Somatotopic Representation of the Respiratory Pathways in the Cervical Cord of Man

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Extensive animal investigations have revealed that the respiratory efferent pathway descends ipsilaterally in the lateral columns to innervate the motor neurons of the phrenic and intercostal nerves. Clinical observations so far seem to indicate that this efferent pathway lies largely in the anterolateral quadrant of the spinal cord of man. These latter observations have been based on patients submitted to high cervical cordotomy, where it has been known for many years that respiration may be seriously affected. Very little quantitative work has been done, however.

High cervical cordotomy is a most valuable means of treating intractable pain occurring at high levels. The risk of interference with respiratory function is particularly great, and a more exact delineation of the respiratory pathway is likely to prove useful. We are reporting our experience with 14 cases of high cervical cordotomy for intractable pain. In 11 cases, diaphragmatic excursions were recorded radiographically both pre- and postoperatively. In 10 cases, investigations of lung function were carried out both pre- and postoperatively along with determinations of acid base balance. In 8 cases, spirometric recordings were made during operation.

Method

Three simple tests were chosen to compare pre- and postoperative pulmonary function. As interest was centered mainly on mechanical functions, it was considered that the vital capacity, the forced expiratory volume in 1 second, and the peak expiratory flow rate would give the required information. The fact that most of these patients were in poor physical condition due to malignancy was also taken into consideration in choosing the tests, and the more tiring procedures were rejected. The vital capacity was measured together with the timed vital capacity using a 6-liter spirometer with an ink pen writing on a rotating drum. The peak expiratory flow rate was measured with the Wright Peak Flow Meter. Each test was repeated three times and, whenever possible, both before and after the administration of a bronchodilator aerosol (Alupent Metered Aerosol). Where bronchodilatation resulted in a significant improvement in pulmonary function, only these better results were recorded. Tests were made with the patient sitting up in bed supported by pillows. The adequacy of ventilation was assessed by estimating capillary blood pH and pCO₂ preoperatively and at regular intervals postoperatively (every 2 to 3 days).

A further test of respiratory function was the measurement of diaphragmatic excursion. This was done by taking routine chest x-rays in the position of full inspiration and full expiration on the same film, and measuring the diaphragmatic movement. These x-rays were taken both pre- and postoperatively at intervals of 2 to 3 days.

To perform spirometry during surgery, an anesthetic technique using spontaneous respiration was necessary. No premedication was given. Anesthesia was induced intravenously with a minimal dose of Thiopentone (150 to 250 mg of 2½% solution), and intubation with the largest cuffed tube possible carried out with the aid of 50 mg Suxamethonium chloride. Anesthesia was maintained with oxygen and Halothane given into a Water's semi-closed circuit. Oxygen was given at the rate of 1 to 2 liters per minute while Halothane was added at the rate of 20 to 40 ml per minute from a “Fluotec” vaporizer. Once the spinal cord had been exposed, the Water's circuit was removed and the patient connected to a 6-liter spirometer through a circle system incorporating a soda lime canister and a Goldman Halothane Vaporiser set at the first calibration. Re-
cordotomies were made with a simple ink-writing device on a slowly moving drum. Oxygen was fed into the spirometer at a rate sufficient to keep the record moving up the drum (150 to 200 ml per minute). The electrocardiogram (Lead 2) was continually monitored and blood pressure recorded every 10 minutes with an oscillometer.

All patients were operated on in the lateral position with a head-up tilt of about 20° and with the chosen side uppermost. For bilateral cordotomy, the side for the highest section was placed on top. We preferred to place the cut at the C-1 segment. If, however, this area of the cord was extremely vascular, section through an avascular area was made immediately below at the C-2 segment. In the unilateral cervical section, a lateral approach was used in order to visualize the anterolateral quadrant of the cord directly without rotating it. Initially, the effect of a complete anterolateral section was studied, but in later cases fractional sections were made and the effect upon respiration recorded.

After the pia had been divided with a tenotome, a superficial cut was made circumferentially and approximately 1 to 2 ml deep. This superficial section was sometimes made completely and sometimes fractionally. The cordotomy blade was then reinserted and a deep cut made, pausing after selected fractions had been cut to observe the effect upon respiration. The areas sectioned were charted diagrammatically.

The abrupt cessation of the powerful analgesias and hypnotics previously required by these patients produced a definite withdrawal syndrome, in the form of irritability and depression, sometimes resulting in poor cooperation during respiratory function assessments. Patients were mobilized early and attempts made to return them to their preoperative state of activity as soon as possible. Thus, the majority of patients were sitting up in bed by the second day, getting out of bed by the third, and usually walking by the fifth day. The sensory levels produced by cordotomy were recorded daily.

Results

Operative Spirometry. Unless great care was exercised to prevent rotation or traction on the cervical cord, the insertion of a cordotomy blade and presumably torsion of the respiratory pathway produced marked although transient changes in the record. After insertion of the blade, therefore, a short pause was made before making the selected section.

The estimated sections and the effect upon the operative spirogram in a patient having a high cervical (C1–2) cordotomy for thoracic pain are shown in Fig. 1 A. The tidal volume was 220 ml immediately before the cut and fell to 120 ml after a superficial cut of about 2 mm; it recovered to 200 ml within 4 minutes. At the deep cut (DC1) a gross reduction of tidal volume occurred, gradually recovering to 160 ml and remaining so until the end of the record 8 minutes later. Postoperatively, this patient (Patient B) had a sensory loss on the right side up to and including the C-2 segment; 3 months later this had dropped to the C-3 segment.

In Patient S, a superficial 2 to 3 mm cut (SC1) at C1–2 resulted in the reduction of tidal volume from 180 to 100 ml, then gradual rise to 160 ml (Fig. 1 B). In the deep fractional section, the more posterior cut (DC1) resulted in a reduction of tidal volume from 160 to 80 ml. Continuance of the cut (DC2) produced a further reduction in tidal volume, which eventually recovered to 140 ml. Postoperatively, this patient had an initial analgesia up to and including C-2 on the right side; this fell to C3–4 by the seventh day, persisting at this level with hypoalgesia of C-2.

In Patient AG, a patient without preoperative respiratory dysfunction, the tidal volume of 180 ml was not affected by a superficial 1 to 2 mm cut (SC1) at the C-1 segment (Fig. 1 C). The deeper posterior cut (DC1) produced an immediate reduction of tidal volume to 100 ml which dropped further to 60 ml when the anterior deep extension cut (DC2) was made. The blade was then reinserted to its full depth of 5 mm (DC3) and the deep section completed. This had no effect upon the already improving tidal volume, which finally reached its original measurement of 180 ml. Postoperatively, this patient had analgesia on the right side up to and including the C-3 level.

The operative findings for a patient subjected to bilateral cordotomy in the high cervical (C1–2) and high thoracic (T-2)