Clinical Observations on Respiratory and Vasomotor Disturbance as Related to Cervical Cordotomies

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Foerster, in 1913, first suggested the upper cervical cord as a site for cordotomy when control of pain in an upper extremity or neck was necessary. It was not, however, until 1931 that he cautioned against a general use of bilateral high cervical cordotomy because of the impaired respiratory function that might result. He reported in 1932 that cordotomies in the high dorsal area were not associated with respiratory motor disturbances and concluded that the efferent tracts from the medulla oblongata to the spinal nuclei are not positioned in the anterior tracts.

Since these reports, there have been numerous authors who have published their experiences with high cervical cordotomies and some divergence of views, particularly in reference to respiratory difficulties, has continued.

Peet et al.,18 in 1933, advised that bilateral high cervical cordotomy should not be performed because of the danger of respiratory paralysis. “The phrenic nerves”, they said, “arise chiefly from cells in the fourth cervical segment. The exact location of the tracts descending to these cell bodies is unknown. Theoretically, at least, edema following section of the anterolateral tracts might involve these descending fibers or the phrenic cells in the anterior horns as well as the motor tracts of the intercostal muscles, resulting in respiratory failure.”

In 1950, White and associates,29 after reviewing their series of patients subjected to high cervical cordotomies, concluded that mortality was greater in the postoperative period when this region was used. Two of 9 deaths they reported were a result of immediate respiratory and circulatory failure.

More information was offered by French and his co-workers.5,9,17 Five of 12 patients undergoing bilateral simultaneous high cervical cordotomy died in the immediate postoperative period. It was concluded that such procedures were fatal if the level of analgesia obtained was high enough to relieve bilateral upper thoracic and lower cervical pain. It also was recognized that transitory paralysis of the ipsilateral intercostal muscles and diaphragm occurred in almost all cases. This usually disappeared within 24 hours and was not associated with pulmonary complications. French commented that patients who exhibited this transitory respiratory muscular paralysis were more likely to maintain a permanent high level of analgesia. Grant and Wood,19 Jackson,12 and Belmusto and Owens2 indicated undesirable mortality figures following high cervical cordotomies.

Brihaye and Retiff3 reported that high cervical cordotomies gave better results in their series, but a higher incidence of mortality was encountered. They concluded that bilateral high cervical cordotomy (if done properly) should never be performed at one sitting. Matson and Shillito26 concurred with this view.

Stookey,22 Roulhaëc30 and Horrax and Price41 reported their experiences with high cervical cordotomies, some of which were bilateral, and these authors were impressed with the absence of postoperative complications.

Foerster,5,6 in 1936, reported his observations on vasomotor alterations following bilateral cordotomies. He concluded that vasoconstrictor pathways to both sides of the body were represented in each anterolateral quadrant of the cord. Others10,14,15,21,25 de-
scribed "orthostatic or postural" hypotension resulting from bilateral cordotomy. White et al.\textsuperscript{8,9} and French\textsuperscript{8,9} inferred that this change might occur in high cervical cordotomies. The consensus, it would seem, is that a bilateral simultaneous high cervical cordotomy is dangerous. Despite this general view, it was obvious that more detailed information relating to respiratory and vasomotor change resulting from cervical cordotomies at different segments, both unilateral and bilateral, was required. This study was, therefore, undertaken. Specifically we wished to establish:

1. The incidence and degree of respiratory and vasomotor alterations following high cervical cordotomies (C1, C2, C3) and low cervical cordotomies (C5, C6, C7, C8) whether unilateral or bilateral.

2. A more precise anatomical location of the pathways of the fibers serving these systems. This interest was sparked initially by 2 fatal complications which were related to high cervical cordotomies for which good explanations were lacking. These cases are reported below.

Case 1. A 62-year-old white male underwent a bilateral high cervical cordotomy because of pain in the lumbar dorsal midline and lower extremity. Four years previously, carcinoma of the rectum had been excised through a combined abdomino-peroneal approach.

Physically, there was no evidence of cachexia or advanced carcinomatosis. The right leg was markedly edematous and little movement of the legs could be elicited because of pain.

At operation, bilateral incisions, 5 mm. deep, were made; one at C2 and the other at C3.

After operation, respiratory difficulties were encountered, but with positive-pressure assistance he recovered nicely within 24 hours. Sensory levels at around C5 bilaterally were recorded. His progress was excellent over the next 3 days.

He was assisted into a chair on the 4th postoperative day and collapsed immediately. Vital signs were unobtainable. External cardiac massage was instituted and resuscitation was possible. Resorptions were very depressed and required positive-pressure assistance. Despite all efforts, he expired 3 days following his collapse and 7 days following operation.

Autopsy revealed atheromata of the coronary artery and a small metastatic nodule in the right auricle. Tumor was encountered extensively elsewhere. There was no untoward surgical damage to the spinal cord.

Case 2. A 39-year-old white female underwent a bilateral high cervical cordotomy because of intractable pain on the basis of widespread abdominal and pelvic adenocarcinoma of the cervix.

Incisions of 4 mm. were made at right C1 and left C3 levels in the anterolateral spinothalamic tracts.

Immediately after, marked respiratory difficulties were encountered and were characterized by thoracic and diaphragmatic asynergy. This persisted for about 1 hour. Within 24 hours, no apparent significant residual disturbance existed. She was discharged 9 days later, but returned in 1 week markedly cyanotic with a respiratory rate of about 2/\text{min}. Immediate resuscitative measures were instituted and positive-pressure respirations were begun. It was learned that barbiturates had been used the previous evening for sleep and that she had been found in this respiratory state shortly before re-admission. She recovered from the acute disturbance, but during periods of natural sleep, respiratory efforts became ineffective and required assistance. She eventually expired as a result of widespread carcinomatosis.

Postmortem examination indicated adequate surgical incisions of the cervical cord. There were no unanticipated findings.

Clinical Observations

Methods. The majority of the 20 patients included in these studies were operated on in the sitting position under general anesthesia administered via an endotracheal tube. Fluothane was the general anesthetic agent of choice, and in 2 instances local anesthesia was employed. In every instance the lower extremities were wrapped with elastic bandages and then elevated so as to prevent vascular pooling. A standard cervical laminectomy was carried out. The incisions aimed at the anterolateral spinothalamic tracts were never less than 4 mm. and never more than 5½ mm. in depth. The anterior cut was carried out perpendicular to the lateral incision so that the entire quadrant was incised. This usually would include all tissue up to and just medial to the emergence of the anterior nerve root. Constant arterial pressures were monitored in most instances via a brachial or femoral artery using a Rochester needle connected to a strain gauge leading
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to a Sanborn recorder. A pneumotachogram also was recorded constantly (Fig. 1). Electromyography was attempted in several patients and was successful when measuring intercostal activity, but not when the diaphragm was monitored. Expired CO₂ was measured in several instances using an infrared CO₂ gas analyzer with a breathe-through cell.

Results

Fig. 2 illustrates the recorded effects produced by a unilateral C₂ cordotomy performed on a 49-year-old man with bronchogenic carcinoma producing intractable pain in the left chest, shoulder and arm. A moderate instantaneous change in the tidal volume (pre-cut 400 cc.) and blood pressure was observed when a 3 mm. incision was made. Fifty sec. later, the depth of the cut was increased to 4.5 mm., and, as indicated by the pneumotachograph, the tidal volume dropped to 50 cc. or less. It was noted that the CO₂ dropped simultaneously. This would appear to be related to the deficient tidal volume making it impossible to clear dead space, thereby reducing the amount of CO₂ presented to the sensing device. Respiratory assistance was necessary for a period of 15 min. At the end of the operation the tidal volume had not returned, however, to the pre-cordotomy level. The blood pressure dropped precipitously after the depth of the cordotomy increased. Intravenous vasopressor agents rectified this situation adequately. During the postoperative period no respiratory or vasomotor abnormalities were encountered. He was ambulatory on the 8th postoperative day, and on discharge had a unilateral sensory level at C₄, including the sacral dermatomes.

Fig. 3 represents the observed changes in a 75-year-old man subjected to a unilateral

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Fig. 1. Example of a pneumotachogram recorded during general anesthesia. Three chart speeds are represented. The marker at the bottom of the chart records the respiratory rate. It is possible, as noted in the illustration, to arrive at an accurate determination of the various volumetric relationships that might be required.

Fig. 2. T.T., #106572, R.P.M.I. Response to unilateral C₂ cordotomy. Arrows designate points at which incision at various depths was made. Blood-pressure response was recorded separately but written in on this chart. Assisted respirations required for 15 min.
right C2 cervical cordotomy because of intractable pain of the left chest, shoulder, and arm resulting from advanced bronchogenic carcinoma. Initial blood pressure was 145/75. There was evidence of a cyclic type of respiration. Tidal volume measured 350 cc. and the respiratory rate was 22/min. The effects of opening the dura mater and arachnoid are observed at A.

At B, the posterior C2 nerve root was crushed and an immediate elevation of blood pressure occurred in association with hyperventilation. At C, a 3 mm. cut in the right anterolateral quadrant of the cord was made. A moderate respiratory response was observed. At D, the incision was increased to 5 mm. Tidal volume immediately diminished to around 50 cc. This response persisted for only about 1 min. Subsequent recovery to a tidal volume of 200 cc. was observed. This was 150 cc. less than the original volume.

The blood pressure responded to the 5 mm. cut by progressively falling to a low of 80/55, at which point intravenous vasopressor substance was administered (Wyamine). Postoperatively, this patient did well and was discharged with a unilateral level at around C5 (sacral region was included).

Fig. 4 illustrates the responses to a bilateral low cervical (C6, C7) cordotomy of a 65-year-old woman with intractable pain in both legs and pelvic region secondary to carcinoma of the colon. There were no significant changes in either measured modalities after 3 or 5 mm. cuts on the first side. When the incision was made on the opposite side the tidal volume remained unchanged but the blood pressure dropped gradually and an intravenous vasopressor agent was required to control the blood pressure. Some flattening was observed in the expiratory activity of the right intercostal musculature following
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completion of the bilateral operation. No other respiratory alterations were observed. No postoperative complications were encountered. A prolonged period of postural hypotension was combatted by administration of an intramuscular vasoconstrictor substance as well as elastic wrapping of the legs. At discharge, the blood pressure remained at a distinctly lower range. Analgesia was maintained at T2 bilaterally. The sacral regions were included.

In every instance following a unilateral high cervical cordotomy, of at least 4 mm., respiratory embarrassment occurred. (Control of pain will be temporary at best if the incision is less than 4 mm. This is in agreement with French.) The degree of respiratory impairment varies even in the unilateral incisions. In general, if respiratory function pre-operatively was adequate, respiratory difficulties following unilateral high cervical cordotomies were transitory and moderate. If pulmonary pathology existed (as it did in all of our cases) more pronounced difficulties were encountered. Death occurred in 1 instance in which radiation therapy to a Pancoast’s type of lesion was followed by emphysema and intractable pain. The moderate degree of respiratory embarrassment in this situation was severe enough to

\[ \text{FIG. 4. M.R., 899856, R.P.M.I. Blood pressure (BP) and pneumotachogram (P) recorded during a bilateral low cervical cordotomy. The right and left intercostal electromyographic responses were also recorded (middle portion of the record). A gradual response in the blood pressure can be observed at 4, becoming more pronounced at 5. The arrow designates the flattened expiratory response on the right intercostal record which corresponds to the completion of the bilateral incisions.} \]
produce rapid deterioration and death within 72 hours. In the presence of diffuse pulmonary metastasis, emphysema, atelectasis, pleural effusion, bronchiectasis, tuberculosis, pulmonary fibrosis, and pneumonectomy, a unilateral high cervical cordotomy is as risky as a bilateral high cervical procedure done at one sitting.

Respiratory depression related to the surgical procedure follows instantaneously. On several occasions apnea lasting less than a minute was noted (?) spinal shock); restoration of respiration then was noted but return to pre-operative ranges of tidal volume were never achieved during the period of study. Postanesthesia pneumotachograms were found to be totally unreliable because of the awake situation. The assumption made by other authors that a period of 24 hours is sufficient to allow restoration of normal function may be correct. We feel, however, that more sensitive and critical evaluation is necessary.

Two patients operated on under local anesthesia had bilateral low cervical procedures. In each instance a fall in the blood pressure was encountered, but no respiratory changes were noted.

Discussion

Little information is available pertaining to the efferent tracts of the spinal cord acting on the respiratory motor nuclei. Allen,1 in 1927, concluded that descending respiratory motor tracts were located in the anterior columns and in the ventral part of the lateral columns and he suggested that the ventral and lateral reticulospinal tracts subserved respiratory impulses. Pitts10 stated that in cats such pathways were located in the anterior columns and anterior part of the lateral columns of the spinal cord. For the most part, he felt that these were uncrossed. He noted that although the initial ipsilateral respiratory paralysis from hemisection of the cord at C1 was complete, recovery of function on the side of the lesion was prompt and within 6 weeks both halves of the thorax, and both halves of the diaphragm became equally active. Crossed connections were felt to exist within the spinal cord between the respiratory neurons on one side of the medulla and the effector motor nuclei on the opposite side of the cord.

In 1954, Hukuhara et al.12 were able to record in dogs respiratory discharges from the lateral reticular formations in the medulla oblongata and from the reticular formation of the spinal cord. They felt that automaticity was not present, therefore, in the motor cells serving the respiratory apparatus. It was concluded by them that these structures (reticular formations) were the centrifugal pathways of the respiratory impulses.

To date, in our studies it is possible to localize grossly an area subserving respiratory function in the spinal cord. This lies in the anterior quadrants bilaterally extending from C1 to at least C9 at a distance from the lateral margins of the cord of 3 to 5½ mm. This would indicate that a region approximately 2½ mm. in width and probably extending caudally at least to C4 subserves respiratory activity together with vasomotor and pain responses. Respiratory activity below C4 in this general region (anteromedial) is less important, but evidence is presented that at least the expiratory phase of intercostal-muscle activity is altered by an incision at C5, C6, C7, when performed bilaterally. The vasomotor response in the lower cervical area is located within a region 3 to 5½ mm. from the anterolateral surface of the cord. The caudal extension of these pathways is unknown. It is obvious that pain, respiration, and vasomotor pathways are inextricably intermingled in the cervical regions described above. For this reason, we feel that an indication of the adequacy of cordotomies performed under general anesthesia in the cervical regions can be evaluated clearly at the time of operation. Unilateral high cordotomies must produce transitory diminution of tidal volume to ranges of between 50 and 100 cc., and hypotension. Bilateral low cervical cordotomies must produce a gradual drop in the blood pressure only after an incision has been made on both sides. A unilateral low cervical cordotomy, in con-
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Contrast, cannot be evaluated adequately by these standards.

Orthostatic hypotension is a well recognized change resulting from cordotomies. Most authors place the afferent tracts in the anterolateral regions.\(^{15,21,24}\) Two years has been reported as the longest duration of this postoperative disorder.\(^{21}\) It is widely accepted that this alteration is caused by a failure of the normal compensatory vasoconstrictor reflex.\(^{22-26}\) In our series, when hypotension is a by-product of surgery an upright posture only increases the already lowered pressure. We feel it is more precise, therefore, to refer to this as orthostatic hypotension occurring in hypotensive individuals.

Conclusions

1. Impaired respiratory activity will result in every instance in which an adequate (at least 4 mm.) cut is made in the upper cervical cord.

2. Rapidly developing hypotension can be anticipated in association with the above.

3. Bilateral high cervical cordotomies in the presence of pulmonary pathology should be abandoned entirely whether done at one time or in a staged procedure.

4. Unilateral high cervical cordotomies, because of respiratory impairment produced, will be associated with high mortalities if pulmonary pathology is present.

5. Adequate relief from pain produced by a high cervical cordotomy may be accurately anticipated during general anesthesia by measurement of the tidal volume (pneumotachogram) and blood pressure. In every instance in our series postoperative success was correlated closely to the degree of temporary respiratory difficulty measured at the time of cordotomy.

6. We are of the opinion that respiratory impairment is on the basis of interruption of a descending respiratory pathway rather than damage to the lower motor neuron.

7. There is little if any respiratory deficit (though disturbance has been noted) produced by either a unilateral or bilateral low cervical cordotomy.

8. Hypotension can be used as a measure of the adequacy of a cordotomy incision in a bilateral procedure when performed in the lower cervical region. In our experience a permanent analgesic level is not produced unless hypotension was observed after cutting the second side.

9. Unilateral low cervical cordotomies will produce little if any alteration in vital signs, and therefore the adequacy of such a procedure cannot be predicted.

10. Recovery from hypotension resulting from a unilateral high cervical cordotomy is prompt (within 48 hours). Recovery from hypotension produced by a low cervical bilateral cordotomy is prolonged (many months). Both hypotensive states require pharmacological correction for varying periods of time.

Summary

The respiratory and vascular changes in 20 patients who underwent cervical cordotomies have been illustrated and discussed.

It appears that cardiovascular and respiratory changes are related to multiple causes which often potentiate each other. The most important factor seems to be related to surgical injury of descending motor respiratory and sympathetic pathways in the spinal cord. Impaired or altered physiologic function of the cardiovascular and respiratory systems enhances the surgically produced changes. It is demonstrated that these changes can be helpful, however, in that they can predict reliably the postoperative effectiveness of the cordotomy.

References


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