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

Edward Hitchcock, F.R.C.S.,* and B. Leece

Department of Neurosurgery and Anaesthesia, Manchester Royal Infirmary, Manchester, England

Extensive animal investigations1,11,12 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.2,4,8,10,12 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-
cordings 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 Cl-2 segments. 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 (Cl-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 (Cl-2) and high thoracic (T-2)
regions are shown in Table 1 and Fig. 2. The superficial cut of 1 to 2 mm (SC1) had no significant effect upon respiration, but the deep cut (DC1) reduced the minute volume from 8.9 to 5.5 liters. Extending the cut anteriorly (DC2) produced a further reduction in minute volume to 3 liters, although extending the cut posteriorly (DC3) produced no further reduction nor did it impede volume recovery. The thoracic cut was then made, but no significant effect was produced either by superficial or deep sections. Postoperatively, this patient (Patient NW) had analgesia up to and including C-2 on the left, with sparing of the sacral and lower lumbar segments. On the right there was complete analgesia up to T-2.

Another patient with a right cervical cordotomy at C-1 and a left thoracic cordotomy at T-1 showed similar findings (Fig. 3). No respiratory effect was produced either by a superficial 1 to 2 mm section in the cervical region (SC1) or a deep cut in the posterior part of the anterior quadrant (DC1). When the cut was continued anteriorly (DC2), however, the tidal volume fell from 240 to 150 ml; it recovered to 200 ml but later deteriorated to 140 ml. Neither a superficial posterior cut (SC2) nor a deep extension (DC3) produced any respiratory effect. The section made at T-1 had no effect on respiration when the superficial portion of the anterolateral quadrant was incised, but when the deep cut was made, gross diminution in respiration occurred with a fall in tidal volume from 140 to 60 ml; this had recovered to 120 ml by the end of the operation. Postoperatively this patient (Patient TH) had analgesia on the left to C3–4 and on the right to T2–3.

Pulmonary Function Tests. Patients with severe unilateral chest disease such as

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**Fig. 1.** Operative spirograms during left anterolateral cordotomies at the C1–2 level. A. Patient B. The effect of superficial (SC1) and deep (DC1) sections on respiratory excursion. (Record speed = 0.25 mm/sec; vertical 1 cm = 200 ml.) B. Patient JS. The effect of superficial (SC1) and deep (DC1, DC2) sections on the tidal volume. Note marked reduction after more anterior deep section DC2. (Paper speed = 1.2 mm/sec fast, 0.25 mm/sec slow.) C. Patient SG. The effect of superficial (SC) and deep (DC1, 2, 3) sections on respiratory excursions. Note marked effect following DC2 while DC3 has no further effect. (Record speed = 0.1 mm/sec.)
 Bronchial carcinoma had mechanical restriction on the side of the cancer and therefore very poor lung function. All were of average height and weight (with one exception), although the vital capacity ranged between 0.8 to 2.0 liters, the forced expiratory volume from 0.5 to 1.2 liters, and the peak flow rate from 110 to 240 liters per minute. Patients without such mechanical disorders, even with generalized chest disease such as bronchitis, had much better pulmonary function. Their vital capacity ranged from 2.2 to 5.3 liters, the forced expiratory volume from 0.9 to 2.9 liters, and the peak flow rate from 260 to 470 liters per minute. Lower ranges were recorded for a patient with less than average height (4 ft, 10 in.).

The results of these pulmonary function tests were graphed as 100% for each patient preoperatively and the percentage reduction charted postoperatively (Fig. 4). In all cases of high cervical cordotomy, a reduction in vital capacity occurred which in the first postoperative days was usually about 45%. The initial fall appeared to be independent of chest disease, but subsequent recovery was fast in those patients without mechanical disorders of respiration (Patients AG, B, TH, PON, O, and JS) while those with mechanical disability failed to improve and some even deteriorated (Patients S and IH). The expiratory volume test proved to be a good test of the mechanical properties of the chest wall in this type of patient and provided an excellent index of progress.

Diaphragmatic Movement. Recordings of diaphragmatic movement were made by periodic chest x-rays, but the variability of excursion from day to day and the difficulty in obtaining standard conditions prevented accurate comparisons of cupola movement. As a result, only general conclusions could be made. Anterolateral cervical cordotomy seemed to produce a relative diminution of diaphragmatic movement on the ipsilateral

![Fig. 2. Position of sections referred to in Table 1 at the right C1-2 and left T-2 levels in Patient NW. Note marked diminution in tidal volume following DC2 section.](image_url)
Edward Hitchcock and B. Leece

side. In one case with preoperative hemidiaphragmatic palsy, however, the previously immobile side became mobile after cordotomy, while the diaphragm on the side of the cordotomy appeared paralyzed.

Acid Base Balance Test. Regular estimations of capillary blood acid base balance (pCO₂) revealed that, with one exception, no significant change occurred in any patient. The one exception was Patient JS who showed a permanently elevated pCO₂ following operation, associated with severe respiratory embarrassment.

Case Report: Patient JS. A 51-year-old man had a peripheral carcinoma resected together with a portion of the right chest wall. He developed severe intractable chest pain, and examination showed gross restriction of chest wall movement. Before lobectomy he had had a vital capacity of 3.03 liters (80% predicted) and forced expiratory volume of 2.3 liters (87% predicted) with normal blood gases. Before cordotomy 1 year later, the vital capacity was 2 liters and the forced expiratory volume 1.3 liters with a normal pCO₂ and pH. This patient had a left C1–2 anterolateral cordotomy with a good level of analgesia up to C-3 and hypoalgesia up to and including C-2.

Two days postoperatively the vital capacity was 1.1 liters and the forced expiratory volume 0.7 liters. At the same time the pH was 7.43 and the pCO₂ 42; the standard bicarbonate was 26.5 mEq per liter. On the third postoperative day he was given a barbiturate; this was followed by serious deterioration of his condition including sputum retention and cyanosis. Even on the tenth postoperative day the pCO₂ was 56, pH 7.38, and standard bicarbonate 28.5 mEq/liter. At the time of discharge the pCO₂ was 65.5, pH 7.39, and standard bicarbonate 29.5. In spite of this, he was ambulatory but dyspneic; he was still pain-free when seen 3 months later.
Preservation of the Respiratory Pathway. Obviously there is great risk of respiratory tract damage in the usual operation of complete anterolateral section at the cervical level. When ipsilateral respiratory muscular efficiency is impaired, the danger is greater. In two such patients we attempted complete pain relief by high analgesic levels avoiding gross injury to the respiratory tract.

Case Report: Patient LB. This 62-year-old man suffered from severe rheumatoid arthritis and had been on steroid therapy. Although not completely immobilized, he had great difficulty in walking. Following an attack of pneumonia at the age of 7 years, he had had severe chronic lung disease and for many years had brought up large volumes of purulent sputum. There was an underlying bronchiectasis, but routine chest x-ray also showed a carcinoma at the right apex. Shortly thereafter he developed severe pain in the right clavicular region and right arm. His pulmonary function was grossly impaired and there was very restricted movement on the right side of the chest. The vital capacity preoperatively was 2 liters and the forced expiration volume 0.8 liters.

At operation, a left C-1 anterolateral cordotomy was performed; in view of his very poor pulmonary condition, he seemed a suitable case for attempting a fractional section avoiding the respiratory pathways. A superficial 1 mm cut (SC1) had no effect. Insertion of a 5 mm knife blade at produced a transitory fall of tidal volume. Deep section (DC1) produced a slight reduction of tidal volume, and DC2 had no effect.

Case Report: Patient LB. This 62-year-old man suffered from severe rheumatoid arthritis and had been on steroid therapy. Although not completely immobilized, he had great difficulty in walking. Following an attack of pneumonia at the age of 7 years, he had had severe chronic lung disease and for many years had brought up large volumes of purulent sputum. There was an underlying bronchiectasis, but routine chest x-ray also showed a carcinoma at the right apex. Shortly thereafter he developed severe pain in the right clavicular region and right arm. His pulmonary function was grossly impaired and there was very restricted movement on the right side of the chest. The vital capacity preoperatively was 2 liters and the forced expiration volume 0.8 liters.

At operation, a left C-1 anterolateral cordotomy was performed; in view of his very poor pulmonary condition, he seemed a suitable case for attempting a fractional section avoiding the respiratory pathways. A superficial 1 mm cut (SC1) had no effect upon respiration (Fig. 5). A 5 mm cordotomy blade was then inserted, and an immediate effect upon respiration noticed. The knife was withdrawn and a section made approximately 3 mm deep (DC1). The tidal volume was slightly reduced, but the effect was by no means as gross as usually seen from deeper cuts in this region. The knife was then removed and a further deep section made in the posterior section of the cord (DC2). Not only was there no further reduction in tidal volume, but improvement continued. Postoperatively there was complete relief of pain and a satisfactory analgesic level to C-4.

![Figure 5: Operative Spirogram during Cordotomy at the C-1 Level in Patient LB.](image)

![Figure 4: Vital Capacity, Forced Expiratory Volume, and Peak Flow Rate Plotted as Percentages of Preoperative Readings (100%) against Number of Postoperative Days.](image)
On the first postoperative day, the vital capacity was 1.7 liters and the forced expiratory volume 0.65 liters. Despite being given an appropriate dose of steroids in view of his previous steroid therapy, he suddenly died on the second postoperative day, without apparent respiratory deterioration.

Autopsy failed to reveal the cause of death but it is possible that, although the respiratory tracts were not directly injured, postoperative edema may have increased the minor effect upon respiration recorded immediately and on the first postoperative day. Despite this, however, a satisfactory analgesic level was obtained without any gross effect upon respiration, as shown by operative spirometry and postoperative pulmonary function tests. Gross examination and staining confirmed the restrictive nature of the incisions. Unfortunately, however, detailed serial sections were unobtainable due to a technical error, and this case should be regarded as unverified.

Case Report: Patient MS. This 61-year-old woman suffered intractable pain due to cervical carcinoma which had involved the pelvis and bladder. The effects of fractional sections upon respiration are shown in Fig. 6. A superficial cut 1 to 2 mm deep (SC1) was made in the more posterior portion of the anterolateral segment at C-1; this produced no effect upon respiration nor did a more anterior extension of this cut (SC2) made on the left side of the C-1 segment. The cordotomy blade was inserted to its full depth of 5 mm and the estimated section made without an apparent effect upon respiration (DC1). The blade was then advanced a few millimeters anteriorly, and a minor diminution in tidal volume occurred (DC2); because of this, the knife was withdrawn and no further section made. This resulted in analgesia up to and including C-4 on the right.

A right C1–2 anterolateral cordotomy was then attempted. A superficial cut (SC1) in a more posterior portion of the cord had no apparent effect upon the tidal volume. The cut was then extended (SC2) a little deeper than intended, and the result was a diminution in respiration from 200 to 140 ml with recovery to 180 ml within 3 minutes. At DC1 the cordotomy blade was inserted to its full depth of 5 mm and the posterior portion of the cut made. This resulted in a

![Fig. 6. Operative spirogram during cordotomy at the left C-1 and right C1–2 levels in Patient MS. Note that superficial section SC1 had no effect, nor did SC2 or deep section DC1 on the left. Deep section DC2 on the right, however, caused a minor fall in tidal volume, and superficial section SC2 a transitory fall.](image-url)
Respiratory Pathways in Cervical Cord

minimal fall of tidal volume from 180 to 160 ml, although when the cut was extended (DC2) a marked diminution in tidal volume occurred from 160 to 50 ml. This anterior extension was made in error because insufficient attention was paid to the minor irregularities of respiration immediately preceding the complete extension.

Postoperatively, the level of analgesia on the left reached T-9, but subsequently fell to T-12. The operative spirometry and postoperative results showed that a good level of analgesia had been obtained without demonstrable effect upon respiration. The analgesia level was not as high as usual (C-2), extending only up to C-4. Although this would have been perfectly adequate for arm and upper thoracic pain, it would have failed to relieve shoulder pain. The right-sided cordotomy, however, produced a gross effect upon respiration during operation, although there was later recovery.

The immediate sensory level obtained was only D-9 and the permanent level D-12; this suggested that cervical fibers of the spinothalamic tract had not been divided by the superficial cut and, in this instance, a greater injury had been inflicted on the respiratory tract than on the spinothalamic tract. Despite this, the postoperative pulmonary function tests showed good recovery of function, presumably due to the intact respiratory pathway on the left. On the fourth postoperative day, the forced expiratory volume was 70% and the vital capacity 90% of the preoperative level. On the eleventh postoperative day, both forced expiratory volume and vital capacity were 85% of the preoperative level. Films of diaphragmatic excursion, far from showing a diminution, showed a small increase. Preoperatively the excursion on the right had been 2.2 cm, rising to 2.4 cm on the fifth postoperative day. Preoperatively on the left the excursion had been 5.5 cm and was still 5.5 cm on the fifth postoperative day. The attempt at preservation of the respiratory pathway was not completely successful. Although the tract was preserved from injury during the left cordotomy, it was injured by the right cordotomy.

Discussion

The existence of a separate pathway concerned with respiration is of considerable interest. Some authors have felt that respiratory disorders following cordotomy were due to injury of the pyramidal tracts rather than of any specific pathway. Nathan, however, stated that lesions producing unilateral paralysis of respiratory movement do not necessarily cause hemiparesis, while Oliver found breathing unaffected after bilateral cervical pyramidalotomy.

Belmusto, et al., concluded that fibers concerned with respiration in man occupied an area from C-1 to C-3 between 3 and 5.5 mm from the lateral margin of the cord. Nathan drew a similar conclusion on the basis of pathological studies of cordotomy specimens.

Our results indicate that superficial circumferential section of the anterolateral quadrant in the cervical cord produces no gross permanent effect on respiration and that most if not all of the respiratory efferent pathway lies at least 2 mm deep in the surface of the cord. The spirogram illustrated in Fig. 3 suggests that that tract lies between 2 and 4 mm from the surface of the cord.

The posterior margin of the tract is difficult to determine with any accuracy except to note that, with anterior extension of the section, the effect upon respiration becomes progressively more severe. In the main, it appears that there is very little effect upon respiration from the equatorial line to about one third of the way anterior in the anterolateral quadrant. The fractional sections have demonstrated clearly that the maximal effect is produced by section of the anterior portion of the deep substance of the cord in the region of the anterior horn and emerging anterior roots. This delineation of the tract based on fractional sections and clinical assessment is obviously fraught with great inaccuracies. Whenever possible we have tried to confirm by autopsy the extent of the sections, although this could only be obtained for a complete section and not for the fractional cuts. The permanent effects of section are, of course, modified by physiological adaptation as when one respiratory tract is left uninjured. The area we have delineated corresponds almost exactly to that outlined by Belmusto, et al., and is included in the rather broader area outlined by Nathan. It is important to note that our sections have been limited to a very restricted area, namely, the first and second
cervical segments, whereas other authors have attempted delineation over a wider extent of the cord.

The work of Hyndman and Van Epps suggests that the spinothalamic tract is laminated not circumferentially but in such a manner that entering fibers displace those already present into a more posterior position. Although it is probably true that there is not a sharp segmental demarcation, there does appear to be a gross distribution of spinothalamic fibers at least at the cervical level so that the lower segments of the body are represented more posteriorly and the upper portions more anteriorly. This knowledge enables the neurosurgeon to attempt selective sections of the spinothalamic tract. Such attempts probably have a greater chance of success in the relatively well-organized spinothalamic system in the upper cervical cord.

The more posterior portion of the respiratory tract appears to be closely associated with posterior portions of the spinothalamic pathways, while the area of the respiratory tract having maximal effect on respiration is adjacent to the cervical segments of the spinothalamic tract. It seems reasonable to postulate that the posterior portion of the respiratory tract supplies the more caudal respiratory musculature, namely, the intercostal muscles and the abdominal and lumbar musculature used in respiration. The more anterior part of the respiratory tract, which is functionally more important, is related to the cervical portions of the spinothalamic tract.

It is well known that diaphragmatic paralysis has a greater effect upon pulmonary function than intercostal paralysis, and it is suggested that the anterior portion of the respiratory tract is largely related to diaphragmatic function. In suggesting this somatotopic relationship it is important to point out the close relationship of the somatotopic representation of the spinothalamic tract. Belmusto, et al., have gone so far as to suggest that respiratory changes are an indication of the adequacy of cordotomies in the cervical region. It is certainly evident in the standard anterolateral cordotomy that the respiratory pathways will be injured, particularly the vital anterior portion, if high levels of analgesia are to be obtained in the usual manner. Where high levels are required, the major part of the respiratory tract may still be preserved in part. A fractional section that secures high cervical analgesia and spares the lower segment might, for example, injure the anterior portion of the respiratory tract and its diaphragmatic function but allow normal function of the remaining part of the tract presumably concerned with the intercostal and abdominal respiratory function. Conversely, in patients with lower segment pain, the fractional high cervical cordotomy will at worst only interfere with the posterior portion of the respiratory tract. Belmusto, et al., are of the opinion that the spinothalamic and respiratory pathways are intermingled. Although a sharp distinction between these tracts is unlikely, our experience suggests that if such intermingling exists it is limited.

Hukuhara, et al., concluded that the respiratory fibers were confined to the reticular formation lateral to the lateral horns; Belmusto, et al., came to similar conclusions after investigating respiratory potentials in the cervical spinal cord of the dog. Both these papers suggest that the efferent respiratory pathway is one of the reticulo-spinal tracts.

There seems little doubt that a portion of the reticulo-spinal tract is concerned with respiration, and there is good evidence for an arrangement of voluntary and involuntary (automatic) respiration. Respiration proceeds automatically as the result of rhythmic discharges from the "respiratory center." This rhythm continues whatever the level of consciousness, although the onset of sleep is accompanied by respiratory change. The reticular activating system plays an important role in consciousness; presumably, fluctuations in its activity that result in sleep may similarly influence respiration through these reticulo-spinal pathways. A control of automatic respiration by the reticular activating system is overridden to some extent by voluntary control of respiration such as breath-holding, although ultimately the supremacy of automatic respiration is reasserted (by automatic "gasping" when skin afferents are stimulated by cold water).

If the reticulo-spinal pathways are damaged by cordotomy or spinal cord injury,
Respiratory Pathways in Cervical Cord

![Diagram of respiratory pathways](image)

Fig. 7. Diagram of the relationship between the spinothalamic (S) and reticulospinal (R) tracts showing the voluntary and involuntary influences on a respiratory neuron (anterior horn cell, A). The diaphragmatic and intercostal components of the reticulospinal system lie adjacent to the cervical and thoracic fibers in the spinothalamic tract.

then only voluntary respiration is possible, which is clearly dependent upon the conscious level. It is not uncommon to see patients with spinal injury or disease who can breathe by voluntary effort but have no rhythmic automatic respiration. The concept of voluntary and automatic respiration regulated by two distinct pathways is a satisfactory explanation of the fact that many patients have died in their sleep following high cervical cordotomy.

The voluntary control of respiration is presumably through the corticospinal tract, and the final common pathway for both the corticospinal and reticulospinal tracts is through the anterior horn cell (Fig. 7). From this cell emerge the cervical and thoracic roots to the diaphragmatic, intercostal, and accessory muscles of respiration; this cell may therefore have reticulospinal and corticospinal fibers that influence its discharge and thus modify each other's activity.

**Summary**

We have presented evidence that automatic respiration in man is mediated through the reticulospinal pathways lying in the anterolateral column of the cervical spinal cord. This evidence is based on the results of pre- and postoperative tests of pulmonary function and operative spirometry in 14 patients who had C1–C2 cordotomy for intractable pain. An attempt has been made to produce satisfactory analgesia without injuring this respiratory pathway.

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