Effects of vertebral column distraction in the monkey

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Experiments were performed to assess the effects of vertebral column distraction on evoked potential responses from multiple recording sites along the conducting pathway in the monkey, and on concurrent blood flows, measured with the radioactive microsphere technique, along the axis of the central nervous system. Linear distractive loads were applied until the amplitude of the evoked response was significantly reduced. In four monkeys, the loads (100 to 150 lb) were sustained, whereas in two monkeys the forces (80 to 110 lb) were relaxed. The earliest response changes were most marked in recordings dependent upon the integrity of the upper cervical dorsal columns or brain stem-lemniscal pathway. The responses returned to control levels with load relaxation, but maintenance of the tractive load produced generalized and progressive response attenuation. At selected periods of significant changes in the evoked potential response, blood flow remained stable except for the late onset of regional ischemia in the middle cervical through upper thoracic spinal cord levels in the animals undergoing sustained loads. These findings indicate that brain-stem or spinal cord dysfunction occurring with both acute and gradual elongation of the spinal canal are the result of excess tensile stress acting on fiber tracts, and the delayed onset of spinal cord ischemia is the probable result of a similar mechanical process acting upon intrinsic spinal cord blood vessels.

KEY WORDS • vertebral column distraction • spinal cord • evoked response • ischemia • axial tensile stress • skeletal traction

There is a paucity of information regarding the effects of distractive forces on the vertebral column. Certain investigators have suggested that such forces serve as a principal component of acute spinal cord injury, and are an important influence on the spinal cord during the application of surgical distraction devices or skeletal traction. A realistic interpretation of the role of vertebral column distraction, however, has been obscured by the controversy regarding the relative importance of mechanical factors versus ischemia in the pathogenesis of any resultant myelopathy. Hypotheses have been based on a variety of experimental spinal cord injury protocols and physiological measurement techniques. The differences in methodology, interpretation of the electrophysiological changes, species of experimental preparation, origins of the forces, and the temporal characteristics of the applied stress make it difficult to compare the studies.

In order to clarify the role of increased axial tensile stress (stretch) upon the spinal cord, the present investigation compares alterations of evoked potential responses, measured at multiple levels along the conduction pathway in the monkey, with concurrent changes in blood flow along the entire central nervous system (CNS) axis as determined by the radioactive microsphere technique. The protocol involved the application of both gradual and rapid distraction to the entire spinal axis.

Materials and Methods

Animal Preparation

Electrodes were implanted in six Macaca mulatta monkeys (weighing 9.5 to 11.8 kg), anesthetized with thiamylal sodium (5 to 8 mg/kg). Electrode pads, consisting of three platinum-iridium discs (0.025 mm thick, 2 mm in diameter, and 4 mm apart on center)
embedded in Dacron-reinforced Silastic (0.25 mm thick), were introduced through a small opening in the interlaminal ligament into the dorsal epidural space at the T12–L1 level. Identical electrodes were placed bilaterally into the epidural space over the sensorimotor cortices and fixed to the calvaria by methyl methacrylate. At the upper thoracic region (T2–3), a flexible electrode (1.0 mm in diameter, with 1.5 mm cylindrical platinum tip exposure) was positioned in the epidural space through a small opening in the interlaminal ligament and maneuvered cephalad to the cervical level (C4–6). The connectors for the spinal electrodes were placed in individual subcutaneous pockets.

After a recovery period of 2 or 3 days, the animals were again anesthetized with thiamylal sodium, and the femoral artery was cannulated for continuous systemic arterial blood pressure (SABP) measurements, intermittent arterial blood gas determinations, and pH analysis. A stainless steel cable, 5 mm in diameter, was positioned beneath the inion and zygomatic arches, with a loop fashioned above the midportion of the calvaria. The cable was then embedded in methyl methacrylate. In four animals, a similar cable was passed through the ischial tuberosities for later use in pelvic fixation. Ventilation was maintained with a volume-cycled respirator via a cuffed endotracheal tube. The left side of the chest was opened, and a polyethylene cannula was positioned in the left atrium through the atrial appendage. A water-seal drainage tube was placed, and the chest was closed. Continuous arterial pressure was measured with a Statham P23db strain gauge* attached to a separate femoral arterial cannula. Rectal temperature was controlled at about 37°C by means of a heating pad.

The loop of cable that was secured to the calvaria was connected to a bar-and-swivel apparatus, which was secured to the head of the table. This attachment would permit subsequent application of linear forces along the spinal axis, with the outward movement of the screw fixed to the support system. The force levels were measured with an in-series Dillon gauge. Two methods of restraint were used: four animals were restrained at the ischial tuberosities by the previously positioned cable; two animals were restrained at the torso using the shoulder straps of an SAEJ-386 seatbelt harness.† Before application of force or recording of control evoked responses, a single dose of intravenous pentobarbital (6 mg/kg) was administered that resulted in a faint or absent corneal reflex and stable SABP recordings in all animals. Arterial blood gas determinations were repeated, and control radiographs of the vertebral column were obtained.

**Evoked Potential Recordings**

When the above parameters normalized, the sciatic nerve was exposed in the thigh through a surgical site infiltrated with 1% lidocaine (Xylocaine). A bipolar clamp electrode was secured about the sciatic nerve, and paired silver electrodes were inserted into the wrist adjacent to the median nerve. The sciatic and median nerves were stimulated using rectangular pulses of 0.2 msec duration at 4 Hz, with intensities above those necessary to obtain a motor response. Similar parameters were used for stimulation of the conus medullaris and sensorimotor cortex via the electrodes previously positioned at these levels for both stimulating and recording. After stimulation of the sciatic nerve, spinal cord, or sensorimotor cortex, evoked potentials were retrieved with the CTC-2000 evoked potential measurement system‡ with the number of sweeps kept at 50 and electrode impedance maintained between 800 and 1200 ohms.

Control recordings were obtained with careful attention to stability and reproducibility. Responses evoked by sciatic nerve (SN) stimulation were recorded from the conus medullaris (SN-CM) and sensorimotor cortex (SN-SMC). Responses evoked by conus medullaris (CM) stimulation were recorded from the cervical cord (CM-cervical) and sensorimotor cortex (CM-SMC). Responses evoked by median nerve (MN) stimulation were recorded from the cervical cord (MN-cervical) and sensorimotor cortex (MN-SMC). Responses evoked by sensorimotor cortex (SMC) stimulation were recorded from the conus medullaris (SMC-CM).

**Blood Flow Measurements**

The reference sample microsphere technique used for determination of cerebral, brain-stem and spinal cord blood flow has been described in detail.1,7,19,24 Microspheres 15 ± 1.5 μm in diameter labeled with cerium-141, strontium-85, chromium-51, and scandium-46 permitted four separate measurements of blood flow at multiple levels of the CNS. These microspheres were suspended in saline to which a drop of Tween-80 was added, and agitated in a Vortex mixer for 10 minutes, followed by sonification for 30 seconds. To ensure adequate sphere density, a 1.0-cc bolus (approximately 3 × 10⁶ spheres) was injected into the left atrium and flushed for 1 minute with a 10-cc saline wash.7 At each microsphere injection, a reference blood sample was withdrawn from the thoracic aorta at a constant rate of 2.5 cc/min for 3 minutes. After the fourth microsphere injection, the

* Statham P23db pressure transducer manufactured by Statham Instruments Co., 2230 Statham Boulevard, Oxnard, California.

† SAEJ-386 seat-belt harness manufactured in accordance with Society of Automotive Engineers Recommended Practice for Seat Belts.

‡ CTC-2000 evoked potential measurement system manufactured by Clinical Technology Corp., Inc., Kansas City, Missouri.
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animals were sacrificed, and the brain and spinal cord were removed en bloc. Multiple samples of tissue from the cortex, basal ganglia, brain stem, and cervical, thoracic, and lumbar regions were weighed and placed in glass scintillation vials. Tissue and reference blood samples were counted for 5 minutes in a well-type gamma counter, with isotope activity determined at four separate energy windows. Calculations of isotope separation and blood flow values were performed on a PDP11/34 computer.56

Experimental Groups

After control evoked potential recordings, vertebral column radiographs, and initial microsphere injection were evaluated, force in the axial plane of the vertebral column (traction) was applied in two different temporal sequences. Four monkeys underwent gradual vertebral column distraction (Group I), and two had rapid distraction (Group II).

Gradual Distraction. In four animals, axial tension loads were applied, with a baseline of 50 lb. Physiological parameters and evoked potential recordings were evaluated to ensure stability to control levels. Tension was increased in 25-lb increments, and physiological parameters, evoked potentials, and radiographs were reevaluated within 10 to 15 minutes of the increase. When any of the evoked responses demonstrated more than 30% to 40% reduction in amplitude of the primary components (initial 10 to 30 msec), the second microsphere was injected and tension was maintained at that level. If the evoked responses showed progressive attenuation, a third microsphere injection and radiograph were carried out when amplitude reduction reached 50% to 70% of control values. If the evoked responses did not demonstrate progressive attenuation, an additional 25 lb of traction was applied and the identical procedure of observations and measurements was carried out. Tension was maintained at that specific load level and evoked potential recordings and radiographs were observed until evoked response attenuation approached 70% to 80% of the control amplitude. The total time required for this maximum evoked response attenuation from the initiation of the procedure ranged from 43 to 62 minutes. The fourth microsphere was injected and, after initiating a buffered saline exchange transfusion, cardiac arrest was induced. The tissues were infused with glutaraldehyde, and the entire spinal cord, brain stem, and cerebellum removed for immersion in glutaraldehyde solution.

Rapid Distraction. In two animals, axial tension load of 75 lb was applied within 5 to 10 seconds. Sensorimotor responses evoked by sciatic nerve stimulation (SN-SMC) were evaluated; if the amplitude of the primary components decreased 40% to 50%, the second microsphere was injected and traction released. If SN-SMC responses were intact or minimally attenuated, traction was rapidly increased with 25-lb increments and responses reevaluated until the 40% to 50% reduction of amplitude was obtained; then the second microsphere was injected and the traction was released to baseline. Evoked responses were allowed to return to almost control levels, and the third microsphere was injected. After the evoked response had stabilized, an axial force 25 lb greater than previously required for the 40% to 50% reduction in amplitude of the SN-SMC response was applied within 5 to 10 seconds. If response attenuation exceeded 70% of the control amplitude, the entire sequence of evoked potentials was recorded, and the fourth microsphere injected. If response amplitude decreased less than 70%, additional 25-lb force increments were rapidly applied until such amplitude suppression was obtained. The entire series of evoked responses was recorded within a 3-minute period. These recordings were repeated twice before a buffered saline exchange transfusion was initiated and cardiac arrest induced. The tissues were immediately perfused with glutaraldehyde, and the entire spinal cord, brain stem, and cerebellum removed for immersion in glutaraldehyde solution.

Results

The data were analyzed separately for the two groups. Tables 1 and 3 give the physiological parameters, the averaged results of blood flow at the cortical, basal ganglia, brain stem and spinal cord levels, and the corresponding changes in amplitude of the primary components (initial 10 to 30 msec) of the evoked responses recorded from the various sites along the conducting pathway. The significance of the evoked response and blood flow changes at each microsphere injection was evaluated using Student's t-test with a 95% confidence level. With the exception of a relative decrease in SABP during the late segments of the protocol and a single occasion of metabolic acidosis that responded to therapy, SABP and arterial blood gas determinations remained stable and within acceptable ranges. The control blood flow values obtained with the first microsphere injection, including the regional variation of spinal cord blood flow (SCBF), agree with flow measurements noted by other investigators using the radioactive microsphere technique.1,16,24

Gradually Applied Linear Distraction

At the second microsphere injection, applied loads ranged from 100 to 150 lb, with the highest levels required in the animals restrained with the shoulder harness system. None of the blood flow measurements derived from averaging the values obtained at the second microsphere injection changed significantly from the values obtained with the first (control) microsphere injection (Table 1, p < 0.05). Direct comparison of these averaged blood flow values were the same or increased relative to control measurements,
except for a slight decrease in cervical cord blood flow which resulted from a marked flow reduction at this level in one animal (Table 2). In contrast to the relatively stable SCBF measurements derived from the second microsphere injection, all corresponding evoked potential responses, except for those recorded at the conus medullaris that were evoked by sciatic nerve (SN-CM) stimulation, showed statistically significant reduction of amplitude in the primary components of the response. The earliest and most marked of the amplitude reductions were noted in the cortical (MN-SMC) and cervical responses (MN-cervical) evoked by median nerve stimulation (Table 1 and Fig. 1). The responses at the cervical level evoked by conus medullaris stimulation (CM-cervical) also showed a statistically significant reduction of response amplitude but of a lesser magnitude (20% to 30%) than noted in responses mentioned previously (Table 1 and Fig. 1).

At the third microsphere injection, cervical and thoracic cord blood flows had markedly diminished in all animals, even though the distractive force had been increased (by 25 lb) in only one animal (Tables 1 and 2). Blood flows in the cerebral cortex, thalamus, and brain stem remained intact. All corresponding evoked potential recordings showed marked amplitude reductions (Table 1 and Fig. 1). The moderately reduced cervical cord responses evoked by conus medullaris stimulation (CM-cervical) demonstrated a progressive increase in latency which terminated in an abrupt obliteration of evoked response primary components (Fig. 2). A similar course of events was noted in the conus medullaris responses evoked by sensorimotor cortex stimulation (SMC-CM). The entire group of evoked responses which had been markedly attenuated at the third microsphere injection proceeded to almost total obliteration by the fourth microsphere injection. This final flow measurement showed the severe reduction in cervical and thoracic cord blood flows noted previously, as well as a statistically significant reduction in lumbar cord blood flow which was of lesser magnitude (approximately 50%, Table 1).

Rapidly Applied and Released Linear Distraction

The loads necessary to induce the initial response changes were 80 and 100 lb. At these force levels all responses were reduced in amplitude, with the most

**TABLE 1**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Microsphere Injections</th>
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<tr>
<td></td>
<td>No. 1</td>
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<tr>
<td>MABP (mm Hg)</td>
<td>111.2 ± 10.3</td>
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<tr>
<td>blood flow (ml/100 gm/min)</td>
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<tr>
<td>cerebral cortex</td>
<td>59.9 ± 12.3</td>
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<tr>
<td>thalamus</td>
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<td>brain stem</td>
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<tr>
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<tr>
<td>thoracic</td>
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<tr>
<td>lumbar</td>
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<tr>
<td>evoked potentials (µV)</td>
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<tr>
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<td>CM-cervical</td>
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<td>SMC-CM</td>
<td>20.2 ± 3.2</td>
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</table>

* Values are means ± standard deviation. Abbreviations: MN = median nerve; SN = sciatic nerve; SMC = sensorimotor cortex; CM = conus medullaris; MABP = mean arterial blood pressure. † Significantly different from control values (p < 0.05).
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significant decreases being recorded at the cortex, evoked by conus medullaris stimulation (CM-SMC), cervical cord responses evoked by median nerve stimulation (MN-cervical), and, to a lesser extent, responses recorded at the conus medullaris evoked by sciatic nerve stimulation (SM-CM) (Table 3 and Fig. 2). This latter response (SN-CM), recorded at the lumbar entry zone, showed complete recovery to control levels on release of the distractive force, but the markedly attenuated responses (CM-SMC and MN-cervical), which had undergone amplitude reductions of 65% and 70%, respectively, in their primary components, failed to demonstrate a full recovery to control amplitudes during the observation period (second to fourth microsphere injections). Blood flow determinations performed during this period of application and release of the distractive forces were unchanged from control values. The blood flows remained significantly unchanged, even at the fourth microsphere injection when repeat application of distractive loads of 20 and 35 lb more than the original load levels resulted in significant amplitude depression of all evoked responses.

Discussion

The brain stem and spinal cord may be regarded as a continuous tissue tract that is anchored rostrally at the mesencephalon and caudally where the nerve roots emerge. This concept has resulted in the opinion that elongation of the vertebral canal during skeletal traction or other distraction procedures may result in harmful tensile forces acting upon this unit.6,8 The present study suggests that the susceptibility of this brain stem–spinal cord tract to the potentially deleterious effects of distraction appears to depend mainly upon both the rate of application and the magnitude of the distractive force.

The few previous experimental studies specifically designed to evaluate the effects of distraction have noted a disparity in the importance of spinal cord ischemia as a contributing factor to changes in the functional integrity of the spinal cord. Dolan, et al.,12 investigating the effects of upper lumbar distraction in the cat through measurements of the spinal evoked response and SCBF, noted a coexisting or preexisting spinal cord ischemia with evoked response amplitude depression. In contrast, Larson, et al.,22 found that the evoked response attenuation occurring with linear distraction applied at the level of a lower thoracic circumferential osteotomy in the monkey completely recovered with relaxation of the distractive force during a state of total spinal cord ischemia induced by ascending aorta occlusion. Although these studies used similar methods to produce distraction, measurements were performed at markedly different times during the force application. Dolan, et al.,12 applied distractive force at 0.25 cm/10 min intervals with at least 40 to 50 minutes of force application before a single SCBF measurement using the carbon-14 anti-

pyrine autoradiological technique was performed. Larson, et al.,22 on the other hand, carried out their observations during a 5- to 10-minute period after the fairly rapid application of regional distraction. These varying results suggest that spinal cord dysfunction during the early stages of distraction may represent a mechanical compromise, and that a corresponding vascular insult may result from prolonged distraction.12,13

The process of administering a constant axial distractive load certainly leads to a "flow" or "creep" in the length of the vertebral column and, therefore, increased axial stresses upon spinal cord components, including its vasculature. In allowing time for the vertebral column to adapt to a given load, its elongation is not limited as are compressive forces by the zygohypophyseal joints, intervertebral discs, and vertebral bodies. Instead, in the absence of surface contact, vertebral canal elongation is the result of increased tensile load on its ligamentous structures.20

Fig. 1. Comparison of the patterns of evoked response attenuation and blood flow changes in a Group I animal during gradual and sustained linear distraction load application. Upper: The percent of response attenuation recorded from the cervical spinal cord following median nerve (MN → cervical) or conus medullaris (CM → cervical) stimulation and sensorimotor cortex following conus medullaris (CM → SMC) stimulation. Lower: The pattern of blood flow alterations during this time period. Arrows along the baseline signify the amount of axial load (pounds) being applied.

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The forces applied in the present study which resulted in altered evoked potential responses agree with previous studies showing spinal column distraction without ligamentous rupture at 75 to 100 lb of gradually applied axial force in the intact monkey preparation. In the present study, the neurophysiological changes noted with the rapid application of axial distraction in conjunction with their recovery on release of these forces contrasts with the progressive and irreversible changes occurring with continuous load application, and emphasizes the concept that time is as important a parameter as force and deflection in biomechanical testing.

The present study supports the hypothesis that spinal cord dysfunction during the early stages of distraction represents a mechanical injury to spinal cord components, and that a vascular insult is the result of prolonged force application. In this investigation, the animals undergoing rapid application of axial distraction until the primary components of the evoked potential response were reduced to approximately 50% of control amplitude showed corresponding normal or slightly hyperemic blood flow values along the entire axis of the CNS. If distraction was maintained at that load level, however, subsequent SCBF measurements showed markedly decreasing values, usually of greatest magnitude at the lower cervical and upper thoracic levels (Table 1). This focal ischemia at the cervicothoracic level with relative preservation of flow at other levels suggests that the ischemia probably arises from compromised intrinsic spinal cord vasculature in this “watershed” zone of the spinal cord rather than from changes of the larger extrinsic or radicular vessels. These findings also support the observations of Breig, who proposed that increased transverse tension resulting from elongation of the canal reduces the lumen of the intrinsic spinal cord arteries that course transversely in that plane. Therefore, vessels undergoing stresses that exceed their elastic resistance in association with attenuation of their supportive collagen fibers may undergo disruption at the points of maximum stress, and, because the radioactive microsphere technique defines blood flow on a morphological basis, a pooling of microspheres occurs at the level of vascular disruption. This event could explain the elevated SCBF values found immediately cephalad to the ischemic cervicothoracic levels.

In conjunction with previous experimental investigations, the present study also uses the evoked potential response as a determinant of neurological dysfunction. Interpretation of these response alterations, however, depends upon definition of the response origins relative to the parameters of stimulation and recording. In this regard, responses recorded within the entry zone of the stimulated dorsal roots, such as those reported by Dolan, et al., have been termed “cord dorsum potentials” by many investigators, and it is generally agreed that a major portion of the initial components (first 30 to 40 msec) of this response represents affenter fiber terminations and internuncial cell depolarization. In the present study, however, the use of multiple recording sites along the conducting pathway of the evoked response permits a more comprehensive evaluation of neurological impairment induced by the application of strong skeletal traction. Initial application of distractive force in all animals caused a similar segmental pattern of response attenuation (Tables 1 and 3). Responses recorded from the...
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cortex evoked by stimulation of the sciatic nerve, median nerve, or conus medullaris and, to a lesser magnitude and consistency, those responses recorded from the conus medullaris evoked by sensorimotor cortex stimulation showed the greatest magnitude of amplitude reduction (Figs. 1 and 2) and, if the distractive force was released, these responses recovered rapidly toward control values. This pattern of response changes indicates compromise of the dorsal column-lemniscal pathway and, to a lesser extent, the corticospinal tract occurring at an undefined location between the upper cervical cord and mesencephalon. The absence of spinal cord compromise caudal to the cervical recording electrode (C4-6) is supported by the intact cord-to-cord responses noted in a previous experimental protocol when the recording electrode was located in the upper thoracic region (T3-4). In the present study, with one exception, corresponding blood flow values from the cerebral cortex through lumbar cord levels obtained during these response attenuations remained normal. These correlations imply that the cause of the neurophysiological alterations during the initial stages of linear distraction is mechanical, and probably represents pathological increased stretch of axons located in the upper cervical cord or brain-stem regions.

If these distractive forces are maintained or increased, the progressive elongation of the spinal canal from the induced “creep” of the vertebral column elements causes the responses recorded at the root entry zones relative to the stimulated nerve, especially the cervical responses evoked by median nerve stimulation (MN-cervical), to undergo a progressive decrease in response amplitude (Figs. 1 and 2). Although these root entry zone responses had mild to moderate attenuation of amplitude (10% to 15%) during the initial stages of distraction when blood flow values remained at normal levels, the later and more marked response alterations corresponded with regional blood flow reductions at the middle cervical through upper thoracic spinal cord levels (Table 1).

The responses most resistant to both distractive forces and ischemia were those recorded from the middle cervical level evoked by conus medullaris stimulation (CM-cervical or cord to cord) (Figs. 1 and 2). Although these responses demonstrated a gradual increase in latency as the process of “creep” caused a progressive elongation of the spinal canal, amplitude reduction was moderate (20% to 25%) until a level was reached which resulted in rapid and total obliteration of its primary components. The characteristics of the response changes that are essentially dependent upon dorsal column integrity correspond to changes noted during spinal cord elevation in the dog preparation, which reemphasizes the concept that after a critical level of tensile stress (stretch) has been exceeded, the axons are irreversibly injured. This temporal sequence of response alterations is compatible with the findings noted with stretch of the isolated frog axon, which demonstrated a progressive reduction of the amplitudes of injury and internodal action currents as stretch was increased. Nerve conduction, however, was maintained until the fiber was near the breaking point. A comparison of the findings obtained from the isolated frog axon preparation with axonal structures of peripheral nerves, spinal cord, and brain stem must take into account the influence imposed by the supportive elements of these structures. However, the very similar characteristic changes of the cervical cord responses evoked by conus medullaris stimulation (cord to cord) suggests that a similar process is occurring in dorsal column axons during progressive distraction. In this process, it is easy to conceptualize that, once the dorsal column axons have achieved a state of resting tension, subsequent increases in tensile stress will not result in major inter-

Fig. 2. Comparison of the patterns of evoked response and blood flow changes in a Group II animal during the sequence of linear distraction load application (initial 6 to 7 minutes), load relaxation (8 to 30 minutes), and load reapplication (30 to 34 minutes). Upper: The percent of response attenuation recorded from the cervical spinal cord following median nerve (MN → cervical) or conus medullaris (CM → cervical) stimulation and sensorimotor cortex following conus medullaris (CM → SMC) stimulation. Lower: The stability of corresponding blood flow measurements, which are in contrast to the marked evoked response alterations.
ference with nerve conduction up to a critical level of stretch. At that juncture, nerve fiber blockade is still reversible, but the occurrence of any additional stretch will cause permanent axonal injury. This concept of nerve fibers undergoing mechanical failure before the elastic limits of their supportive structures has been exceeded is documented by stretch studies of peripheral nerves. Yamada, et al., applying graduated amounts of traction to the filum terminale of the cat, noted that distractive forces could be increased up to a critical level after which irreversible metabolic changes and ultrastructural tissue damage were demonstrated.

The major clinical interest in the effects of distraction have centered upon the neurological deficits iatrogenically produced with strong skeletal traction or distraction rod instrumentation in the treatment of vertebral column deformities. Rapidly increasing skeletal traction in the treatment of scoliosis has occasionally caused cranial nerve palsies, which fairly consistently resolved with a prompt reduction of the traction. This sequence of neurological involvement and recovery is compatible with the findings of the present study, which indicate that the predominant and reversible evoked potential response alterations during the rapid application of strong traction were occurring within the area of the upper cervical cord through the brain stem. It is acknowledged that the magnitude of the tractive forces used in these selective treatment situations as well as the large force levels used in the present study do not replicate the usual clinical usage of skeletal traction; however, these findings still emphasize the potential dangers of strong skeletal traction. Interpretations of the tractive force necessary to cause separation of vertebral column components have varied widely, but it is now generally agreed that cervical intervertebral distraction in normal awake humans occurs with 25 to 40 lb of traction during a period of 7 to 10 seconds. This relatively minor degree of distraction, however, may be exaggerated in subjects with vertebral column injuries, especially those with coexisting cervical spondylotic disease. The myelopathies that occasionally occur with distraction rod instrumentation, however, usually present with more local neurological impairment in the thoracic region which may occur hours or days after the surgical procedure, and the quality of recovery in these situations appears to be mainly dependent upon the degree of injury as well as on the prompt removal of the distractive force.

This sequence of events, in conjunction with our present findings, indicates that, when linear distractive forces have not exceeded critical tolerance levels of tensile stress in the axes of the spinal cord or brainstem white matter fiber tracts, prompt force reduction will result in a functional recovery. The frequent clinical resolution of the neurological impairment after force reduction supports a mechanical basis for the underlying causative factor. In accordance with present investigational evidence, however, the continued maintenance of the distractive force may result in a corresponding spinal cord ischemia with a predilection for the lower cervical through middle thoracic spinal cord levels. In this situation, the presence of decreased SCBF in the already mechanically compromised spinal cord as well as the acknowledged vulnerability of CNS structures to prolonged ischemia may well indicate a poor prognosis for recovery.

References

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