>
</tbody>
</table>

Legend follows at end of Table on page 49
TABLE I, Continued

B.

DESCRIPTIVE STATISTICS FOR THE DEPENDENT VARIABLES IN TEST SESSION B FOR SITTING AND RIGHT SIDELYING [n=19]

POSITION: SIT-B

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>OBSERVED VALUE</th>
<th>SD</th>
<th>%PREDICTED VALUE</th>
<th>SD</th>
<th>RANGE %PREDICTED MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC</td>
<td>4.00</td>
<td>0.94</td>
<td>113</td>
<td>14</td>
<td>85</td>
<td>142</td>
</tr>
<tr>
<td>FEV1</td>
<td>2.74</td>
<td>0.68</td>
<td>99</td>
<td>18</td>
<td>51</td>
<td>129</td>
</tr>
<tr>
<td>FEF25-75%</td>
<td>1.81</td>
<td>0.76</td>
<td>69</td>
<td>25</td>
<td>26</td>
<td>121</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>69.00</td>
<td>0.13</td>
<td>88</td>
<td>11</td>
<td>51</td>
<td>101</td>
</tr>
<tr>
<td>DLCO</td>
<td>23.46</td>
<td>5.52</td>
<td>99</td>
<td>16</td>
<td>77</td>
<td>126</td>
</tr>
<tr>
<td>DLCO/VA</td>
<td>4.24</td>
<td>0.82</td>
<td>97</td>
<td>15</td>
<td>74</td>
<td>134</td>
</tr>
<tr>
<td>DN2%L</td>
<td>2.15</td>
<td>1.03</td>
<td>140</td>
<td>78</td>
<td>40</td>
<td>371</td>
</tr>
</tbody>
</table>

POSITION: RIGHT SIDELYING

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>OBSERVED VALUE</th>
<th>SD</th>
<th>%PREDICTED VALUE</th>
<th>SD</th>
<th>RANGE %PREDICTED MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC</td>
<td>3.87</td>
<td>0.89</td>
<td>110</td>
<td>13</td>
<td>85</td>
<td>139</td>
</tr>
<tr>
<td>FEV1</td>
<td>2.63</td>
<td>0.67</td>
<td>96</td>
<td>17</td>
<td>56</td>
<td>124</td>
</tr>
<tr>
<td>FEF25-75%</td>
<td>1.64</td>
<td>0.77</td>
<td>62</td>
<td>24</td>
<td>31</td>
<td>104</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>68.05</td>
<td>7.26</td>
<td>87</td>
<td>10</td>
<td>58</td>
<td>100</td>
</tr>
<tr>
<td>DLCO</td>
<td>22.81</td>
<td>4.87</td>
<td>97</td>
<td>18</td>
<td>71</td>
<td>130</td>
</tr>
<tr>
<td>DLCO/VA</td>
<td>4.16</td>
<td>0.87</td>
<td>95</td>
<td>16</td>
<td>73</td>
<td>138</td>
</tr>
<tr>
<td>DN2%L</td>
<td>2.46</td>
<td>1.52</td>
<td>154</td>
<td>96</td>
<td>28</td>
<td>386</td>
</tr>
</tbody>
</table>

Legend follows at end of Table on page 49

48
TABLE I, continued

LEGEND:

FVC - forced vital capacity (L, BTPS)
FEV1 - forced expiratory volume in one second (L, BTPS)
FEF25-75% - forced expiratory flow during the middle 50% of the forced vital capacity (L/s, BTPS)
DLCO - pulmonary diffusing capacity for carbon monoxide (ml CO/min/mmHg)
DLCO/VA - pulmonary diffusing capacity for carbon monoxide per unit of alveolar volume (ml CO/min/mmHg/L, BTPS)
DN2%/L - slope of Phase III of the single-breath nitrogen test

* For source of predicted values, see text

* significant difference between sitting and left side lying (A) or sitting and right side lying (B), p<0.05

** significant difference between sitting and left side lying (A) or sitting and right side lying (B), p<0.01
INTERRELATIONSHIPS BETWEEN THE DEPENDENT VARIABLES

Pearson product-moment correlations between FVC, FEV1, FEF25-75%, DLCO, DLCO/VA, and DN2%/L are given in Table II for each of the body positions (Sit-A, LSL, Sit-B, RSL). FVC correlated positively with DLCO in both left side lying and right side lying. All other comparisons were nonsignificant.

REPRODUCIBILITY WITHIN SUBJECTS AND BETWEEN TEST SESSIONS

The within-subject variability of each of the dependent variables (FVC, FEV1, FEF25-75%, DLCO, DLCO/VA, and DN2%/L) was examined by calculating the coefficient of variation. The coefficients of variation for the sitting positions (Sit-A and Sit-B) are given in Table III, along with the reports of other investigators.

The reproducibility of the dependent variables was also examined by comparing repeated measures within and between the two sessions for sitting (i.e. sit-A and sit-B). Table IV shows the significance levels for both paired t-tests and Pearson product-moment correlation coefficients. On the basis of these tests, there were no significant differences for these variables between the sitting positions.
TABLE II

INTERRELATIONSHIP BETWEEN VARIABLES IN EACH TEST POSITION:
PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS (r); n=19

<table>
<thead>
<tr>
<th>COMPARISON</th>
<th>BODY POSITION</th>
<th>PEARSON r</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC vs DLCO</td>
<td>SIT-A</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>LSL</td>
<td>0.54 *</td>
</tr>
<tr>
<td></td>
<td>SIT-B</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>RSL</td>
<td>0.52 *</td>
</tr>
<tr>
<td>FVC vs DLCO/VA</td>
<td>SIT-A</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td>LSL</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>SIT-B</td>
<td>-0.24</td>
</tr>
<tr>
<td></td>
<td>RSL</td>
<td>0.07</td>
</tr>
<tr>
<td>FVC vs DN2%/L</td>
<td>SIT-A</td>
<td>-0.29</td>
</tr>
<tr>
<td></td>
<td>LSL</td>
<td>-0.26</td>
</tr>
<tr>
<td></td>
<td>SIT-B</td>
<td>-0.18</td>
</tr>
<tr>
<td></td>
<td>RSL</td>
<td>-0.41</td>
</tr>
<tr>
<td>FEV1 vs DLCO</td>
<td>SIT-A</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>LSL</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>SIT-B</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>RSL</td>
<td>0.38</td>
</tr>
<tr>
<td>FEV1 vs DLCO/VA</td>
<td>SIT-A</td>
<td>-0.06</td>
</tr>
<tr>
<td></td>
<td>LSL</td>
<td>-0.14</td>
</tr>
<tr>
<td></td>
<td>SIT-B</td>
<td>-0.06</td>
</tr>
<tr>
<td></td>
<td>RSL</td>
<td>0.00</td>
</tr>
<tr>
<td>FEV1 vs DN2%/L</td>
<td>SIT-A</td>
<td>-0.14</td>
</tr>
<tr>
<td></td>
<td>LSL</td>
<td>-0.29</td>
</tr>
<tr>
<td></td>
<td>SIT-B</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td>RSL</td>
<td>-0.35</td>
</tr>
</tbody>
</table>

* p<0.05 (nonsignificant with Bonferroni correction)
TABLE II, continued

INTERRELATIONSHIP BETWEEN VARIABLES IN EACH TEST POSITION:
PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS (r); n=19

<table>
<thead>
<tr>
<th>COMPARISON</th>
<th>BODY POSITION</th>
<th>PEARSON r</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEF25-75% vs DLCO</td>
<td>SIT-A</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>LSL</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td>SIT-B</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>RSL</td>
<td>0.17</td>
</tr>
<tr>
<td>FEF25-75% vs DLCO/VA</td>
<td>SIT-A</td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td>LSL</td>
<td>-0.44</td>
</tr>
<tr>
<td></td>
<td>SIT-B</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>RSL</td>
<td>-0.10</td>
</tr>
<tr>
<td>FEF25-75% vs DN2%/L</td>
<td>SIT-A</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>LSL</td>
<td>-0.22</td>
</tr>
<tr>
<td></td>
<td>SIT-B</td>
<td>-0.12</td>
</tr>
<tr>
<td></td>
<td>RSL</td>
<td>-0.41</td>
</tr>
<tr>
<td>DLCO vs DN2%/L</td>
<td>SIT-A</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>LSL</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>SIT-B</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>RSL</td>
<td>-0.10</td>
</tr>
<tr>
<td>DLCO/VA vs DN2%/L</td>
<td>SIT-A</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>LSL</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>SIT-B</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>RSL</td>
<td>0.07</td>
</tr>
</tbody>
</table>
TABLE III

REPRODUCIBILITY OF THE DEPENDENT VARIABLES:
COEFFICIENTS OF VARIATION [SD/Mean %] WITHIN SUBJECTS
[n=19] FOR THE TWO SITTING POSITIONS

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>POSITION</th>
<th>SIT-A</th>
<th>SIT-B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MEAN</td>
<td>SD</td>
</tr>
<tr>
<td>FVC</td>
<td></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>FEV1</td>
<td></td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>FEF25-75%</td>
<td></td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>DLCO</td>
<td></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>DLCO/VA</td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>DN2%/L</td>
<td></td>
<td>19</td>
<td>10</td>
</tr>
</tbody>
</table>

* Coefficients of variation reported by other investigators:
  For FVC and FEV1: <5% (McCarthy et al, 1975); <3% (Chinn and Lee, 1977)
  For FEF25-75%: 6% (McCarthy et al, 1975; Chinn and Lee, 1977)
  For DLCO: 3.7% (Castillon et al, 1976)
  For DN2%/L: 22% (McCarthy et al, 1975)
TABLE IV

REPRODUCIBILITY OF VARIABLES WITHIN AND BETWEEN THE TWO SESSIONS FOR SITTING: PAIRED t-TESTS AND PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS (r) [n=19]

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>PAIRED t-TEST</th>
<th>PEARSON r</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t</td>
<td>p LEVEL</td>
</tr>
<tr>
<td>FVC</td>
<td>0.05</td>
<td>0.97</td>
</tr>
<tr>
<td>FEV1</td>
<td>1.07</td>
<td>0.30</td>
</tr>
<tr>
<td>FEF25-75%</td>
<td>1.51</td>
<td>0.15</td>
</tr>
<tr>
<td>DLCO</td>
<td>0.67</td>
<td>0.51</td>
</tr>
<tr>
<td>DLCO/VA</td>
<td>1.00</td>
<td>0.33</td>
</tr>
<tr>
<td>DN2%/L</td>
<td>-0.74</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Legend:
FVC - forced vital capacity
FEV1 - forced expiratory volume in one second
FEF25-75% - forced expiratory flow over the middle half of the forced vital capacity
DLCO - pulmonary diffusing capacity for carbon monoxide
DLCO/VA - pulmonary diffusing capacity for CO per unit of alveolar volume
DN2%/L - slope of Phase III of the single breath nitrogen test

mean (diff) - mean difference between % predicted values for the two sitting positions (sit-A - sit B)
DISCUSSION

COMPARISON OF LUNG FUNCTION INDICES OBTAINED WITH SENSORMEDICS 2200 AND NORMS

One way of determining the validity of a new clinical measurement tool is to establish whether the results for known healthy subjects agree with established norms. The present study describes a "normal" older population, based on a questionnaire of medical history and general activity, and includes ex-smokers, two subjects on antihypertensive medication, and another three subjects on anti-anginal medication. In the absence of physical examinations and diagnostic aids such as chest x-rays, we were particularly interested in establishing the normality of the subject group with respect to their lung function. As expected, individual data expressed as a percent of a predicted value for each dependent variable resulted in widespread ranges. To establish that no individual fell below (for spirometric tests and DLCO) or above (for DN2%/L) an accepted limit, we compared each subject's data for each variable in the sitting position with the appropriate 95% confidence interval for that variable. All subjects were categorized as having normal values with the exception of three individuals whose values for FEF25-75% fell below the 95% confidence interval. Thus, overall these results provided us with added confidence that our subjects had normal pulmonary function. Collectively, these findings lent support to the use of the SensorMedics 2200 as a measurement instrument.

An important step in establishing the acceptability of a new clinical or research tool is to compare its results with those of an established system. Diffusing capacity results from the SensorMedics 2200 system have compared favorably with those obtained from the PK Morgan Pulmonary Function System (Model Transfer Test USA), a well-established system that meets ATS standards and is regularly used for assessment of lung
function at the Vancouver General Hospital Pulmonary Function Laboratory. For example, in a group of 64 patients with lung lesions who were being evaluated for possible malignancy, the mean DLCO from the SensorMedics 2200 (70.7 percent of predicted) agreed closely with the mean DLCO from the traditional PK Morgan system (69.1 percent of predicted) (Abboud, 1991, personal communication). In a similar comparative study of 43 patients with interstitial lung disease, the mean DLCO from the SensorMedics 2200 (54.7 percent of predicted) did not differ from the mean DLCO from the Morgan system (56.5 percent of predicted). On the basis of these results, we were confident with the acceptability of the SensorMedics 2200 as a tool for measuring DLCO.

REPRODUCIBILITY

For each of the dependent variables, the within-subject variability for both Sit-A and Sit-B, expressed as a coefficient of variation, agreed with that reported by other investigators (McCarthy et al, 1975; Castillon et al, 1976; Chinn and Lee, 1977). The results of the other test-retest assessments of reproducibility in this study, i.e. paired t-tests and Pearson product-moment correlation coefficients, were also favorable. This conclusion was based on the absence of significant mean differences and the presence of significant correlations between measures recorded in the two sitting test sessions.

THE EFFECT OF A POSITION CHANGE FROM SITTING TO SIDE LYING ON EACH DEPENDENT VARIABLE

i. Spirometric variables

From the summary of the descriptive statistics and results of the analyses shown in Table I, FVC, FEV1, and FEF25-75% were lower in both left and right side lying than
in the sitting position. The majority of previous studies, which compare spirometric measures taken in sitting and in recumbent positions, have investigated FVC in sitting and in supine rather than in side lying (Craig et al, 1960; Agostini and Hyatt 1986; Pistelli et al, 1991). The reduction in FVC from sitting to recumbency observed in the present study is in agreement with these studies, supporting that the effect of side lying on FVC is similar to that observed in supine. Behrakis et al (1983), who are among the few investigators to study the effect of side lying on lung function, reported similar findings for FVC. The decrease in FVC in recumbency may reflect both increased thoracic blood volume (due to the gravitational facilitation of venous return) and cephalad displacement of the diaphragm (caused by abdominal encroachment). In side lying, even though only the dependent hemidiaphragm is displaced, the effect on FVC appears to be similar to that in supine.

The significant decrease in FEV1 in side lying compared to sitting is in agreement with the relatively few studies which report changes in FEV1 with recumbency (Norregaard, 1989; Pistelli 1991). Although direct comparison with these studies cannot be made as the recumbent position varies between side lying (present study only) and supine, the similarity of results support that recumbent positions compromise expiratory flow. The cause of the obstructive process, which could be due to an increase in airway resistance or a decrease in elastic recoil of the lung, presumably affecting the larger upper airways, is not apparent from the present study. Care was taken to position subjects so that the head was in alignment with the trunk and in a neutral position (in both sitting and side lying). This neutral position was adopted to avoid extraneous stress on the upper airways. Anthonisen (1986) has reported that hyperextension of the neck results in an increase in FEV1, secondary to elongation and stiffening of the trachea, thereby facilitating airflow. Conversely, the relaxed recumbent positions examined in the present
study may effectively shorten and increase the compliance of the airways, so rather than augmenting forced expiratory maneuvers, these maneuvers are reduced.

The FEF25-75%, which is generally considered to be a more sensitive test than FEV1 of small airway obstruction (Bates, 1989; Ruppel, 1991) was also significantly decreased in side lying compared to sitting. Similar mechanisms to those underlying reductions in FEV1 may be responsible. For example, side lying may cause a decrease in the cross-sectional area of the medium-sized and small airways, thereby increasing airway resistance. Because we studied an older age group, the decrease in elastic recoil of the lung with aging may have contributed further to such positional changes in these airways. Comparison of our results with those from a younger age group will shed light on this issue.

In contrast to other spirometric variables, FEV1/FVC showed a significant decrease from sitting to left side lying but not to right side lying, suggesting an increase in airway obstruction specific to the left side lying position. While the mean percent predicted values for FEV1/FVC in both sitting (90%) and left side lying (86%) are both far above the 65% "hallmark of obstructive disease" (Ruppel, 1991), the results further support that left side lying may have altered respiratory mechanics and/or the interaction of the heart and lungs in our subject group in some way. The primary anatomical difference between the left and right lung is the presence of the heart on the left, which may apply pressure on the small airways of the left lung during left-side lying. However, as the FEF25-75% was not different between right and left side lying, it is unlikely that airway compression due to the weight of the heart could fully explain the side-related difference in FEV1/FVC.
ii. DN2%/L

DN2%/L was significantly higher in left side lying compared to Sit-A but not higher in right side lying compared to Sit-B. These results for older subjects contrast with those for younger subjects. In a study of 17 young healthy subjects (Ross et al, 1992), DN2%/L was significantly higher in right side lying, both horizontal and head-down positions, than in sitting. The left side lying position was not studied by these investigators. Intraregional differences were thought to be important in explaining their results. In the present study, in which subjects were considerably older, intraregional differences may have an even greater role. From consideration of pleural pressure gradients alone, a smaller gradient in side lying (due to the decrease in vertical lung height from sitting to side lying) would be reflected by a decrease in ventilatory inhomogeneity and hence by a lower DN2%/L. However, the pleural pressure gradient accounts for interregional inhomogeneity only; intraregional inhomogeneity is also expected to be significant in an older population and may explain the increase in DN2%/L that was seen in side lying.

The mechanisms underlying the greater ventilatory inhomogeneity in side lying compared to sitting could reflect several factors that affect the distribution of ventilation, especially in an older population. There is a general consensus in the literature that key contributory factors include airway closure and increased pulmonary time constants. Airway closure, which functionally dissociates peripheral airways from central airways, has been shown to increase ventilatory inhomogeneity in seated subjects (Engel et al, 1975; Crawford et al, 1989). This finding is related to the inhomogeneity of airway closure (i.e. some small airways may be open while others, which are in close proximity and subjected to the same distending pressure, may be closed). In healthy young seated subjects, in whom FRC exceeds closing capacity, airway closure would contribute
minimally to ventilatory inhomogeneity; however, when closing capacity exceeds FRC, which can be detected by middle age, inhomogeneous airway closure may be a significant determinant of ventilation distribution and progressively so with advancing age (Craig et al., 1971; Leblanc et al., 1970). Furthermore, the decrease in FRC which accompanies recumbency would be expected to favor an increase in airway closure and hence an increase in ventilatory inhomogeneity.

As described by Otis et al. (1956), the concept of pulmonary time constants explains the variable rate of gas entry into independently ventilated lung units. Increased pulmonary time constants, caused by regional changes in airway resistance and compliance, and leading to varying degrees of filling of lung units, can increase the inhomogeneity of ventilation (Bates, 1989). From determinations of lung resistance and lung compliance in different body positions, Behrakis et al. (1983) concluded that pulmonary time constants overall were greater in side lying compared to sitting in healthy young adults. This conclusion was based on the disproportionate increase in lung resistance in side lying (40% greater than in sitting) compared to the decrease in lung compliance (10% less than in sitting); the product of resistance and compliance (i.e. the pulmonary time constant) was thus greater in side lying than in sitting. Michels et al. (1991) compared supine to sitting and found a similar position-related increase in resistance of the respiratory system in a healthy group of adults (supine compared to sitting) (subjects 20 to 67 years of age). Furthermore, they found that in a subgroup of young subjects the increase was more marked in smokers than nonsmokers. In addition, in smokers versus nonsmokers the increase was more marked with aging, such that over the age of 50 years, both nonsmokers and smokers demonstrated position-related increases in resistance that were of the same magnitude. Although resistance was not measured in the present study, the increase in ventilatory inhomogeneity in side lying is likely explained in part by an increase in pulmonary time constants. The older age of our
group favors this proposition. The cause of an increase in airway resistance between positions is unclear; Behrakis et al (1983) suggested that changes in geometry of the upper airways and/or the aperture of the glottis may be contribute to this effect. Michels et al (1991) proposed that intrinsic narrowing of the peripheral airways of smokers may be more pronounced in recumbency than in sitting.

On the basis of the above discussion, one would anticipate that, in comparison to the sitting position, both left and right side lying would reflect the effects of airway closure and increased pulmonary time constants with an increased ventilatory inhomogeneity. What then, in the present study, could account for the difference between left and right side lying that was observed for DN2%/L when compared to sitting? The answer may be related to yet another factor that may affect ventilatory inhomogeneity to an increasing degree with advancing age, namely the compressive effect of the heart on the surrounding lung parenchyma. From age 20 to age 70 in a healthy population, the weight of the heart increases by 20 percent and the volume of the heart increases by approximately eight percent (Astrand and Rodahl, 1970). The increased weight and volume would be expected to increase compressive forces, particularly those on the left lung while in left side lying due to the anatomical position of the heart. The compression of airways, alveoli, and blood vessels in this position may contribute to an increase the inhomogeneity of ventilation. In contrast, the right lung is somewhat protected from the compressive effects of the heart due to the intervening mediastinal structures and further the impact of the heart on pulmonary function in right side lying may be countered by the heart being less mobile in the older versus the younger individual.
iii. Diffusing capacity variables

The effect of recumbency on diffusing capacity is conflicting in the literature and may reflect age-related factors. The lack of a significant difference in DLCO or DLCO/VA between sitting and either left or right side lying in older subjects is consistent with the work of Stam et al (1991), although the latter investigators used supine (versus side lying) as the recumbent position. However, these findings are in contrast to those of many investigators who report increases of up to 15 percent in DLCO and DLCO/VA from sitting to a recumbent position (commonly supine) (Bates and Pearce, 1956; Ogilvie, 1957; Stokes and Nadel, 1981). This discrepancy may be explained in part by a greater unevenness of DLCO/VA through the lung in side lying compared to supine (due to the fact that the transverse diameter of the chest is greater than the posterior-anterior diameter). Furthermore, few investigators have targeted an older population for the study of position-related changes. It is known that DLCO decreases with increasing age; Georges et al (1978) attribute the decrease to a decline in Dm (the membrane component of DLCO) after the age of 40 and a decrease in Vc (pulmonary capillary blood volume) after the age of 60. In addition, the anatomic changes associated with aging which affect Dm and Vc may account for the apparent differences in response to a position change compared to a young population. For example, Brody and Thurlbeck (1986) describe a loss of alveolar surface area, a possible decrease in number of pulmonary capillaries, and an increase in the inner diameter of alveoli (which may affect the mixing of gases by diffusion) as morphologic changes accompanying aging. These changes may reduce the increase of Vc from sitting to recumbency and be reflected by a constancy of DLCO between positions. However, further study of underlying mechanisms is required in light of reports that there is no significant difference in the distribution of pulmonary perfusion between older versus younger individuals (Kronenberg et al, 1972) and little change in pulmonary capillary density (Knudson, 1986).
COMPARISON OF THE EFFECT OF SIDE LYING ON EACH DEPENDENT VARIABLE

Although some of the dependent variables showed a significant change from sitting to left side lying but not from sitting to right side lying (as discussed above), none of the dependent variables showed a significant difference between left and right side lying. This combination of significant and nonsignificant findings may be due to (1) the fact that left and right side lying were tested on different days, introducing the factor of day-to-day variability, and (2) changes from sitting to right side lying being less pronounced than changes from sitting to left sidelying.

The similarity of the results for left side lying and right side lying are in agreement with the results of Behrakis et al (1983); one of the few studies comparing lung function in the side lying positions. These investigators reported no significant differences between the side lying positions for VC, expiratory reserve volume, static and dynamic compliance of the lung, resistance of the lung, or pulmonary time constants in a young group of subjects. In other studies of the side lying position, there is either the selection of only one of the side lying positions (usually the right) (Roussos et al 1977a, 1977b; Chevrolet et al, 1989; Ross et al, 1992) or no reported differentiation between left and right side lying (Kaneko et al, 1966; Hazlett and Watson, 1971; Roussos et al, 1976).

In healthy younger adults there is no reason to suspect a significant difference in lung function between left and right side lying. However, in an older population, the age-related variation in cardiopulmonary status, for example, the increase in weight and volume of the heart or changes in mediastinal compliance, may result in differences in function between left and right side lying. Thus, age-related effects on pulmonary function in recumbent positions may have a more significant impact than previously recognized. Furthermore, in the presence of cardiopulmonary or cardiovascular disease,
position-related effects on cardiopulmonary status may be accentuated in left and right side lying. For example, Zack et al (1974) reported that in 13 patients (ages not reported) with equally distributed bilateral lung disease, arterial oxygen tension was generally higher in right side lying than left side lying, whereas in six control subjects (mean age 25 years) there was no difference in arterial oxygen tension between side lying positions. The patient response was attributed to the smaller volume of the left lung and compression of the heart on the left lung in left side lying. The morphological changes in the lung that are associated with aging could have a similar effect if the changes are unequally distributed between the left and right lungs; however, there is no evidence to suggest that this is the case. Regional age-related changes in the lung related have not been reported other than a greater degree of emphysematous change (considered as a normal part of the aging process in non-smokers) in the lower zones compared to the upper zones of the lung (Brody and Thurlbeck, 1986).

INTERRELATIONSHIPS BETWEEN THE DEPENDENT VARIABLES

Of the various individual comparisons made between the dependent variables (Table II), only FVC versus DLCO in side lying (both left and right side lying) were statistically significant. In Sit-A the correlation coefficient for FVC versus DLCO approached the 0.05 significance level ($r=0.44$, df=17, $p=0.06$). The directional aspect of this interrelationship, i.e. an increase in DLCO with an increase in FVC, has been described previously. For example, this observation was reported by Van Ganse et al (1972) for a group of 142 subjects, ranging in age from 24 to 79 years, in the sitting position. The positive correlation between FVC and DLCO is expected as DLCO increases with increasing volume of gas inspired during the test maneuver (Ogilvie, 1957; Cadigan, 1961; Bates, 1989). For example, Rose et al (1979), in a study of 7 healthy young adults, reported that the single-breath DLCO was 18% greater when the test was
performed near TLC versus near FRC. The underlying physiological mechanism is likely an increase in effective surface area of the lung as lung volume increases, however, enhanced venous return with a vital capacity breath may contribute. Regardless of the mechanism, the presence of such a relationship between DLCO and FVC emphasizes the importance of taking into account lung volumes when making comparisons of DLCO between individuals.

Diffusing capacity is known to be affected not only by lung volume but also by inhomogeneities within the lung, for example the mismatch of alveolar ventilation and perfusion (Piiper and Sikand, 1966; Chinet et al, 1971; Ruppel, 1991). Furthermore, these inhomogeneities are known to exist to some extent even in normal lungs and are known to increase with age. Thus, a negative correlation between DLCO and DN2%/L would be predicted, but this was not observed in the present study. Inhomogeneities such as ventilation to perfusion matching may have been too small in the present group of subjects to be detected by the selected tests of lung function. Indeed, even in patients with obstructive airway disease such as bronchitis, only markedly abnormal ventilation to perfusion patterns may reduce DLCO (Ruppel, 1991). Furthermore, different methods of measuring DLCO have varying sensitivities to inhomogeneity. The single breath method used in this study is less affected by ventilation to perfusion mismatch than are steady-state methods, in which the subject breathes a low concentration of carbon monoxide for several minutes (Van Kessel, 1982).
CONCLUSIONS

1. With the SensorMedics 2200, we were able to obtain measures for several indices that are reflective of processes integral to oxygen transport. In the sitting position, measures for spirometry, homogeneity of ventilation, and diffusing capacity had high test-retest reproducibility and the coefficients of variation for all dependent variables were comparable to those in the literature. In addition, based on unpublished reports of diffusing capacity measures made with this system compared to an established system, and on the present results for healthy older subjects, the SensorMedics gave predictable results. The SensorMedics 2200 proved to be readily adaptable to measuring the variables of interest in different body positions.

2. We conclude that in healthy older persons in side lying (versus sitting) there are decreases in forced vital capacity, forced expiratory volume in one second and forced expiratory flow between 25 and 75% of the vital capacity that are comparable to those reported for younger persons. The quantitative aspect of this similarity between older and younger persons requires further study.

3. We conclude that in healthy older persons in side lying (versus sitting) there is no change in diffusing capacity. This finding supports that side lying may not induce comparable changes in pulmonary capillary blood volume and venous return that are reported for the supine position (and which explain the reported increase in diffusing capacity in supine). Based on the supine measurements reported in the literature, side lying versus supine may have a differential effect on diffusing capacity. Whether or not this phenomenon is specific to subject age requires further study.
4. We conclude that left and right side lying may have differential effects on the homogeneity of ventilation in healthy older subjects. We observed no change in the slope of Phase III of the single-breath nitrogen test between sitting and right side lying (in contrast to younger subjects, who have been previously reported to show an increase between these positions); however, we observed an increase in this variable between sitting and left side lying. These observations support the conclusion that the effect of side lying on older subjects has a more profound effect on ventilation homogeneity than has been previously recognized. Marked age-related increases in heart mass and volume and/or age-related changes in mediastinal deformability may contribute to this relationship.

5. The results of this study support that body position has a profound effect on respiratory mechanics. In recumbency, contributing factors likely include external compression of the chest wall, impingement of the abdominal contents on the diaphragm, compression of airways and blood vessels by the heart, and the age-related increase in the mass and volume of the heart. Further studies to elucidate the effect of body position on the respiratory mechanics of healthy older versus younger persons are warranted. In particular, studies are needed to elucidate the mechanisms of the apparent increase in airflow resistance and reduced lung compliance in side lying.

6. The results of this work have implications for the positioning of hospitalized patients with or without cardiopulmonary disease. Specific body positions may maintain, improve, or adversely affect oxygen transport. The adverse effects of unfavorable positions may be compounded by age, smoking history, immobility, breathing at low lung volumes, and cardiopulmonary disease. Clinical trials are needed to investigate
these relationships so that body positioning can be used therapeutically to the best advantage of a specific individual.
REFERENCES


Hutchinson J. [1846] On the capacity of the lungs, and on the respiratory functions, with a view of establishing a precise and easy method of detecting disease by the spirometer. Med Clin Transactions 29:139.


APPENDICES

A. Questionnaire: General Activity Level and Medical History

B. Individual Subject Characteristics and Individual Data for Each of the Dependent Variables
APPENDIX A

LUNG FUNCTION STUDY: SCHOOL OF REHABILITATION MEDICINE, UBC

Name: ___________________________ ID: ____________________

Today's date: ____________________

Your Doctor's name and telephone #: ____________________________

Please complete this questionnaire by placing a check mark or an answer on the line next to the most appropriate response.

1. In the last three hours have you exercised or engaged in any unusually strenuous activity? ______
   If yes, what? ___________________________________________________________

2. Over the past week, did you get some form of regular exercise? ______
   If so, what type? ______________________________________________________
   what intensity? (mild, moderate, heavy) _________________________________
   how often? ___________________________________________________________
   how long have you been doing this program for? __________

3. Over the last 24 hours, how far could you walk on level ground at a comfortable pace (in good weather)?
   ____ 1 block or less
   ____ 2 blocks
   ____ 3 blocks
   ____ 4 blocks
   ____ 5 or more blocks

4. Check the ONE category which best describes the maximal LEVEL of activity that you feel you could have attained over the last 3 days (you may not have actually performed the activities listed):

   a. self-care
      reading or watching TV
      driving a car
      working at a desk
      walking at 1 mph
   b. cooking
      fixing a car
      bowling
      golfing with a motorcart
      walking at 2 mph
      bicycling at 5 mph
   c. general housework
      pushing a light lawnmower
      badminton (doubles)
      golfing with a handcart
      walking at 3 mph
      bicycling at 5 mph
   d. heavy housework
      raking leaves or grass
      tennis (doubles)
      golfing (carrying clubs)
      dancing
   e. digging in the garden
      hiking or skiing
      walking at 4 mph
      bicycling at 10 mph
   f. light downhill skiing
      tennis (singles)
      walking/jogging at 5 mph
      bicycling at 11 mph
      mowing lawn with hand mower
5. In the last 24 hours, how would you best describe your shortness of breath:
   ____ not troubled with breathlessness except with strenuous exercise
   ____ troubled by shortness of breath when hurrying on the level or walking up a slight hill
   ____ walk slower than people of the same age on the level because of breathlessness or have to stop for breath when walking at own pace on the level
   ____ stop for breath after walking about 100 yards or after a few minutes on the level
   ____ too breathless to leave the house or breathless when dressing or undressing

6. Did you have a normal sleep last night and feel reasonably rested this morning? ______

7. Over the last 3 days, how many hours of continuous sleep did you usually get in a night?
   ____ 7 hours or more
   ____ 6 hours
   ____ 5 hours
   ____ 4 hours or less

8. Over the last 3 days, how many pillows (under your head) did you sleep with?
   ____ 1 pillow or no pillow
   ____ 2 or more pillows

9. What position(s) do you find most comfortable to sleep or rest in?
   ________________________________
   Are there positions that you find particularly uncomfortable to rest in or to stay in for a period of about an hour? ______
   If so, which positions and why? ______________________________
   ________________________________

10. Do you smoke? ______
    If you are a smoker:
    How much do you smoke? ________________________________
    What do you smoke? (cigarettes, cigars, pipe) ______
    How long have you been a smoker for? ___________________
    Have you smoked in the last 24 hours? ______ If yes, how much? __________________
    how long ago? ___________________
11. If you are an ex-smoker, when did you quit? __________
    When you did smoke, what did you smoke?
    (cigarettes, cigars, pipe) __________
    for how long? __________

12. Did you have a cough in the last 24 hours? __________
    If you did, did the cough occur:
    ___ only in the morning (when you first got up)
    ___ with activity such as 2 flights of stairs
    ___ with activity such as 1 flight of stairs
    ___ during the day (not related to activity)
    Was the cough productive of phlegm? __________
    If it was, when was it productive? __________
    was the amount:
    ___ less than usual
    ___ the same as usual
    ___ more than usual

13. Are you aware of coughing more when in certain positions? __________
    If so, which positions? ______________________

14. Are you taking any medications at present? __________
    If so, what are they, what dosage are you taking,
    and why are you taking them?
    ______________________
    ______________________
    ______________________

15. Do you have any heart irregularities? __________
    If so, what type? ______________________

16. In the last three hours have you ingested any caffeine in the form
    of coffee, tea, hot chocolate or soft drinks? __________

17. In the last three hours have you ingested a heavy meal? __________

18. Has your health been normal over the past week? __________
APPENDIX B

TABLE 1

SUBJECT CHARACTERISTICS

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>GENDER</th>
<th>AGE (yr)</th>
<th>SMOKING</th>
<th>HEIGHT (cm)</th>
<th>WEIGHT (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>53</td>
<td>N</td>
<td>180</td>
<td>73</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>73</td>
<td>N</td>
<td>178</td>
<td>62</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>59</td>
<td>N</td>
<td>163</td>
<td>57</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>62</td>
<td>N</td>
<td>163</td>
<td>66</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>64</td>
<td>X</td>
<td>157</td>
<td>58</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>51</td>
<td>X</td>
<td>178</td>
<td>73</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>73</td>
<td>N</td>
<td>168</td>
<td>55</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>67</td>
<td>X</td>
<td>176</td>
<td>70</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>68</td>
<td>N</td>
<td>163</td>
<td>76</td>
</tr>
<tr>
<td>10*</td>
<td>F</td>
<td>57</td>
<td>N</td>
<td>145</td>
<td>45</td>
</tr>
<tr>
<td>11**</td>
<td>M</td>
<td>53</td>
<td>X</td>
<td>183</td>
<td>93</td>
</tr>
<tr>
<td>12</td>
<td>F</td>
<td>59</td>
<td>N</td>
<td>163</td>
<td>52</td>
</tr>
<tr>
<td>13</td>
<td>F</td>
<td>60</td>
<td>X</td>
<td>155</td>
<td>52</td>
</tr>
<tr>
<td>14</td>
<td>F</td>
<td>74</td>
<td>X</td>
<td>165</td>
<td>61</td>
</tr>
<tr>
<td>15</td>
<td>M</td>
<td>63</td>
<td>X</td>
<td>183</td>
<td>83</td>
</tr>
<tr>
<td>16</td>
<td>F</td>
<td>63</td>
<td>X</td>
<td>160</td>
<td>46</td>
</tr>
<tr>
<td>17</td>
<td>M</td>
<td>72</td>
<td>X</td>
<td>163</td>
<td>56</td>
</tr>
<tr>
<td>18</td>
<td>F</td>
<td>59</td>
<td>N</td>
<td>157</td>
<td>57</td>
</tr>
<tr>
<td>19</td>
<td>F</td>
<td>64</td>
<td>X</td>
<td>155</td>
<td>64</td>
</tr>
</tbody>
</table>

Legend: M - male; F - female; N - lifetime nonsmoker; X - exsmoker
*Philippino subject
**North American Native subject
TABLE 2

INDIVIDUAL DATA FOR FORCED VITAL CAPACITY (FVC) IN ALL TEST POSITIONS

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>FVC (%Predicted)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SIT-A</td>
</tr>
<tr>
<td>1</td>
<td>112</td>
</tr>
<tr>
<td>2</td>
<td>114</td>
</tr>
<tr>
<td>3</td>
<td>143</td>
</tr>
<tr>
<td>4</td>
<td>118</td>
</tr>
<tr>
<td>5</td>
<td>118</td>
</tr>
<tr>
<td>6</td>
<td>111</td>
</tr>
<tr>
<td>7</td>
<td>114</td>
</tr>
<tr>
<td>8</td>
<td>97</td>
</tr>
<tr>
<td>9</td>
<td>106</td>
</tr>
<tr>
<td>10</td>
<td>104</td>
</tr>
<tr>
<td>11</td>
<td>93</td>
</tr>
<tr>
<td>12</td>
<td>124</td>
</tr>
<tr>
<td>13</td>
<td>131</td>
</tr>
<tr>
<td>14</td>
<td>119</td>
</tr>
<tr>
<td>15</td>
<td>87</td>
</tr>
<tr>
<td>16</td>
<td>129</td>
</tr>
<tr>
<td>17</td>
<td>105</td>
</tr>
<tr>
<td>18</td>
<td>111</td>
</tr>
<tr>
<td>19</td>
<td>119</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>MEAN</th>
<th>110</th>
<th>113</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD</td>
<td>13</td>
<td>13</td>
<td>14</td>
</tr>
</tbody>
</table>

Legend: Sit-A=sitting position tested during the session which included left side lying
LSL=left side lying
Sit-B=sitting position tested during the session which included right side lying
RSL=right side lying

*%Predicted values of Crapo et al, 1981
TABLE 3

INDIVIDUAL DATA FOR FEV1 IN ALL TEST POSITIONS

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>FEV1 (%Predicted)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SIT-A</td>
</tr>
<tr>
<td>1</td>
<td>110</td>
</tr>
<tr>
<td>2</td>
<td>111</td>
</tr>
<tr>
<td>3</td>
<td>132</td>
</tr>
<tr>
<td>4</td>
<td>115</td>
</tr>
<tr>
<td>5</td>
<td>110</td>
</tr>
<tr>
<td>6</td>
<td>86</td>
</tr>
<tr>
<td>7</td>
<td>101</td>
</tr>
<tr>
<td>8</td>
<td>92</td>
</tr>
<tr>
<td>9</td>
<td>85</td>
</tr>
<tr>
<td>10</td>
<td>89</td>
</tr>
<tr>
<td>11</td>
<td>57</td>
</tr>
<tr>
<td>12</td>
<td>111</td>
</tr>
<tr>
<td>13</td>
<td>119</td>
</tr>
<tr>
<td>14</td>
<td>123</td>
</tr>
<tr>
<td>15</td>
<td>82</td>
</tr>
<tr>
<td>16</td>
<td>100</td>
</tr>
<tr>
<td>17</td>
<td>86</td>
</tr>
<tr>
<td>18</td>
<td>102</td>
</tr>
<tr>
<td>19</td>
<td>108</td>
</tr>
<tr>
<td>MEAN</td>
<td>101</td>
</tr>
<tr>
<td>SD</td>
<td>18</td>
</tr>
</tbody>
</table>

LEGEND:  
Sit A = sitting position tested during the session which included left side lying  
Sit-B = sitting position tested during the session which included right side lying  
LSL = left side lying  
RSL = right side lying  
FEV1 = forced expiratory volume in one second  
* %Predicted values of Crapo et al, 1981
TABLE 4

INDIVIDUAL DATA FOR FEF25-75% IN ALL TEST POSITIONS

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>POSITION</th>
<th>SIT-A</th>
<th>LSL</th>
<th>SIT-B</th>
<th>RSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>106</td>
<td>88</td>
<td>99</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>96</td>
<td>97</td>
<td>98</td>
<td>104</td>
</tr>
<tr>
<td>3</td>
<td>102</td>
<td>87</td>
<td>94</td>
<td>82</td>
</tr>
<tr>
<td>4</td>
<td>117</td>
<td>95</td>
<td>96</td>
<td>99</td>
</tr>
<tr>
<td>5</td>
<td>85</td>
<td>70</td>
<td>67</td>
<td>68</td>
</tr>
<tr>
<td>6</td>
<td>48</td>
<td>41</td>
<td>41</td>
<td>39</td>
</tr>
<tr>
<td>7</td>
<td>59</td>
<td>68</td>
<td>61</td>
<td>68</td>
</tr>
<tr>
<td>8</td>
<td>74</td>
<td>59</td>
<td>35</td>
<td>31</td>
</tr>
<tr>
<td>9</td>
<td>46</td>
<td>46</td>
<td>53</td>
<td>44</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>37</td>
<td>76</td>
<td>37</td>
</tr>
<tr>
<td>11</td>
<td>38</td>
<td>23</td>
<td>26</td>
<td>32</td>
</tr>
<tr>
<td>12</td>
<td>75</td>
<td>63</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>13</td>
<td>80</td>
<td>60</td>
<td>70</td>
<td>61</td>
</tr>
<tr>
<td>14</td>
<td>136</td>
<td>85</td>
<td>121</td>
<td>98</td>
</tr>
<tr>
<td>15</td>
<td>62</td>
<td>61</td>
<td>61</td>
<td>49</td>
</tr>
<tr>
<td>16</td>
<td>44</td>
<td>45</td>
<td>40</td>
<td>38</td>
</tr>
<tr>
<td>17</td>
<td>39</td>
<td>43</td>
<td>56</td>
<td>44</td>
</tr>
<tr>
<td>18</td>
<td>70</td>
<td>65</td>
<td>78</td>
<td>65</td>
</tr>
<tr>
<td>19</td>
<td>75</td>
<td>65</td>
<td>61</td>
<td>51</td>
</tr>
</tbody>
</table>

Legend: Sit-A=sitting position tested during the session which included left side lying
LSL=left side lying
Sit-B=sitting position tested during the session which included right side lying
RSL=right side lying
FEF25-75%=forced expiratory flow during the middle half of
the forced vital capacity

*%Predicted values of Crapo et al, 1981
TABLE 5

INDIVIDUAL DATA FOR FEV1/FVC IN ALL TEST POSITIONS

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>FEV1/FVC% (%Predicted)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSITION</td>
<td>SIT-A</td>
</tr>
<tr>
<td>1</td>
<td>99</td>
</tr>
<tr>
<td>2</td>
<td>99</td>
</tr>
<tr>
<td>3</td>
<td>93</td>
</tr>
<tr>
<td>4</td>
<td>98</td>
</tr>
<tr>
<td>5</td>
<td>94</td>
</tr>
<tr>
<td>6</td>
<td>78</td>
</tr>
<tr>
<td>7</td>
<td>89</td>
</tr>
<tr>
<td>8</td>
<td>95</td>
</tr>
<tr>
<td>9</td>
<td>89</td>
</tr>
<tr>
<td>10</td>
<td>86</td>
</tr>
<tr>
<td>11</td>
<td>61</td>
</tr>
<tr>
<td>12</td>
<td>90</td>
</tr>
<tr>
<td>13</td>
<td>91</td>
</tr>
<tr>
<td>14</td>
<td>103</td>
</tr>
<tr>
<td>15</td>
<td>95</td>
</tr>
<tr>
<td>16</td>
<td>78</td>
</tr>
<tr>
<td>17</td>
<td>82</td>
</tr>
<tr>
<td>18</td>
<td>93</td>
</tr>
<tr>
<td>19</td>
<td>91</td>
</tr>
</tbody>
</table>

MEAN 90 86 88 87
SD 10 11 11 10

Legend: Sit-A=sitting position tested during the session which included left side lying
LSL=left side lying
Sit-B=sitting position tested during the session which included right side lying
RSL=right side lying
FEV1=forced expiratory volume in one second
FVC=forced vital capacity
TABLE 6

INDIVIDUAL DATA FOR DLCO IN ALL TEST POSITIONS

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>DLCO (%Predicted)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>POSITION</td>
</tr>
<tr>
<td></td>
<td>SIT-A</td>
</tr>
<tr>
<td>1</td>
<td>101</td>
</tr>
<tr>
<td>2</td>
<td>84</td>
</tr>
<tr>
<td>3</td>
<td>116</td>
</tr>
<tr>
<td>4</td>
<td>117</td>
</tr>
<tr>
<td>5</td>
<td>96</td>
</tr>
<tr>
<td>6</td>
<td>116</td>
</tr>
<tr>
<td>7</td>
<td>84</td>
</tr>
<tr>
<td>8</td>
<td>96</td>
</tr>
<tr>
<td>9</td>
<td>101</td>
</tr>
<tr>
<td>10</td>
<td>117</td>
</tr>
<tr>
<td>11</td>
<td>89</td>
</tr>
<tr>
<td>12</td>
<td>117</td>
</tr>
<tr>
<td>13</td>
<td>93</td>
</tr>
<tr>
<td>14</td>
<td>103</td>
</tr>
<tr>
<td>15</td>
<td>84</td>
</tr>
<tr>
<td>16</td>
<td>121</td>
</tr>
<tr>
<td>17</td>
<td>73</td>
</tr>
<tr>
<td>18</td>
<td>111</td>
</tr>
<tr>
<td>19</td>
<td>87</td>
</tr>
<tr>
<td>MEAN</td>
<td>100</td>
</tr>
<tr>
<td>SD</td>
<td>15</td>
</tr>
</tbody>
</table>

Legend: Sit-A=sitting position tested during the session which included left side lying
LSL=left side lying
Sit-B=sitting position tested during the session which included right side lying
RSL=right side lying
DLCO= pulmonary diffusing capacity for carbon monoxide

*%Predicted values of Miller et al, 1983
TABLE 7

INDIVIDUAL DATA FOR DLCO/VA
IN ALL TEST POSITIONS

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>DLCO/VA (%Predicted)*</th>
<th>POSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SIT-A</td>
</tr>
<tr>
<td>1</td>
<td>99</td>
<td>84</td>
</tr>
<tr>
<td>2</td>
<td>76</td>
<td>79</td>
</tr>
<tr>
<td>3</td>
<td>86</td>
<td>99</td>
</tr>
<tr>
<td>4</td>
<td>106</td>
<td>95</td>
</tr>
<tr>
<td>5</td>
<td>93</td>
<td>81</td>
</tr>
<tr>
<td>6</td>
<td>104</td>
<td>101</td>
</tr>
<tr>
<td>7</td>
<td>84</td>
<td>84</td>
</tr>
<tr>
<td>8</td>
<td>89</td>
<td>84</td>
</tr>
<tr>
<td>9</td>
<td>92</td>
<td>94</td>
</tr>
<tr>
<td>10</td>
<td>143</td>
<td>133</td>
</tr>
<tr>
<td>11</td>
<td>93</td>
<td>94</td>
</tr>
<tr>
<td>12</td>
<td>108</td>
<td>111</td>
</tr>
<tr>
<td>13</td>
<td>85</td>
<td>93</td>
</tr>
<tr>
<td>14</td>
<td>112</td>
<td>88</td>
</tr>
<tr>
<td>15</td>
<td>94</td>
<td>93</td>
</tr>
<tr>
<td>16</td>
<td>110</td>
<td>106</td>
</tr>
<tr>
<td>17</td>
<td>83</td>
<td>87</td>
</tr>
<tr>
<td>18</td>
<td>111</td>
<td>101</td>
</tr>
<tr>
<td>19</td>
<td>93</td>
<td>92</td>
</tr>
</tbody>
</table>

|         | MEAN                  | 98        | 95  | 97    | 95    |
|         | SD                    | 15        | 13  | 15    | 16    |

Legend: SIT-A=sitting position tested during the session which included left side lying
LSL=left side lying
SIT-B=sitting position tested during the session which included right side lying
RSL=right side lying
DLCO= pulmonary diffusing capacity for carbon monoxide
per unit alveolar volume

*%Predicted values of Miller et al, 1983
## TABLE 8

**INDIVIDUAL DATA FOR DN2%\%L IN ALL TEST POSITIONS**

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>DN2%%L (%Predicted)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>POSITION</td>
</tr>
<tr>
<td></td>
<td>SIT-A</td>
</tr>
<tr>
<td>1</td>
<td>267</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
</tr>
<tr>
<td>3</td>
<td>119</td>
</tr>
<tr>
<td>4</td>
<td>192</td>
</tr>
<tr>
<td>5</td>
<td>53</td>
</tr>
<tr>
<td>6</td>
<td>158</td>
</tr>
<tr>
<td>7</td>
<td>56</td>
</tr>
<tr>
<td>8</td>
<td>307</td>
</tr>
<tr>
<td>9</td>
<td>136</td>
</tr>
<tr>
<td>10</td>
<td>193</td>
</tr>
<tr>
<td>11</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>100</td>
</tr>
<tr>
<td>13</td>
<td>145</td>
</tr>
<tr>
<td>14</td>
<td>52</td>
</tr>
<tr>
<td>15</td>
<td>131</td>
</tr>
<tr>
<td>16</td>
<td>121</td>
</tr>
<tr>
<td>17</td>
<td>164</td>
</tr>
<tr>
<td>18</td>
<td>82</td>
</tr>
<tr>
<td>19</td>
<td>47</td>
</tr>
<tr>
<td>MEAN</td>
<td>135</td>
</tr>
<tr>
<td>SD</td>
<td>70</td>
</tr>
</tbody>
</table>

Legend: SIT-A=sitting position tested during the session which included left sidelying  
LSL=left sidelying  
SIT-B=sitting position tested during the session which included right sidelying  
RSL=right sidelying  
DN2%\%L=slope of Phase III of the single breath nitrogen test