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# Head position and its effect on pulmonary function in tetraplegic patients

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To test the influence of head position on pulmonary function in tetraplegic individuals 15 subjects with chronic $C_4-C_7$ injuries participated in a one group pre-post test comparing the relationship between orthostatic position of the head (OPH) and standard pulmonary function tests (PFTs). Twelve subjects with habitual forward head posture and three with non-forward head posture performed PFTs in (1) their habitual posture, and (2) an experimental posture imposed by placement of thoracic and/or lumbar rolls behind their back. Results showed that changing head posture did not alter mid-forced expiratory flow or forced inspiratory vital capacity, but significantly affected forced vital capacity ($t=2.83$; $P<0.05$) and 12 s maximum voluntary ventilation ($t=2.07$; $P<0.05$). In cases where pulmonary function was altered by head position, the resulting performance was best in the subject's habitual posture, although no differences in resting pulmonary tests were observed between subjects with and without forward head position. These data show that temporary postural alterations affecting OPH, if not allowing sufficient time for muscular adaptation, adversely affect pulmonary function in tetraplegic patients.

**Keywords:** tetraplegia; pulmonary; ventilation; head position; pulmonary function tests

## Introduction

Neuromuscular diseases and neurotrauma affecting muscles and posture of the neck and trunk are often associated with inefficient movement of the chest wall and diaphragm, and compromised pulmonary ventilation. Such respiratory dysfunction commonly occurs following cervical spinal cord injury,[1–4] in which progressively greater degrees of pulmonary impairment are strongly associated with ascending levels of cord lesion.[5,6] While survivors of complete tetraplegia below the third cervical vertebra retain the ability to use their diaphragm during inspiration, the primary expiratory muscles, including the abdominals, are often paralyzed.[7] This accounts for previous reports in which survivors of spinal cord injury experience paradoxical movement of the chest wall during their breathing cycle, reduced total lung capacity (TLC), vital capacity (VC), forced vital capacity (FCC), and expiratory reserve volume (ERV),[1,6,8–10] but increased residual volume (RV).[3–9,11,12–17]

It is known that paralysis of the intercostals and abdominals in tetraplegic patients increases the burden of neck and shoulder muscles during breathing.[5,6,11,18] Thus, several muscles or muscle groups, including the scalenes, sternocleidomastoids, and trapezius muscles, must share greater dual functions both of maintaining head posture and assisting in ventilation. For example, when stabilized at their sternoclavicular and first rib attachments, the sternocleidomastoid and scalenes flex the neck and assist its rotation, respectively. In this capacity they function as postural muscles that serve to properly align the head.[19] Conversely, the scalenes assist in respiration via their attachment to the upper rib cage[19,20] while the trapezius muscles are recruited during inspiration to stabilize the head and prevent excessive shortening of the sternocleidomastoids as they draw the sternum cranially.[21] The platysma, myohyoids, and sternohyoids also depend on stabilization by the trapezius muscles during ventilation,[21] as their simultaneous contraction pulls the sternum cranially, expands the upper rib cage, and inwardly displaces the lateral walls of the lower rib cage.[21]

Examination of individuals without neurological disability has shown that prolonged sitting is associated with forward head inclination caused by decreased lumbar lordosis.[22] This forward head position and rounded shoulders shortens the cervical extensors, serratus anterior, pectoralis minor and upper trapezius muscles, and lengthens the cervical flexors, middle, and lower trapezius muscles.[23] Habitual postural malalignment of these muscles, however slight, may lead to alterations in their

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length-tension properties, and decrease their ability to generate peak tension during either breathing or head stabilization. Whilst the respiratory function of those who are tetraplegic is reported to differ in the supine, sitting, and upright positions,[6] the possibility that subtle changes in head position similarly alters pulmonary function has yet to be investigated. Thus, the purpose of this study was to (1) determine whether tetraplegic individuals display forward head posture as assessed by standard criteria, and (2) assess whether their pulmonary function is altered by experimental manipulation of head position.

## Methods

*Subjects*
The subjects were fifteen volunteers (14 males and one female) aged 18 to 31 years with tetraplegias (Frankel Grades A-C) at the C4-C7 levels. They were screened by a personal interview and written questionnaire to exclude those having (a) duration of injury less than 3 months, (b) mechanical ventilatory support within 8 weeks of study testing, (c) artificial airway, (d) history of chronic obstructive pulmonary disease, (e) pneumonia within 2 weeks of testing, (f) asthma, (g) acute active communicable disease, and (h) surgical procedure performed within 4 weeks of testing. Subjects consented to participate in the study in accordance with the guidelines and approval of the Medical Sciences Subcommittee for the Protection of Human Subjects. Descriptive characteristics of the subjects are shown in Table 1.

*Postural analysis*
The orthostatic position of the head (OPH) was determined by the Rocabado technique in which the horizontal distance between the following sites is measured (1) a vertical tangent through the apex of the thoracic spine, and (2) the surface of the mid-cervical spine (Figure 1).[24] This distance averages 6 centimeters (cm) in persons without postural dysfunction, while those with abnormal posture display an OPH greater than 6 cm.[24] Thus, non-forward and forward head postures for this study were operationally defined as OPH less than, or greater than 6 cm, respectively. Intra-rater reliability measured prior to this study established the following intra-class correlation coefficients: mid-cervical = 0.99, thoracic apex = 0.99.

Measurement of the OPH was performed with the back of the subject's wheelchair placed parallel to a wall and a posture grid positioned at their side. With subjects assuming their habitual posture, including the forearms placed on their wheelchair armrests, the distances from the apex of the thoracic spine to the wall and the mid-cervical spine to the wall were gauged with a tape measure. Three measurements were taken from each site, the average difference of which determined the OPH.

**Table 1** Descriptive characteristics of the study subjects

| Subject# | *Age (years)* | *Gender* | *Level of injury* | *Injury duration (years)* |
|---|---|---|---|---|
| 1 | 30 | M | C5–6 | 13.0 |
| 2 | 30 | M | C4 | 3.0 |
| 3 | 18 | M | C4–5 | 0.7 |
| 4 | 28 | M | C5 | 6.1 |
| 5 | 20 | M | C5–6 | 2.8 |
| 6 | 29 | M | C5 | 4.2 |
| 7 | 30 | M | C3–4 | 1.3 |
| 8 | 22 | M | C5–6 | 2.8 |
| 9 | 20 | M | C6 | 1.4 |
| 10 | 19 | M | C6–C7 | 0.8 |
| 11 | 27 | M | C6 | 8.2 |
| 12 | 27 | F | C5 | 2.8 |
| 13 | 31 | M | C5–6 | 8.3 |
| 14 | 25 | M | C4–5 | 2.5 |
| 15 | 28 | M | C5–6 | 4.7 |
| Mean | 25.6 | | | 4.2 |
| SD | 4.4 | | | 3.3 |

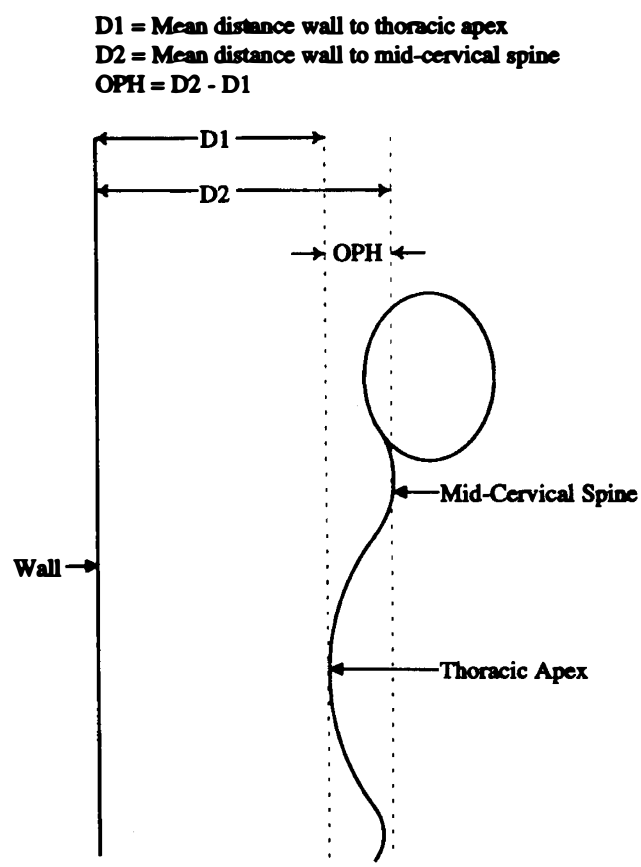


**Figure 1** Schematic showing the Rocabado technique used for measuring the orthostatic position of the head (OPH)

*Postural modifications*
Subjects performed pulmonary function tests (PFT) in their habitual posture and an experimentally-imposed posture. If the subject met the study criteria for forward head posture (ie OPH > 6 cm), the OPH was experimentally altered to < 6 cm by placing rolled cloth towels in the lumbar- to mid-thoracic spine regions. Conversely, in cases where the subject displayed habitual non-forward head posture (ie OPH < 6 cm), the position was altered to > 6 cm by placement of the towel rolls in the mid- to upper-thoracic regions.

*Pulmonary function tests*
Pulmonary function tests (PFT) were performed on a Horizon System Pulmonary Function Analyzer (SensorMedics Corporation, Loma Linda, CA) interfaced with a computer microprocessor. The analyzer was standardized prior to each trial using a 5 liter calibration syringe. Standard pulmonary flow-volume loops were generated under both test conditions from which the following variables were derived (1) forced vital capacity (FVC), (2) forced mid-expiratory flow ($FEF_{25-75}$), and (3) forced inspiratory vital capacity (FIVC). Additionally, a standard 12 s maximum voluntary ventilation (MVV) challenge was performed in both the habitual and experimental head posture.

Subjects performed three PFT trials in which the order of testing for habitual and experimental postures was randomized. Two minutes of test separated each trial. Following a 10 min rest period, subjects underwent one MVV challenge and then rested for 10 min during which postural adjustments (placement or removal of towels) and postural analysis were performed. Three PFT trials and one MVV trial were then repeated. Verbal encouragement was given to subjects throughout the tests.

To minimize head movement, ensure sitting stability, and provide balance support during the PFT, an investigator stood behind the subject's wheelchair and provided light bilateral tactile support inferior to the mid-clavicular region. The subjects were videotaped from the lateral view using a posture grid to confirm that their position was unchanged during the PFT and assess whether untoward movement occurred during testing.

*Data analysis*
The study used a one group pre-post test design in which the best effort of three trials in the habitual and test postures for FVC, $FEF_{25-75}$, FIVC, and MVV, were analyzed. Differences in pulmonary performance were analyzed using paired Student *t* tests, with the criterion for significance set at $P < 0.05$. All data were analyzed using a Statistical Analytical System (SAS) software program (SAS Institute Inca Cary, NC).

# Results

Table 2 shows the habitual head posture for the 15 subjects and their FVC and MVV tests in both habitual and experimentally-altered positions. Table 3 shows the FIVC and $FEF_{25-75}$ pulmonary tests for the same habitual and altered head positions. Eighty percent (%) (12/15) of the subjects displayed habitual forward head posture of $8.8 \pm 1.6$ (mean $\pm$ SD) cm. One subject (#1) with a profound habitual forward head position was not correctable to a non-forward position, as this adjustment caused him to lose his sitting balance. Thus, his experimentally-altered head position was defined as the greatest possible correction without imposing sitting instability (6.5 cm).

**Table 2** Effect of habitual and experimentally-altered head position on forced vital capacity (FVC) and maximum ventilatory volume ($MV_{12}$) in subjects with forward and non-forward head posture

| | *Subjects with habitual forward head posture* | | | | | |
|---|---|---|---|---|---|---|
| | *Habitual* | | | *Altered* | | |
| *Subject#* | *OPH (cm)* | *FVC (L)* | *MVV (L/min)* | *OPH (cm)* | *FVC (L)* | *MVV (L/min)* |
| 1 | 11.35 | 4.02 | 152 | 6.50[1] | 3.23 | 112 |
| 2 | 7.35 | 1.29 | 44 | 5.35 | 1.62 | 67 |
| 4 | 8.21 | 4.24 | 162 | 3.54 | 3.96 | 104 |
| 5 | 11.63 | 2.18 | 84 | 4.97 | 1.89 | 61 |
| 6 | 6.14 | 2.18 | 64 | 3.97 | 2.03 | 39 |
| 7 | 8.26 | 2.63 | 68 | 3.71 | 1.96 | 56 |
| 8 | 10.41 | 2.97 | 132 | 4.39 | 2.83 | 128 |
| 9 | 8.78 | 2.45 | 141 | 3.92 | 2.28 | 125 |
| 12 | 7.34 | 1.78 | 45 | 5.09 | 1.84 | 70 |
| 13 | 10.11 | 2.40 | 124 | 5.40 | 2.42 | 110 |
| 14 | 7.46 | 2.21 | 86 | 5.30 | 2.31 | 85 |
| 15 | 8.88 | 2.29 | 62 | 5.28 | 1.80 | 59 |
| Mean | 8.8 | 2.62[2] | 97.0[2] | 4.8 | 2.4 | 84.7 |
| SD | 1.6 | 0.8 | 40.9 | 0.8 | 0.7 | 28.8 |
| 3 | 5.25 | 2.73 | 91 | 6.99 | 2.40 | 94 |
| 10 | 2.27 | 2.25 | 87 | 6.50 | 2.23 | 72 |
| 11 | 4.88 | 2.63 | 102 | 12.22 | 2.18 | 79 |
| Mean | 4.1 | 2.5 | 93.3 | 8.4 | 2.3 | 81.7 |
| SD | 1.3 | 0.2 | 6.3 | 2.5 | 0.1 | 9.2 |

[1]Correction greater than this amount caused the subject to lose his balance. [2]Differing significantly from the experimentally-altered condition ($P < 0.05$)

**Table 3** Effect of habitual and experimentally-altered head poistion on forced inspiratory vital capacity e(FIVC) and mid-expiratory forced expiratory force ($FEF_{25-75}$) in subjects with forward and non-forward head posture. OPH measurements are identical to those shown in Table 2

| | *Habitual* | | *Altered* | |
|---|---|---|---|---|
| | *FIVC (L)* | *$FEF_{25-75}$ (L/min)* | *FIVC (L)* | *$FEF_{25-75}$ (L/min)* |
| Mean | 2.5 | 3.4 | 2.3 | 3.2 |
| SD | 0.8 | 1.2 | 0.6 | 1.1 |

A significant effect of head posture on pulmonary function was observed for FVC ($t=2.83$; $P<.05$) and MVV ($t=2.07$; $P<0.05$) with pulmonary volumes for these variables averaging 8.5% and 14.5% greater in the habitual than altered position, respectively. In most cases, the larger lung volumes and flow rates were observed when testing the subjects' habitual position, regardless of forward head or not. For example, only four subjects had greater FVC in their altered than native position (# 2,12,13, and 14), with three of these cases (#12, 13, and 14) representing clinically-nominal differences. Similarly, only three subjects had a higher MVV in the altered position (#s 2, 3 and 12), with one case (#3) representing only a 3.2% increase. Averages for FIVC and $FEF_{25-75}$ were lower in the non-habitual posture, but this difference was not significant.

## Discussion

The pulmonary responses of subjects in their habitual sitting position are consistent with previous reports of pulmonary limitation after cervical spinal cord injury.[1–14] These studies have observed restrictions of functional capacity and forced expiratory volume in one second (FEV-1) of those with tetraplegia in the upright, sitting, and supine positions when compared to nondisabled control subjects.[11,14] These differences are attributed to respiratory muscle paralysis below the level of spinal cord injury which results in excessive excursion of the abdominal wall and viscera during inspiration.[16,25] This excessive motion is accompanied by paradoxical movement of the chest wall and inward movement of the rib cage during inspiration as the diaphragm descends toward the abdomen.[12,13,16,21,25,26]

The results of this study reveal two novel findings. First, that a high percentage of individuals with tetraplegia display forward head posture; and second, that deviation from habitual posture – in most cases whether forward head or not – compromises pulmonary function. In biomechanical studies, this type of forward head position has most often been associated with 'postural' headache in which the dorsal neck muscles function as antagonists to gravity.[27] Recent electromyographic (EMG) study has shown that a deficiency of neck muscle performance accompanies repositioning of the head into non-neutral positions.[28,29] Acute changes in muscle length alone were believed to be the cause for abnormal *integrated* EMG/muscle moment relationships observed in these non-neutral postures.[30] That this position-dependent muscle insufficiency might similarly translate to performance deficits in ventilation, especially for muscle groups that share postural and pulmonary functions, was the focus of this investigation.

The coordination of skeletal and chest wall muscles during breathing is essential for promoting efficient respiratory function. This balance is especially important in those who are tetraplegic for whom paralysis of sublesional respiratory muscles challenges the paralysis-spared primary and accessory musculature to play a greater role in maintaining adequate ventilation. By definition, accessory respiratory muscles include those attached to the rib cage, shoulder girdle, or vertebral column which assist with inspiration during elevated respiratory demand, but not during quiet ventilation.[31,32] The sternocleidomastoid and trapezius muscles fully satisfy these criteria,[31–33] and the scalenes are also classified by several reports as primary muscles of ventilation.[33,34] This view is supported by subdermal needle EMG analysis showing recruitment of the scalenes during quiet ventilation.[29]

The observation that habitual head posture alone does not influence pulmonary function is consistent with known chronic adaptation of skeletal muscles to changes in their length.[35] These muscles accommodate to chronic shortening and lengthening by adjusting their structure and function, and in some though not all cases, recover their original length-tension properties. For example, immobilized lengthening of a muscle results in increased weight reflecting changes in its protein content.[36,37] Some investigators have noted increased peak tension of chronically lengthened muscles,[38] although the magnitude of active peak tension at its original resting length is diminished – a phenomenon referred to as 'stretch weakness'.[39] Similarly, chronic positioning of a muscle in a shortened position results in loss of sarcomeres, and reduction of passive and active tension.[40,41] One study suggests that recovery of peak isometric tension occurs within 120 days after resumption of 'free' movement in shortened muscles.[42] Even after resumption of their free movement, however, these muscles display steeper passive tension curves than unshortened muscles,[43] increased deposition of connective tissue,[44] and loss of elastic properties.[45]

While the degree to which habitual forward head posture alone contributes to pulmonary limitations in tetraplegics cannot be determined by this study, it is probable that short term adjustments from habitual position exert more pronounced effects on breathing capacity than the accommodated position itself. Interestingly, the change in head posture of as little as 4 cm resulted in reduction of FVC and MVV of 10.6% and 14.3%, respectively, in subjects with habitual forward head position. It is likely that this response is attributable to changes in the length-tension properties of the muscles sharing postural and breathing assignments. Many studies have shown that acute elongation or shortening of skeletal muscle alters its ability to generate peak tension by changing passive and active length-tension relationships.[35] Such changes as would occur when moving the head from a forward to a non-forward position, would lengthen the sternocleidomastoid and scalene muscles and shorten their antagonist trapezius stabilizers. For persons without pulmonary dysfunction, these subtle changes in length tension relationships of cervical stabilizing muscles might not be consequential, although tetraplegic individuals who rely to a greater extent on accessory muscles in assisting the mobilization of their chest wall, might experience more pronounced effects.

## Conclusions

We conclude that a high percentage of those who are tetraplegic display forward head posture. Movement of the head to a non-habitual posture alters their pulmonary function, likely by modifying the length-tension relationships of cervical muscles that serve dual functions in postural maintenance and respiration. As the metabolic cost of breathing in tetraplegic individuals is already elevated, and as fewer respiratory muscles are available to assume the burden of ventilatory support, changes in breathing should be anticipated following body or head repositioning resulting from surgical placement or removal of spinal instruments, changes in wheelchair seating, pain, or aging.

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