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Article *in* Physiotherapy Theory and Practice · January 2003

DOI: 10.1080/09593980307958

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Physiotherapy Theory and Practice, 19: 109–119, 2003
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ISSN: 0959-3985 print/1521-0510 online
DOI: 10.1080/09593980390194119

A comparison of tidal volume, breathing frequency, and minute ventilation between two sitting postures in healthy adults

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Few studies have compared the difference in pulmonary function in normal subjects while sitting in an upright posture as compared to a slumped posture. The purpose of this study was to demonstrate differences in tidal volume (TV), breathing frequency (fb), and minute ventilation (V_E) between these two sitting postures in a population of healthy adults.

A sample-of-convenience of 30 adult subjects (17 females and 13 males) participated in the study. Standard spirometry methods were used to measure differences in TV and fb between forward slumped and upright sitting postures. Spirometry data were collected for each subject over a five-minute period in each of the two sitting postures. TV was calculated using V_E and fb data.

Results of repeated measures ANOVA demonstrated statistically significant increases in TV and V_E in the upright sitting when compared to a slumped sitting posture. Breathing frequency was shown to be not significantly different from one posture to the next.

Many have attributed adverse musculoskeletal conditions to poor sitting posture. Results of this study suggest that poor sitting posture may also adversely affect pulmonary function in healthy adults.

INTRODUCTION

One of the most common paradigms in physical therapy is that poor posture will adversely effect the musculoskeletal system. These adverse effects are a component behind many physical therapy interventions and have received considerable attention in the literature. Some

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Accepted for publication 24 December 2002.

assert that sitting in poor postures will result in deleterious effects to the musculoskeletal system (Harms, 1983; La Grone, 1988; Takmitsu et al, 1988; Esses and Moro, 1992; Griegel-Morris, Larson, Mueller-Klaus, and Oatis, 1992; Panjabi, 1992a, 1992b; Christie, Kumar, and Warren, 1995; Weinhoffer, Guyer, Herbert, and Griffith, 1995; Pynt, Higgs, and Mackey, 2001). Significant contribution also has been made by others who have described the biomechanics of the spine and musculoskeletal system that are a result of altered or abnormal spinal mechanics and posture (Harms, 1983; La Grone, 1988; Takmitsu et al, 1988; Esses and Moro, 1992; Griegel-Morris et al, 1992; Panjabi, 1992a, 1992b; Christie et al, 1995; Weinhoffer et al, 1995).

We believe that it is becoming clear that the musculoskeletal system may not be the only body system effected by poor posture. Many research studies have focused on the relationship between scoliosis and pulmonary function (Mellin and Harjula, 1987; DiRocco and Vaccaro, 1988; Kesten, Garfinkel, Wright, and Rebuck, 1991; Upadhyay, Mullafi, Luk, and Leong, 1995) as well as changes in pulmonary function between different gross postures, i.e., sitting, standing, kneeling, supine, prone and sidelying (Castile et al, 1982; Townsend, 1984; Crosbie and Myles, 1985; Dean, 1985; Appel et al, 1986; Nwaobi and Smith, 1986; Paek, Kelly, and McCool, 1990; Smalley et al, 1990; Lalloo, Becklake, and Goldsmith, 1991; Tanskanen, Kytta, and Randell, 1997; Manning, Dean, Ross, and Abboud, 1999; Vilke, Chan, Neuman, and Clausen, 2000). However, little is found in the literature that demonstrates a relationship between changes in sagittal plane spinal posture, i.e. thoracic kyphosis, and changes in pulmonary function. Nwaobi and Smith (1986) demonstrated an improvement in pulmonary function in children with cerebral palsy when seated in a wheelchair with modular inserts for adaptive seating compared to sitting in a regular sling-type wheelchair. This adaptive seating ensured that the child was seated with the head and trunk in an upright position as opposed to the slumped position, which the sling-type wheelchair promoted.

Breathing mechanics are such that compliance and lung ventilation are partially a result of thoracic mobility as well as excursion of the diaphragm. The ability of the thorax to expand during inspiration and to return to resting position during exhalation is dependent on the mobility of the thoracic spine and ribs. A change in the position of the thoracic spine, i.e. scoliosis, may alter the mechanics of the chest wall, which may cause a uniform or asymmetrical change in the ability of the thorax to expand. Investigations on scoliosis have demonstrated that there is a correlation between thoracic spinal posture and the shape and volume of the thoracic cavity, and subsequent lung volumes (Mellin and Harjula, 1987; DiRocco and Vaccaro, 1988; Kesten et al, 1991; Upadhyay et al, 1995). Scoliosis, however, involves changes in spinal posture in three planes. The investigation by Nwaobi and Smith (1986) is the only study that has investigated changes in pulmonary function with changes in sitting spinal posture specifically in the sagittal plane. Based on the results of this study and the anatomical relationship that exists between spinal posture and lung volume, it is reasonable to suggest that a similar relationship exists between pulmonary function and spinal posture in one plane of motion. Therefore, it is the purpose of this study to investigate changes in pulmonary function as they relate to changes in sagittal plane posture in normal subjects while sitting. This is a pilot study for a follow-up study on subjects with pulmonary pathology.

METHOD

Subjects

Data was collected from 30 subjects consisting of 17 females and 13 males. The subjects were recruited from the physical therapy student body at Creighton University. Subject characteristics are summarized in Table 1. Obesity has been shown to cause pulmonary impairment by affecting breathing mechanics and decreasing lung volumes (Bray, 1985; Zerah et al, 1993). Therefore, a height/weight index called the

Table 1
Characteristics of the sample

Characteristic[a]	Gender	Age	Height (cm)	Weight (kg)	BMI[b]
Female	*n* = 17	22.5 ± 1.50	167.2 ± 6.23	64.0 ± 8.14	22.2 ± 2.71
Male	*n* = 13	24.2 ± 2.03	180.8 ± 7.14	84.9 ± 10.35	26.0 ± 3.40
Both	*N* = 30	23.2 ± 1.91	173.1 ± 9.46	73.1 ± 13.85	23.9 ± 3.55

[a] With the exception of Gender, values are reported as means and standard deviations.
[b] Body Mass Index (BMI) calculated using Quetelet Index (kilograms/meters^2) (Smalley et al, 1990).

Body Mass Index (BMI), was used to describe the testing population. Although falling below a particular BMI value was not used as an exclusionary criterion, eight of the subjects fell within 25 and 29 kg/m^2, which is considered mildly obese (Zerah et al, 1993). All subjects were required to read and sign an informed consent statement in compliance with the guidelines set forth by Creighton University. In addition, all subjects met the following criteria for participation in the study: (1) non-smoker, (2) no prior history of pulmonary dysfunction, and (3) no prior history of scoliosis, vertebral fusion, or congenital thoracic malformations.

Measurement Equipment

V_E and fb were measured in both of the two sitting postures using the Aerosport KB1-C Metabolic Analyzer (Medical Graphics Corporation, St. Paul, Minnesota). This spirometry system was calibrated prior to data collection as per protocols specified by the manufacturer. Prior to testing, a standard 10-inch goniometer was used to measure ankle and knee angles at 90° to standardize lower extremity positioning when subjects sat on a height-adjustable, backless stool. The LMI mid-sagittal contour gauge (Life Mechanics Institute, Inc., Salem, Utah) was used to qualitatively describe the two sitting postures as well as to provide tactile feedback to each subject's spine during the duration of the testing. The LMI mid-sagittal contour gauge measures spinal curvature in the sagittal plane by deflection of a series of movable rods, which are in contact with the spinous processes along the entire length of the spine (see Figs. 1 and 2). The curvature of the spine can then be graphically represented by tracing the amount of deflection. The tactile feedback provided by the rods enabled subjects to maintain a continual and consistent sitting posture during the five-minute period of measurement. Each step in the testing process was conducted by the same examiner.

Procedure

After each subject read and signed a consent for participation, measurements of height and weight were taken. Subjects were then screened for exclusionary criteria, which included known prior history of scoliosis, vertebral fusion, congenital malformations of the vertebrae and/or rib cage, or pulmonary dysfunction. Also included was a standard visual screening exam for scoliosis. Subjects were randomly assigned to one of the two sitting postures each subject was to assume initially. Subjects were then fitted with Aerosport spirometry equipment, and instructed to assume either sitting posture A (Fig. 1) followed by B (Fig. 2), or B followed by A. Instruction for assuming sitting posture A included the following:

1. Ankles and knees at 90° with the arms relaxed in the lap,
2. Spine/upper body relaxed so as to sit in a full slumped posture, and
3. Head in the neutral position facing forward, without bending forward at the hips.

Instruction for assuming sitting posture B included the following:

1. Ankles and knees at 90° with the arms relaxed in the lap,
2. Rib cage lifted upward so as to axially extend the spine, and
3. Head in the neutral position facing forward, without bending forward at the hips.

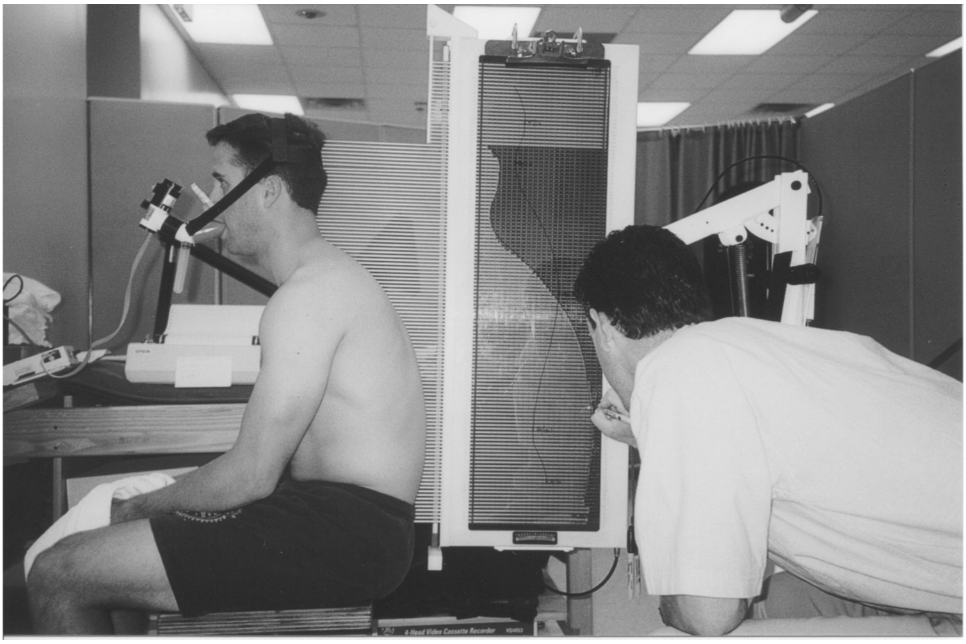

Fig 1 Slumped sitting posture.

In sitting posture A, the subjects were instructed to sit in a full slumped posture. This served to ensure that each of the subjects was maximally slumped forward. After each subject had assumed either sitting posture, V_E and fb were measured every minute over a five-minute

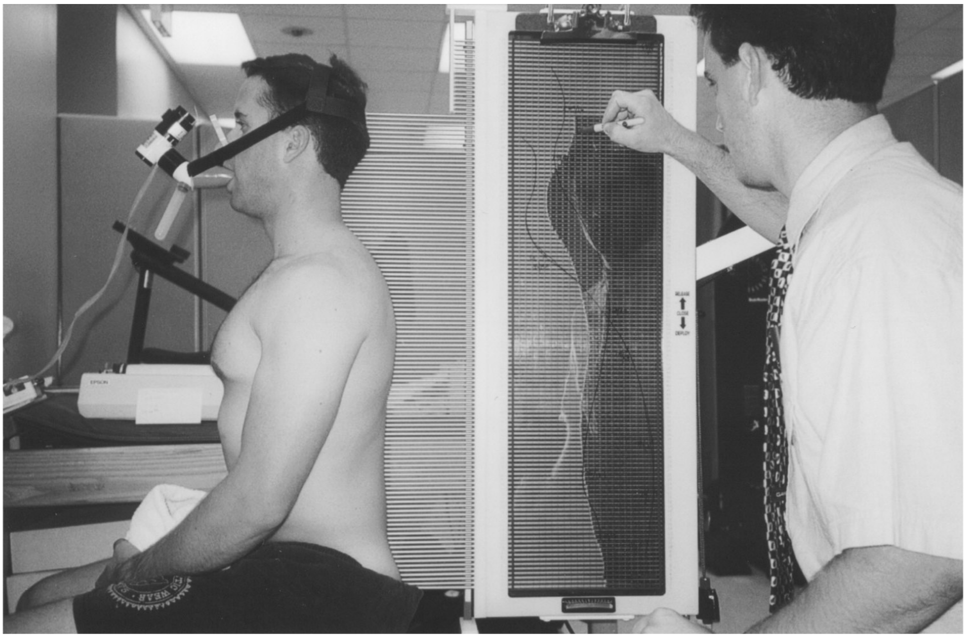

Fig 2 Upright sitting posture.

period. Average TV was calculated for each of the five minutes by dividing fb into V_E. After taking a two-minute standing rest, the subjects were then instructed to assume the other sitting posture. The procedure for measuring V_E and fb was then repeated. No attempt was made to standardize or control depth of breathing. This was done to avoid subject bias as compensatory breathing was a primary study measurement.

Data Analysis

A two factor (posture and time) repeated measures ANOVA was used to assess differences in TV, fb, and V_E data between the two sitting postures (A-slumped vs. B-upright). Level of significance was set at $\propto = .05$. Reliability was established using a subset of the sample. Five randomly selected subjects were retested a second time on another day. Test and retest data (TV, fb and V_E) were graphed individually for each subject and visually analyzed to determine if they presented with the same pattern of response from test to retest. On each graph, the x-axis was time (minutes 1–5) and the y-axis was the variable (TV, fb, and V_E). For a given subject, each variable (test and retest) in the two postures were graphed on one graph for comparison. A dissimilar pattern of response from test to retest between the two postures was operationally defined as poor reliability. A similar pattern of response, such as an overall increase and/or decrease over time for the variable for both testing sessions was defined as reliable. This method of visual analysis of graphs comparing test and retest data was selected because of the small number of subjects selected for retesting.

RESULTS

Table 2 shows the mean values for TV, fb, and V_E between sitting postures (A and B) measured every minute for five minutes. Numerical differences found in TV and V_E can be seen in TV and V_E, but no obvious difference is observed numerically in fb. Differences observed in V_E can be attributed to differences in TV, as TV is determined by fb and V_E.

Results of two factor (posture and time) repeated measures ANOVA are summarized in Table 3. ANOVA results revealed significance only in the main effect of Posture (P). Results also demonstrated that there was no statistical significance for the main effect of Time (T), nor was there any significant interaction effect for the two independent variables of Posture (P) and Time (T). TV (Fig. 3) and V_E (Fig. 4) were shown to be significantly larger during upright sitting when compared to slumped sitting ($p = 0.0002$, $p = 0.0158$ respectively). There was no significant difference noted in fb (Fig. 5) between the two sitting postures tested. Although graphical representation of TV (Fig. 3) and V_E (Fig. 4) demonstrates a pattern of decreasing difference over the five minute testing period, no statistically significant interaction was found between Posture and Time.

The mean difference in V_E between posture A and B was calculated to be an average of 0.78± .18 liters/minute. Significance of this

Table 2
Mean and standard error values for tidal volume, breathing frequency, and minute ventilation in postures A and B measured at 5 minute intervals ($N = 30$)

Dependent variable	Posture	Minute 1	Minute 2	Minute 3	Minute 4	Minute 5
Tidal volume	A[a]	0.52 ± 0.06	0.54 ± 0.06	0.57 ± 0.06	0.57 ± 0.06	0.59 ± 0.06
	B[b]	0.63 ± 0.06	0.67 ± 0.07	0.65 ± 0.07	0.65 ± 0.07	0.65 ± 0.07
Breathing frequency	A	14.6 ± 0.6	14.2 ± 0.6	14.2 ± 0.7	14.0 ± 0.7	14.3 ± 0.7
	B	14.2 ± 0.7	13.8 ± 0.8	13.9 ± 0.8	13.9 ± 0.8	14.3 ± 0.8
Minute ventilation	A	7.21 ± 0.66	7.63 ± 0.69	7.43 ± 0.66	7.67 ± 0.72	7.72 ± 0.65
	B	8.30 ± 0.73	8.42 ± 0.75	8.32 ± 0.71	8.25 ± 0.76	8.32 ± 0.73

[a] A represents the slumped posture.
[b] B represents the upright posture.

Table 3
Summary of two-way repeated measures analysis of variance: Tidal volume, breathing frequency, and minute ventilation tested in slumped and upright sitting posture over five minutes ($N = 30$, $\propto = 0.05$)

	Degrees of freedom	*F*	*p*
Main effect for posture			
TV	1	18.872	0.0002
V_E	1	6.566	0.0158
fb	1	0.364	0.5508
Main effect for time			
TV	4	1.726	0.1479
V_E	4	1.497	0.2061
fb	4	0.577	0.6825
Interaction between time and posture			
TV	4	1.469	0.2146
V_E	4	0.517	0.7257
fb	4	0.585	0.6764

value becomes clear during later discussion of potential cumulative effects.

Mean TV and V_E data from test-retest subjects ($n = 5$) were graphed and demonstrated the same pattern of response from day one to the next. Therefore, testing of TV and V_E was considered to be reliable. However, mean fb data demonstrated no repeatable pattern from one day to the next. Thus, based on our definition of reliability adopted for this study, measures of fb cannot be considered reliable.

DISCUSSION

The results of this study suggest that there is a difference in measures of pulmonary function (TV and V_E) between two sitting postures. The hypothesis of this study was that a decrease in TV and a subsequent increase in fb would occur in the slumped sitting posture. It is reasonable to expect this inverse relationship to occur when this posture is assumed, since the position of the spine and rib cage tend to alter the shape and volume of the chest and abdominal cavity restricting their expansion (Nwaobi and Smith, 1986). If this decreased volume of air to the lungs is significant enough, the homeostatic processes of the body may cause an increase in fb in order to keep ventilation constant.

This study demonstrated that a decrease in tidal volume is associated with a slumped sitting posture. V_E also was significantly decreased in

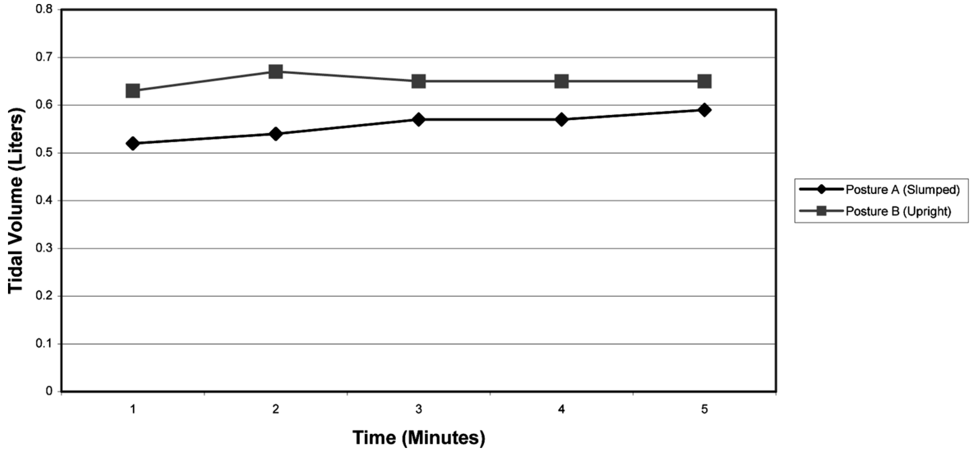

Fig 3

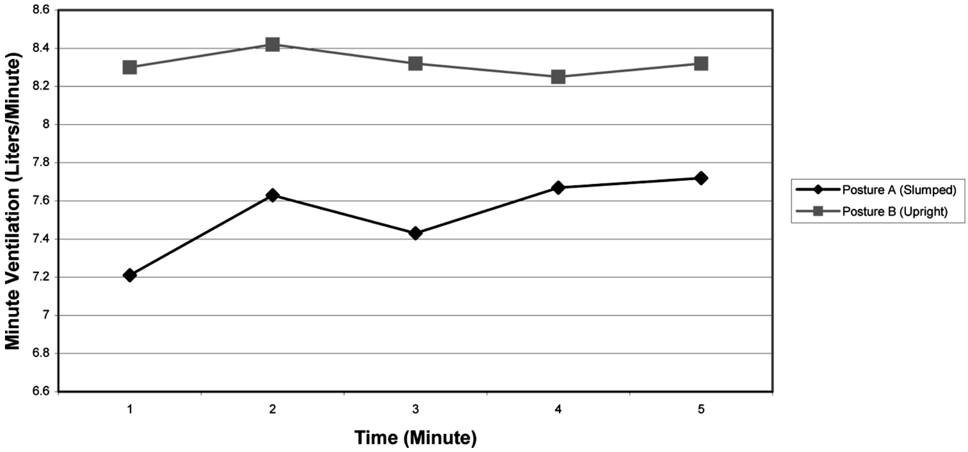

Fig 4

the slumped sitting posture. These results are consistent with other studies that also have demonstrated similar improvements in pulmonary function. Most notably is the study by Nwaobi and Smith (1986). Their results showed a 57.7% increase in vital capacity, a 51.6% increase in forced expiratory volume in one second, and a 55% increase in expiratory time in eight children with cerebral palsy in an adaptive seating system (upright sitting) compared to a standard sling-type wheelchair that promoted a slumped posture. This study supports our assertion of the possible underlying physiologic mechanisms that may be responsible for position-related pulmonary changes. Namely, that erect postures enhance the mechanics of the thoracic spine and ribs, and increases the caudal excursion of the diaphragm. Sitting in a slumped posture decreases the ability of the chest wall to expand and limits the caudal excursion of the diaphragm. That is, in a slumped posture the abdominal contents are compressed by the approximation of the ribs to the pelvis. This causes a relative increase in intra-abdominal pressure, which would limit the ability of the diaphragm to descend caudally during inspiration. Furthermore, thoracic flexion with concomitant lower cervical extension causes a shortening of the accessory inspiratory muscles (e.g. scalenes,

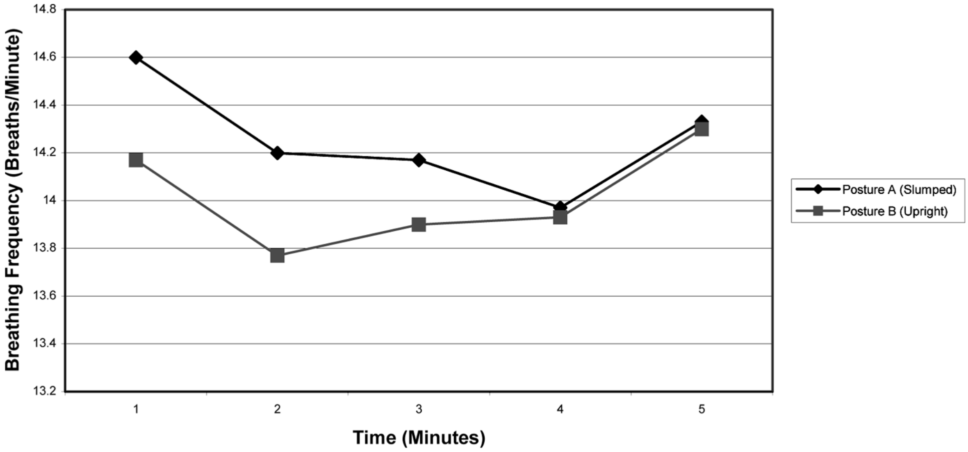

Fig 5

sternocleidomastoid, pectoralis major, pectoralis minor, etc.), which serve to expand the thorax by elevating the ribs. Also, in this position the ribs internally rotate at the costotransverse articulation causing a decrease in the intercostal spaces and a subsequent decrease in thoracic volume.

Other investigators have reported position-related spirometric differences in other postures as a result of these mechanisms (Moreno and Lyons, 1961; Meysman and Vincken, 1998; Vilke et al, 2000). In the supine position, pressure on the diaphragm increases compared to sitting or standing. This pressure limits diaphragmatic excursion caudally. Likewise, in the prone position, lung volume is reduced even more because the ribs are compressed anteriorly by the weight of the body, and thus, limiting the ability of the thorax to expand. Vilke et al (2000) found a statistically significant decline in spirometric values (forced vital capacity, forced expiratory volume in the first second, and maximal voluntary ventilation) in supine and prone compared to sitting in 20 young healthy males. Moreno and Lyons (1961) demonstrated a similar decrease in spirometric values (TV, V_E, and oxygen consumption) in the same three positions. These studies support our assertion that the aforementioned physiologic mechanisms would explain our findings.

The results of this study showed that fb was not significantly changed in the slumped sitting position. Since $PaCO_2$ is the main variable controlling breathing, it can be assumed that the $PaCO_2$ level did not change enough during the testing period to provoke a compensatory increase in fb. It also is possible that the oxygen demand of the body in this static posture, even with a notable volume deficit (0.78 ± 0.18 L/min.), was not great enough during the five-minute testing period to cause a compensating change in breathing.

The clinical rationale for this study becomes evident when one considers that a decrease in pulmonary function as defined by a decrease in TV and a subsequent decrease in V_E, if prolonged, could adversely effect oxygen saturation in the blood because of a decrease in alveolar ventilation. This may ultimately impact the processes of blood gas exchange as well as the ability of the body to produce energy. When an individual breathes at lower than normal lung volumes, airway closure is more apt to occur (Dean, 1985). Even in healthy adults, a reduction in arterial oxygen saturation can occur secondary to breathing at low lung volumes (Dean, 1985). A relationship between arterial oxygen saturation and various postures has been established in patients who have had an acute stroke (Elizabeth, Singarayar, Ellul, Barer, and Lye, 1993), critically ill postoperative patients (Doering, 1993), and obese patients with obstructive sleep apnea (Hakala, Maasilta, and Sovijärvi, 2000).

Extrapolation of this study's results to populations other than healthy adults would not be appropriate without specifically investigating those populations. However, it is interesting to consider the implications of these findings if they were to hold true across other groups. These may include those with osteoporosis and subsequent thoracic kyphosis, compromised pulmonary function from underlying disease or trauma, or those of a sedentary or wheelchair bound population. A more clinically relevant implication is that of the potential cumulative effects of decreased TV over a longer period of time, which, if continued beyond 5 minutes, may subsequently result in decreased arterial oxygen saturation (Dean, 1985). If this is the case, then consideration should be given to the office worker who functions for hours at a time at a computer in a slumped posture day after day. Similar cumulative effects could be more adverse in the elderly population, or those with pulmonary pathology. Hough (1984) suggests that the slumped Fowler position, commonly assumed in hospital beds, may have detrimental effects on patients with respiratory disorders. Hough further states that there is a greater variation in gas exchange in patients with COPD than in normal subjects when there is an alteration in posture. Work by Crosbie and Myles (1985) demonstrates that a slumped Fowler position caused a significant reduction in vital capacity (12%) and forced expiratory volume in one second (FEV_1) (15%) when compared to an upright sitting position in 20 young, healthy adults. This slumped Fowler position, like the slumped sitting posture in this study, increases thoracic kyphosis with a subsequent decrease in anterior motion of the ribs. Also, compression of the abdominal viscera will decrease the downward excursion of the diaphragm. Crosbie and Myles conclude that patients with pulmonary pathology may have a further reduction of function as a result of this slumped Fowler position, which may be potentially deleterious. These results, as well as the results of this study, support the hypothesis that prolonged sitting in similar slumped postures, often observed in hospitals, extended care facilities, offices, and industrial settings, could be potentially adverse for those with and without pulmonary dysfunction. Further research involving these specific populations would be necessary to validate these speculations and further investigate their implications. Future research involving subjects with or without pulmonary pathology should include measurements of arterial oxygen saturation.

It should be noted, however, that leaning forward while sitting may actually be of some benefit in patients with marked hyperinflation associated with certain pathologies. The forward leaning sitting posture, however, is different from the slumped sitting posture in our study. Forward leaning involves mostly hip flexion with minimal increase in thoracic kyphosis. The slumped sitting posture in our study was carefully controlled to involve only forward flexion of the lumbar and thoracic spines without any hip flexion. Both positions, though, may be associated with an increased force of the abdominal contents against the diaphragm. In patients who are hyperinflated with flattened diaphragms, the abdominal viscera are thought to passively stretch the diaphragm cranially, which improves inspiration by enhancing the muscle length-tension relationship of the diaphragm. Furthermore, the forward leaning position is typically associated with stabilization of the upper extremities which facilitates the use of accessory breathing muscles. Stabilization of the upper extremities might be of primary importance in relieving dyspnea in patients with hyperinflated lungs. It has been demonstrated that patients with severe chronic obstructive pulmonary disease with marked hyperinflation and low flat diaphragms may have pronounced relief of their dyspnea from assuming a forward leaning posture while sitting (Sharp, Druz, Moisan, Foster, and Machnach, 1980). O'Neill et al (1983) reported an increase in maximal static inspiratory pressure by 15 cm H_2O in a seated leaning forward position, compared to sitting erect, in three severely clinically affected patients with cystic fibrosis demonstrating clinical signs associated with hyperinflation. While the forward leaning position is different from the slumped posture of this study, these results indicate that avoidance of the slumped posture may not be deleterious in cases associated with pulmonary hyperinflation.

One limitation of our study is that measures of pulmonary function were done in a static position for five minutes. Normal sitting behavior consists of a variety of different postures that are not entirely static for the same length of time. Because only five minutes of static sitting posture was investigated, some homeostatic compensatory changes may not have become evident. Further research should be done with subjects in dynamic settings over a longer period of time in order to determine a more functional analysis of this relationship.

Another limitation is that the slumped posture was not quantitatively described. The results of reliability testing also limit this study. These results indicate that measures of mean TV and V_E for five subjects were reliable upon re-testing. However, there appears to be more variability in fb. Although measures were taken to control external factors that would influence fb (i.e. temperature and nervousness), other factors that may effect fb were not controlled. This may explain why fb was not graphically consistent in the retest group. To add strength to the results of this study, it would be necessary to repeat testing with a larger test-retest group using statistical analysis, (i.e. intraclass correlation coefficient) to better establish reliability.

CONCLUSION

From a clinical perspective, educating patients in proper spinal posturing is common in physical therapy practice. It is well accepted among therapists that improper postural mechanics and habits can lead to a variety of musculoskeletal problems. Results of this study indicate that improper postural mechanics and habits can also influence the pulmonary system in a population of young healthy adults. Sitting in a slumped posture results in decreased V_E and TV, which may lead to decreased oxygen delivery to physiological systems and organs of the body. The addition of this knowledge provides practicing clinicians with another logical reason for training patients in proper posture during sustained static activities.

ACKNOWLEDGMENTS

The investigators of this project thank the valuable assistance received from Mike Halliday, PT, MS, Andrea Zardetto-Smith, PhD and Jeff Fox, PhD. We also acknowledge the Creighton University physical therapy students who participated as subjects and the Creighton University Physical Therapy Department for the use of equipment and space.

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