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Static respiratory pressures in patients with post-traumatic tetraplegia

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The purpose of this study was to examine ventilatory muscle strength as represented by static respiratory pressures in 30 tetraplegic patients with a complete lesion between the fifth and the eighth cervical vertebrae. The Inspiratory/Expiratory Pressure Meter was used to obtain maximum static expiratory mouth pressure (PE_{max}) and maximum static inspiratory mouth pressure (PI_{max}) measurements. The PE_{max} was measured at vital capacity and the PI_{max} at residual volume. The measurements were effected while the patient was in the supported sitting position. The mean PE_{max} for the group was 50 cm H_2O and the mean PI_{max} was -65 cm H_2O. There was a significant difference between the PE_{max} and PI_{max} values. Unlike normal individuals most tetraplegic subjects in this study showed PI_{max} values to be much higher than their PE_{max} values.

Keywords: spinal cord injuries; pulmonary infection; static respiratory pressures; respiratory muscle strength; tetraplegia

Introduction

Pulmonary complications, present a major threat to the lifespan of patients suffering from a complete lesion at any level of the cervical cord (tetraplegia). Several reports confirm that respiratory insufficiency is neurogenic in nature due to paralysis of the intercostal and abdominal muscles.[1–7]

The pathophysiological sequelae of respiratory muscle paralysis have been reported by several workers.[3,8,9] In a low level cervical cord lesion normal function of a fully innervated diaphragm is impaired by several factors. Diaphragmatic dysfunction is caused by paralysis of the other muscles of inspiration, alteration in chest wall properties and paralysis of the abdominal muscles. The interaction between diaphragmatic function and abdominal muscle contraction in normal subjects during the inspiratory phase of ventilation has been widely reported.[9–14]

This is referred to as the inspiratory facilitating action of the abdominal muscles.

It has been found that paralysis of the abdominal muscles provides no opposition to the diaphragmatic descent, causing the rib cage of the tetraplegic individual to move out of phase. During the inspiratory phase, their abdominal wall is pushed out and the lower ribs drawn in causing a paradoxical pattern in rib cage movement.[9,11]

The use of mechanical support has shown to improve rib cage motion and vital capacity when the abdomens of tetraplegic subjects were stabilised with a binder or pneumobelt.[10,15,16]

In addition to diaphragmatic dysfunction, paralysis of all of the intercostal muscles causes major changes in rib cage compliance. Rib cage instability has a detrimental effect on diaphragmatic function, causing it to operate from a mechanically disadvantaged position.[9,11,17,18] Axen and Guttmann stressed the importance of intercostal muscle tone on thoracic cage compliance.[18,19]

The tetraplegic patient also develops respiratory muscle weakness caused by structural changes in the muscles that have been partially or totally spared by the lesion. A patient with a low lesion may have innervation to the diaphragm, sternaocleidomastoid, scalene and trapezius muscles. These muscles serve a vital role in maintaining adequate ventilatory function. However these muscles lack the force and endurance stimuli usually available to normal individuals and therefore have a tendency to develop disuse atrophy because of minimal demands for increase in exercise.[20]

Paralysis of important respiratory muscles causes a marked reduction in vital capacity and in expiratory reserve volumes to levels lower than 50% of the normal predicted values.[1,3,19,21]

Expiratory muscle dysfunction can be demonstrated by a marked reduction in static expiratory mouth pressures. This decreases the patient's ability to cough effectively.[22,23] This leads to a serious compromise in one of the primary respiratory defence systems and exposes the tetraplegic patient to pulmonary infection.[24–32]

The need in those with tetraplegia for a comprehensive pulmonary care programme is well documented.[2,3,4,11,25,33,34] However the existing protocol for pulmonary rehabilitation is largely therapist or carer orientated with little emphasis on an ongoing preventative programme which demands optimal patient involvement. The inclusion of respiratory muscle training in the pulmonary care programme could allow the tetraplegic patient the opportunity to develop his respiratory capacity to optimal levels.

Because the underlying mechanisms for the impairment of the cough reflex is expiratory muscle paralysis, improvements in accessory expiratory muscle strength should have a direct effect on the patient's ability to cough.

The quantification of respiratory muscle strength in neuromuscular disorders should therefore constitute an important component in the total evaluation of pulmonary function.[35] The measurement of static respiratory pressure has been found to be a reliable method of reflecting the contractile force developed by the ventilatory muscles.[35–37,39]

Maximum static expiratory mouth pressure (PE_{max}) represents the global expiratory muscle strength while maximum static inspiratory mouth pressure represents the global inspiratory muscle strength. Black and Hyatt point out PE_{max} to be volume dependant.[37] Therefore for the purpose of standardising the measuring technique and to improve reliability, they and others recommended PE_{max} be measured at total lung capacity and PI_{max} at residual volume.[38,40] PE_{max} and PI_{max} therefore depict a reliable measure of expiratory and inspiratory muscle strength. These measurements could be used to assess the efficacy of exercise programmes. However respiratory muscle training in clinical practice is still in the experimental stage and the scientific basis for training has as yet not been firmly established.

The purpose of our study was to examine expiratory and inspiratory muscle strength using PE_{max} and PI_{max} values in tetraplegics with low cervical lesions.

Method

Thirty tetraplegic patients were included in this study. They were all diagnosed as having complete lesions between the fifth and eighth cervical segments. In all but two cases the post injury period (period between the onset of tetraplegia up to the time of this study) was over 6 months.

The majority of the patients were located in general hospitals while a small number were resident at other institutions such as homes for the disabled. Two

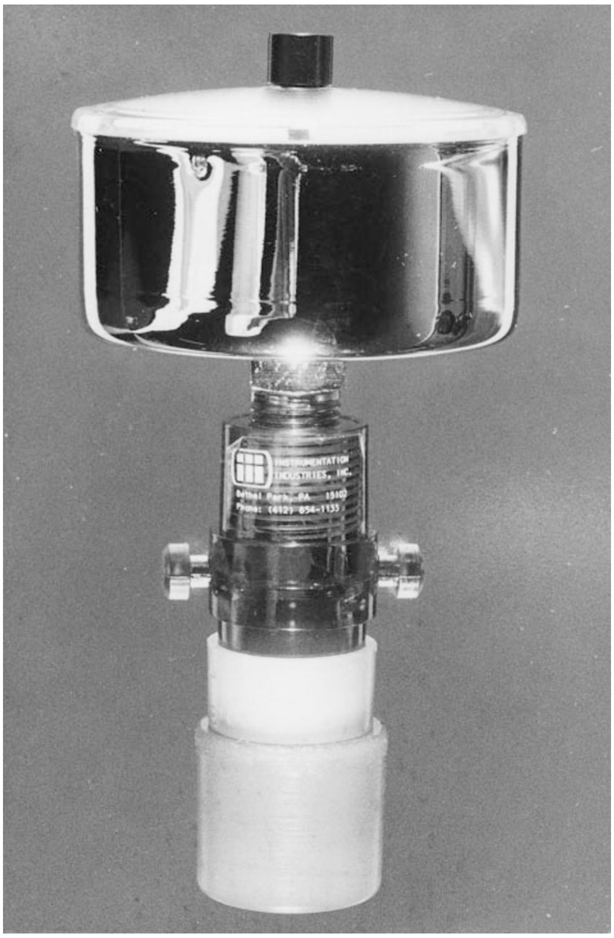

Figure 1

Table 1 Values for PE_{max} and PI_{max} measured in the sitting position

Subject	*Level of lesion*	*PE_{max} (cmH_2O)*	*PI_{max} (cmH_2O)*
1	C5	+60	–80
2	C6	+80	–100
3	C4/5	+60	–90
4	C5	+65	–52
5	C7	+60	–63
6	C6	+65	–90
7	C6/7	+55	–75
8	C5	+23	–25
9	C6	+60	–62
10	C5/6	+36	–60
11	C6	+40	–70
12	C6	+65	–50
13	C5	+32	–60
14	C5	+20	–28
15	C5	+50	–65
16	C6	+50	–86
17	C6	+42	–60
18	C6	+56	–40
19	C5/6	+22	–45
20	C8/T1	+48	–70
21	C5/6	+40	–60
22	C5/6	+40	–84
23	C5/6	+80	–52
24	C6/7	+40	–90
25	C5	+42	–44
26	C5	+52	–56
27	C7/T1	+40	–68
28	C6/7	+40	–70
29	C5	+50	–80
30	C5/6	+52	–60

patients in the study group presented with lesions between the eighth cervical and first thoracic segments. The patients' levels of functional abilities and involvement in general activities varied. While some patients were involved in intensive rehabilitation programmes others were attending Physiotherapy Departments for general activities approximately three times a week.

Each patient was given a detailed explanation of the purpose of the test which included an explanation on the technique of measurment. An informed consent was obtained from each patient.

Measurements of static respiratory pressures

Measurements of PE_{max} and PI_{max} were made with a measuring device known as Inspiratory/Expiratory Force Meter (Boehringer Laboratories) (Figure 1).

The measurements were obtained while the patient was seated. After a maximum inspiratory effort the mouthpiece was placed well into the mouth and the PE_{max} measured while the patient expired as forcibly and quickly as possible.[36,37] The mean of three trials was recorded. After a brief rest the PI_{max} was measured. The PI_{max} measurement were made near residual volume[36,37] ie after a maximal expiratory effort the subject was asked to inspire as forcibly as possible. The method of documentation was the same as that for the PE_{max} values.

In order to prevent the patient from creating significant pressures with the aid of their buccal muscles a tiny orifice (diameter 0.5 mm) was included in the system.

Results

Data obtained from 30 tetraplegic patients during maximum inspiratory and expiratory efforts are presented in Table 1. PI_{max} values from 26 subjects were higher than their PE_{max} values Figure 2. Four subjects yielded PE_{max} values which were only marginally higher than their values for PI_{max}.

The mean maximal positive pressure for the group was 50 cm H_2O and the mean maximal negative pressure was -65 cm H_2O. There was no relationship between the level of the lesion and the static respiratory pressures.

Patients number 8 and 14 showed the lowest values for both PE_{max} and PI_{max}. Both these patients were studied in the first 2 months of their injury. Using the paired t test there was a significant difference between the PE_{max} and PI_{max} values as shown in the summary of data analysis in Table 2. There was poor correlation between PE_{max} and PI_{max} values as indicated in Figure 3.

The Pearson correlation coefficient revealed significance between PE_{max} and PI_{max} ($P=0.018$). However,

Table 2 Summary of data analysis comparison between PE_{max} and PI_{max} measured in the sitting position ($n=30$)

	Mean cmH$_2$O	*SD*
PE_{max}	48.83	15.0
PI_{max}	64.5	18.33
Diff	–15.67	18.098

There was a significant difference between the PE_{max} and PI_{max} values in the sitting position

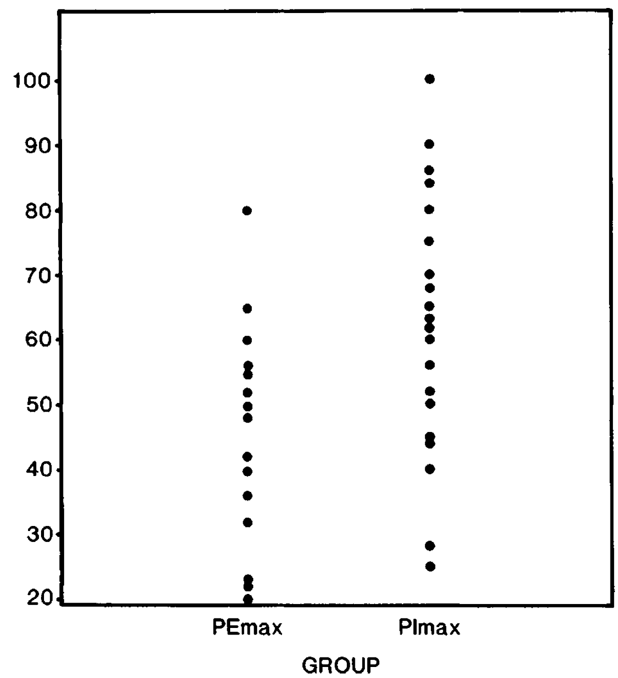

Figure 2

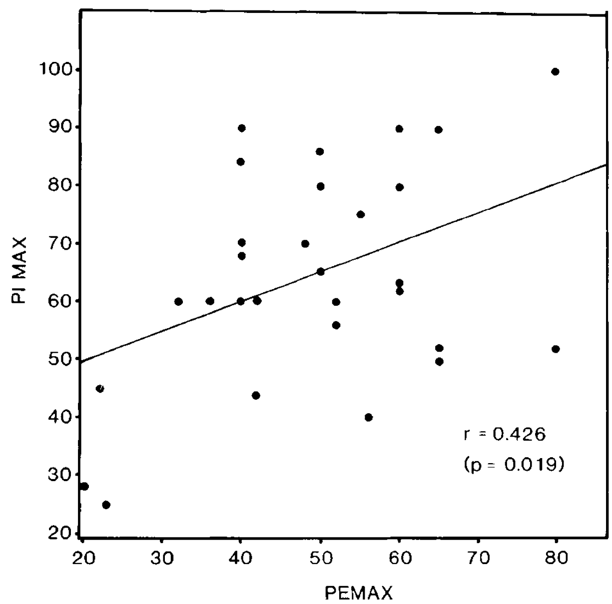

Figure 3

there was only 18% of the variation in PI_{max} as explained by the variation in PE_{max} ($r = 0.426$) revealing a poor correlation Figure 3.

Discussion

The mean PE_{max} value in this predominantly male group (27 male, three female) was 48.83 cm H_2O and mean PI_{max} was -64.5 cm H_2O. The mean values for PE_{max} and PI_{max} were (not unexpectedly), far lower than the figures reported for non-injured individuals.[36,40,41] The figures reported by Black *et al*,[36] Gilbert *et al*,[40] and O'Neill *et al*,[42] show PE_{max} values to be higher than the values for PI_{max} in both non-injured males and females. The mean values for PE_{max} and PI_{max} in a group of 100 non-injured individuals examined at our centre showed PE_{max} to be higher than PI_{max} ($P < 0.0001$). In another non-injured male group (50 clerical staff in our local hospital, between ages of 25 and 50, all smokers) the mean PE_{max} was 112 cm H_2O and the mean PI_{max} was -93 cm H_2O. Tobin after an extensive literature review published standard values for PE_{max} and PI_{max} in reasonably sized sample non-injured population. He found mean PE_{max} values in the male group to be 180 cm H_2O and mean PI_{max} values at 115 cm H_2O where as the PE_{max} for the female group to be 135 cm H_2O and PI_{max} to be -85 cm H_2O. He also found PE_{max} and PI_{max} values to decline linearly with age by approximately 20% in the 20 to 75 age group.[35] In the non-injured subject the force generated by global expiratory muscles effort is significantly higher than the force generated by the inspiratory muscle group. Unlike non-injured individuals most tetraplegic patients in this study showed PI_{max} values to be significantly higher than their PE_{max} values. The marked reduction in the PE_{max} values is associated with the neuromuscular respiratory insufficiency caused by paralysis of the expiratory muscles.

Earlier reports also show maximum expiratory mouth pressures to be obtained at lung volumes greater than 70% of total lung capacity and maximal inspiratory pressures at values less than 40% of the total lung capacity. The static respiratory pressure measurements were therefore found to be volume dependent.[37,38]

For the purpose of standardising the measuring technique thereby improving reliability the investigators recommend PE_{max} to be measured at total lung capacity and PI_{max} at residual volume.[38,40]

In this study all PE_{max} measurements were effected at total lung capacity (vital capacity) and all PI_{max} measurements at residual volume.

In tetraplegia, rib cage instability coupled with diaphragmatic dysfunction could cause a marked reduction in vital capacity. Since the static respiratory pressure measurements are volume dependent the dramatic drop in PE_{max} (in tetraplegia) could be associated with the drop in vital capacity.

Four patients numbers 1, 2, 3 and 6 with a long standing history of tetraplegia and in receipt of regular rehabilitation care had readings which were higher than those obtained from the rest of the group.

Hoffman in an extensive report on the fitness and training of patients with spinal cord injured patient discussed the implications of lack of training.[41] In describing the debilitative cycle he discusses the reduction in physical activity due to the sedentary lifestyle. Hjeltnes and associates have also noted that the deterioration in general muscle function in the tetraplegic individual to be closely related to the marked decrease in daily activities.[43] Mollinger also reported on the number of metabolic changes associated with reduced activity following spinal cord injury.[44]

Hoffman compared the lung function values of sedentary tetraplegic patients with that of 'athletic' spinal cord injured patients.[41] The 'athletic' group had higher values for vital capacities and for maximum ventilation.[41] The improved respiratory condition in the 'athletic' group was attributed to the general training effect on the ventilatory muscles. This form of training was non-specific consisting of general activities which required increased inspiratory efforts. The higher values obtained from subjects 1, 2, 3 and 6 could be attributed to their involvement in intensive rehabilitation programme.

Measurements of maximal static respiratory pressures are important to the subjects under study. Expiratory pressures provide relevant information regarding the patient's ability to cough. High expiratory pressures are required during the explusive phase of cough reflex in order to cause dynamic compression of the airways. In the normal subject this is not a problem because the pressure generated by the expiratory muscles is higher than the pressure generated by the inspiratory muscles.

Because the tetraplegic patient with paralysed expiratory muscles finds difficulty in generating sufficient expiratory pressures for effective coughing, it is important to monitor PE_{max} values regularly in order to assess and to implement appropriate prophylactic measures to prevent the occurrence of pulmonary infection.

Improvements in accessory respiratory muscle strength could also serve a prophylactic purpose.

A study conducted at our centre involving progressive resistive loading on accessory expiratory muscles in tetraplegic patients demonstrated significant improvement in muscle strength.[45,46] The long term clinical value of such a programme cannot be commented on at this stage.

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