The spinal cord as organizer of disease processes: Some preliminary perspectives

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The spinal cord acts as an organizer not only of normal adaptive behavior but also of disease processes. Spinal cord segmental relationships are not the basis for normal neurophysiologic function or activity but are prominent in clinical practice. Examples are situations in which tissues and organs may be disturbed by each other through shared nerves and cord levels. The injurious factors that may invoke segmental facilitation, other than direct trauma to the spinal cord, are disturbances in afferent input from the musculoskeletal system or the viscera and/or physicochemical disturbances in neuronal excitation and conduction. Some of the consequences of these disturbances are described. Osteopathic medicine is the only system of therapy that attributes adequate significance to the role of the spinal cord as an organizer of disease processes.

The purpose of this article is to identify and to characterize briefly the ways in which the spinal cord may contribute to illness through the influences it exerts on the tissues and organs of the body. Subsequent articles will examine each of these ways and the underlying mechanisms, with appropriate documentation from the research literature.

The concept of the spinal cord as an organizer of disease processes is based on two well-established premises: (1) The spinal cord is a highly complex organizer of *normal* adaptive activity; and (2) all disease, whatever its nature and whatever the role of the cord, is the highly organized response or adaptation of the total organism to disturbing factors in and around it. In the presence of disturbing factors, the spinal cord and its peripheral extensions continue to behave according to their nature. Unfortunately, the responses that are thereby organized under these circumstances are frequently maladaptive and deleterious.

It is appropriate, therefore, to begin with a summary of the ways in which the spinal cord functions as organizer of normal adaptive activity. Before then proceeding to discussion of pathogenic cord dysfunction, it is necessary to examine the meaning of spinal cord "segments" (not to be confused with vertebral segments) in normal and clinical situations.

Spinal cord: Information and command center

The spinal cord is the origin of most of the innervation of the body. It is that portion of the central nervous system where, by far, most of the nerves originate. Indeed, every tissue and organ of the body receives some kind of innervation from the spinal cord. The spinal cord is the site of entry, via the dorsal roots, of most of the "information" about the body itself. It is in the cord that impulses from most of the tissues of the body receive their first screening, gating, arranging, and routing for transmission elsewhere, including the brain.

As the site of origin of the "final common path," the spinal cord is also the final command center. Orders that are issued, consciously or unconsciously, in the higher centers, for most of the motor activity of the body, are issued to the spinal cord, which recedes them, so to speak, and then composes and dispatches the actual orders to the muscles, innervated by motoneurons, and to other tissues and organs, innervated by the autonomic nervous system. The latter includes blood vessels, viscera, sweat glands, et cetera, innervated by the sympathetic nervous system, which has its entire origin in the spinal cord, as well as those visceral structures that receive their innervation from the sacral portion of the parasympathetic division of the autonomic nervous system. For the moment, our concern will be with the activity of the skeletal musculature.

In a sense, therefore, the spinal cord is the keyboard on which the brain plays when it calls for activity or for change in activity. But each "key" in the console sounds, not an individual "tone," such as the contraction of a particular group of muscle fibers, but a whole "melody" of activity, even a "symphony" of motion. In other words, built into the cord is a large repertoire of

patterns of activity, each involving the complex, harmonious, delicately balanced orchestration of the contractions and relaxations of many muscles. The brain "thinks" in terms of whole motions, not individual muscles. It calls, selectively, for the preprogrammed patterns in the cord and brainstem, modifying them in countless ways and combining them in an infinite variety of still more complex patterns. Each activity is also subject to further modulation, refinement, and adjustment by the afferent feedback continually streaming in from the participating muscles, tendons, and joints.

Spinal cord as trophic center

Before further examining the meaning of "patterns" (which, of course, are based on controlled impulse traffic), it is important to emphasize that impulses (and the neurotransmitters released at neuroeffector junctions) are not the sole means by which spinal neurons influence innervated tissues. Impulses are the means by which moment-to-moment activity is regulated through excitation and inhibition. In addition, there are the long-term influences on the structural, functional, chemical, and metabolic properties which are subsumed under "trophic functions of nerves." For some tissues, most notably striated muscle, neurotrophic support is even essential for survival.

The trophic functions appear to be related to the delivery of neuronally synthesized macromolecules, rather than to the conduction of impulses. It may be assumed, however, that the trophic conditioning of various muscles and other tissues is related to the functional roles of those tissues, that is, the parts they play in the various cord-organized activity patterns. Since the overwhelming majority of peripheral neurons and nerves are cord-derived and cord-connected, the spinal cord may be said to be responsible through its organization for patterning trophic influences also.

Spinal patterns

The patterns of activity to which I have referred are essentially equivalent to the familiar, named motor reflexes, such as the (ipsilateral) flexor reflex, crossed extensor reflex, stretch reflex, et cetera. The reflexes, however, are commonly viewed as the relatively stereotyped responses, each based on an anatomically definable "arc," to specific stimuli. These stimuli, which are usually artificial, in contradistinction to those encountered in daily life, are experimentally or diagnostically applied to selected areas or structures, for example, electrical stimulation of an afferent nerve or area of skin, a tendon tap, a pinprick.

I prefer to view these reflexes not as stereotyped mechanisms ever ready to be sprung into action from appropriate push-buttons, but as the physiologist's way of demonstrating the built-in, highly *plastic* patterns of motion that are available to be combined and synthesized into total activities, such as walking, dancing, swimming. These modifiable, assemblable, highly organized reflex "modules" collectively compose the massive, automatic reflex substrate on which the consciously designed volitional actions are based.

The volitional part of every activity is the small, conspicuous tip of a massive, largely subconscious, and invisible iceberg. That reflex "mass," which from moment to moment automatically adjusts the muscular forces around each joint, the parts of the body to each other and to the body as a whole, and of the body to the forces of gravity, et cetera, relieves the cortex of responsibility for attention to these countless details and enables it to concentrate on the objectives, design, and execution of the learned, skilled, volitional components of each motion. The reflexes built into the spinal cord and brainstem are the largest portion of the iceberg.

As has already been mentioned, the spinal reflexes, described as "plastic," are subject to continual modulation and adjustment in force, velocity, amplitude, trajectory, final configuration, and so forth. Part of the modifying influences, of course, are conveyed over descending pathways from the higher centers, such as the motor cortex and vestibular nuclei. Much of the adjustment and refinement are due, however, to the ceaseless feedback, conveyed to the cord through the dorsal roots, from the participating and affected parts of the musculoskeletal system. Unlike the experimental situation in which a nerve or its endings are stimulated, these segmental sensory pathways are not ordinarily responsible for *initiating* motor activity, that is, for eliciting reflexes, but for regulating them according to volitional demand, the total motion in process, and the circumstances in the involved muscles, joints, ligaments, and tendons.

Our concern until now has been with muscles and motor activity, but it is important to recall that the spinal cord is the site of origin also of the sympathetic nervous system (SNS). This anatomic intimacy between the sympathetic division of the autonomic nervous system and the somatic nervous system is most appropriate, since it is one of the main functions of the SNS continually to tune visceral, metabolic, and circulator activity to the rapidly changing requirements of the skeletal musculature. Every motor activity, organized via the somatic innervation originating in the spinal cord, also involves the simultaneous, coordinated activity of the SNS and the tissues and processes regulated by it.

"Spinal patterns," therefore, must be viewed not merely as motor reflex patterns but as somatosympathetic patterns.

In order for the SNS to meet its supportive "responsibilities" to the musculoskeletal system, it must be continually apprised of the activities and requirements of that system. Hence, somatoautonomic integration is possible only with simultaneous afferent input both to the motoneurons and to the sympathetic preganglionic neurons in the cord, from the higher centers via descending pathways, and from countless musculoskeletal reporting stations, via the dorsal roots.

The question of segments

It is evident that the execution of even a very simple motion such as the flexion of the elbow involves immensely complex, delicately controlled, and rapidly changing impulse traffic in thousands of motoneurons (and sympathetic neurons) innervating not only the muscles traversing the elbow joint, but those arranging and fixing the shoulder and wrist. Impulse frequency in each axon is continually adjusted, by presynaptic neurons, according to the contribution that the muscle fibers that it innervates are to make at a given moment. The complexity related to the elbow joint alone is immense; that related to the rest of the extremity is even much more so. If one adds to this that massive portion of the "iceberg" concerned with adjustment of the posture of the rest of the body in accordance with the motion of the arm - and with autonomic support, for example, for appropriate distribution of blood flow - the complexity is almost beyond imagining.

In the execution of a given motion and its autonomic support, what are the criteria according to which efferent neurons are called into play from moment to moment? The neurons are brought into action according to what effector (for example, which muscle or group of arterioles) lies at the peripheral end, and not according to segmental levels. Indeed, the participating neurons may be distributed throughout the spinal cord. The corresponding sensory inputs are also widely and nonsegmentally disposed.

In other words, the neuronal basis for even a simple reflex pattern, such as a flexor reflex, has a vertical (multisegmental) distribution, rather than the horizontal (unisegmental) arrangement implied by the usual representation of a "reflex arc." Indeed, it can be safely said that no total motion is carried out through a single spinal segment. Efferent neurons that are collectively involved in a given motion are collaborators not because they are neighbors - in fact, they may be widely scattered - but because cofunction of their *effectors* is required.

Hence, "segmental relations" (functional coordination of organs and tissues innervated from the same segments) are not the basis for normal function and behavior, important as they may be in clinical situations. The participation of individual segments is not apparent in total patterns of activity. In cord-organized patterns, the anonymity of individual segments is similar to that of individual rows in a column of well-drilled marching men: All that one sees is the flow of motion in the total parade. But let one of the rows be disarrayed by missteps of one of two of the marchers and that row is immediately conspicuous. What is more, as rows in front and behind seek to compensate, the entire parade is soon in disarray. So it is with the spinal patterns. Segments are in evidence only in dysfunction; they are "out of step" with the rest of the "parade." A segment in view is a segment in trouble, as are all the patterns in which it participates.

Where, then, is the segmentation? What are the segments implied by "segmental relationships," "segmental nervous system," "segmental pathway?" Segmentation is certainly not inherent in the spinal cord itself, in which segmented structure is no more evident than segmented function.

The segmentation appears to be entirely in the "stringing of lines" of communication between the cord and the periphery. Segmentation is the bunching of nerve fibers into the compact "cables" that we identify as the spinal roots and spinal nerves extending bilaterally from C1 to S5. It is they that are segmentally arrayed and not the spinal cord, to which and from which they transmit impulses.

To what is the segmental arrangement of the roots and nerves related? The segmental grouping of nerve fibers was not, apparently, in evolutionary adaptation to some functional demand. Segmentation seems to have been imposed, in the course of evolution, by the segmented structure of the bony armor that *surrounds* the spinal cord, but it is not in the cord. That is, it is the segmented spinal column, rather than the cord, that dictates the segmental arrangement of peripheral nerve fibers: The axons are bunched and compacted for passage through more or less regularly spaced holes in the armor - the intervertebral foramina. The compacting of a particular group of axons (emerging in rootlets from the cord) into a particular "cable" is purely a matter of location, without regard to the patterns in which those axons normally cofunction.

In short, neurons are, as previously stated, recruited according to what they innervate and what activity is being called for, and *not* according to which intervertebral foramen they pass through. It is for these

reasons that segmental relationships, having no basis in normal neurophysiology, are irrelevant to normal behavior, prominent though they may be in clinical practice.

Segments in view

Before we examine how segments, normally anonymous and invisible, are made to *come* into view in clinical situations, let us review the manner in which they *are* in view, clinically. Segmental relationships perhaps are most familiarly evident in the phenomenon of referred pain. Pain arising in a visceral organ, due, for example, to chemical irritation, spasm, or distention, often is felt instead (or also) in somatic structures that receive their innervation from the same segments as the viscus. The pain is said to be referred to corresponding dermatomes, myotomes, and sclerotomes, which make up the "reference zone." The reference zone may be quite remote from the site of instigation, as when an organ or tissue has migrated in the course of embryonic development, taking its innervation with it (for example, the diaphragm).

Too often overlooked is the fact that the phenomenon of referred pain is not solely, if at all, a matter of faulty perception or sensory localization by the patient. Objective pathophysiologic changes can be found in the reference zone, for example, vasomotor and sudomotor activity, muscle spasm. Over a period of time these may lead to chronic "organic" changes in the affected tissues. At various stages the tissues in the reference zone may become secondary sources of afferent bombardment, with the establishment of self-sustaining vicious circles of impulses and reflexes.

As shown many years ago, reference is not solely from viscus to soma. Pain in a muscle, bone, or joint may be referred to other segmentally related somatic structures, also with accompanying objective changes in the reference zone.

Much of the practice of osteopathic medicine, of course, is based on segmental relationships similar, and possibly identical, to those exemplified by referred pain and associated phenomena. By palpatory and other means, the osteopathic physician detects and evaluates the pathophysiologic changes in the somatic tissues segmentally related to a disordered viscus. The palpatory findings may even contribute substantially to the diagnosis of visceral pathologic disturbance.

The osteopathic physician recognizes, however, that segmental relationships are two-way *mutual* relationships; that the somatic changes in the reference zone (whether or not pain is present) not only *reflect* pathologic processes in the visceral structure, but also *influence* them, usually unfavorably. Osteopathic manipulative therapy is designed to exert favorable influences on this exchange, possibly by silencing or otherwise altering the afferent impulse traffic coming from the somatic components so that the "vicious circle" can come to a halt and permit healing processes to operate under more favorable circumstances.

The osteopathic physician recognizes also that the spread of pathophysiologic influences along segmental pathways may *begin* with somatic dysfunction and involve autonomic as well as somatic pathways, with consequences to visceral and somatic tissues and function. Manipulative therapy is directed toward amelioration of somatic dysfunction, regardless of whether it is primary or secondary, with the expectation that this will benefit structures on the same segmental circuit. The widely accepted concept of segmental facilitation as it relates to somatic dysfunction presumes only that through some influence that selectively affects a given segment or group of segments and that is probably conveyed over their dorsal roots, neurons located in that portion of the spinal cord are maintained in a hyperexcitable state, producing sensory, motor, and autonomic manifestations.

The purpose in this section has not been to examine segmental relationships in detail, but only to characterize them by illustration, to contrast clinical and normal circumstances sufficiently. Thus, an ulcer in the duodenum may, through pain afferents synapsing in the cord, provoke circulatory disturbances, excessive sweating, paraspinal and abdominal muscular contraction, pain and tenderness in joints, muscles, and areas of skin that, like the duodenum, are innervated from midthoracic segments. Conversely, somatic dysfunction in these segments may, through segmental pathways involving the splanchnic outflow, produce functional changes in the duodenum that predispose it to autodigestion.

In normal life, however, there is no "meaningful dialogue" between the duodenum and segmentally related tissues or organs, at least none that is essential to their functional regulation or integration, their functions being quite independent of each other. The midthoracic paravertebral musculature, for example, makes no contribution to duodenal function, just as the duodenum is not involved in locomotion or maintenance of posture. There is no reason, in normal life, therefore, to communicate with each other, even though both duodenum and musculature are, so to speak, hooked up to the same portion of the spinal cord through a shared "cable," passing through a particular hole in the bony armor.

However, should either the duodenum (to continue the illustration) or the segmentally related portion of the vertebral column become sufficiently and appropriately injured, the activities and problems of one soon become the business of the other, through a newly established "party line" that provokes both into continual, inappropriate, nonadaptive, deleterious responses. The disruptive entanglements that are thus created by segmental facilitation are deleterious not only to the unintended partners, but also to the total patterns in which they participate, hence, to the total person. In effect, a segment has gone out of step, messing up the entire parade. The question before us now is, how do segments get out of step?

How segments come into view

How do tissues and organs that ordinarily have little direct functional interaction or interdependence, such as the duodenum and midthoracic dermatomes and myotomes, become entangled with and disturbed by each other, through the nerves and cord levels that they share? In seeking to identify the mechanisms I shall not consider such factors as direct trauma to the spinal cord itself. The most common disturbing factors seem to fall into two main categories: (1) disturbances in afferent input; and (2) physicochemical disturbances in neuronal excitation and conduction. Each of these will be described briefly. As will be seen, the second category contributes to the first. It may also occur under circumstances that induce the first. In other words, though different in mechanism, they may be present together and indistinguishable in their impact.

1. Disturbed afferent input

a. From the musculoskeletal system. As previously mentioned, streams of impulses continually enter the cord, via the dorsal roots, from specialized receptors (proprioceptors) in muscles, joints, tendons, and ligaments. They are, in effect, transducers which convert changes in shape (mainly length) of the structures in which they are situated, or in the forces (tension, pressure) acting upon them, into variations in impulse frequency in the sensory fibers that end in them. These afferent fibers have central connections that are appropriate to their peripheral endings.

Collectively, these endings are the sources of information about circumstances in the periphery continually fed back into the central nervous system. Although, as has been said, the receptors are each responsive mainly to changes in force or shape of the tissue in which they are embedded, the variety of their sensitivities, responses, and locations (for example, a Ruffini ending in a specific portion of a particular joint capsule, a spindle in a particular fascicle of muscle fibers, a Golgi ending in a particular portion of a tendon) and the variety of their central connections are such that, collectively, the report on the direction, velocity, and amplitude of motion of each part, and on position, load, resistance, et cetera.

This continuous feedback, subject to rapid change in accordance with activity and posture, is continually used by the CNS to adjust efferent discharges (motor and autonomic) in accordance with the activity called for and with the circumstances in the participating and affected parts of the body. Although the spinal cord is capable of making discrete responses to experimental stimulation of this or that proprioceptor, it ordinarily does not "read" individual reports form the innumerable reporting stations. Rather, it seems to watch the changing patterns of their collective reports. These patterns present of the cord a continual motion picture of "what is going on out there," which it utilizes in formulating its commands to all the tissues "out there."

As has already been emphasized, this patterned feedback reaches the cord via the dorsal roots along the entire length of the spinal cord. The central influence of a given volley of impulses in a given sensory fiber is determined by its central connections (which postsynaptic neurons?) and the frequency of the impulses, and not by the foramen and root through which it reaches the cord.

When, whatever the reason, there is a disturbance in the movement of a particular intervertebral, costovertebral, or other join, involving such functional disturbances as muscle spasm (and hence persistent changes in length and tension), torsion or other deformation of the capsule, or persistent asymmetric ligamentous tension, then the affected proprioceptors will fire equally persistent and discordant barrages of impulses. These enter the cord via the one or two dorsal roots in which the corresponding sensory fibers lie.

In other words, instead of contributing to the fluctuating "hum" of feedback on which the cord relies for refinement and adjustment of its motor autonomic patters, they transmit a steady "roar" into the cord over those selected roots. That portion of the cord becomes dominated by this noisy input, and in that portion of the cord the "picture" of the periphery which the CNS steadily watches is garbled and distorted by the high noise-to-signal ratio. Reports from the various proprioceptors may be so conflicting that the cord is presented with "pictures" of impossible situations. Its responses to such unintelligible reporting cannot possibly be adaptive, any more than nausea and vomiting can be said to be adaptive to the confused sensory reporting in motion sickness and vertigo.

The central excitatory state at the corresponding level (and side) of the cord is exaggerated, leading to the establishment of and "irritable focus," described in recent years in terms of facilitated segments. In the portions of the cord that are receiving the noisy, garbled input, all kinds of neurons become susceptible to "facilitation," making exaggerated responses to incoming impulses from any source. Unintended partners, such as the duodenum and spinal muscles, find themselves on the same "party line," and responding together and to each other in ways that make no functional sense. These portions of the cord, therefore, cannot participate appropriately in the vertical patterns in which they are ordinarily involved, resulting in faulty, disarrayed patterns.

If the firing of pain endings is added to this segmented input, then the "roaring" input and the domination of the affected portion of the cord is even more severe and the noise-to-signal ratio even higher. How much the disruptive influence of activity of pain fibers on spinal patterns is ascribable to imbalance between small-fiber and large-fiber activity and how much to other factors, such as subjective responses, has yet to be determined.

b. From the viscera. Similarly "roaring," segmentally dominating inputs may develop as a result of visceral disturbances that activate pain endings. Visceral pain fibers are mainly associated with sympathetic nerves (for example, the splanchnic), traversing the ganglia without synapse and entering the cord through the dorsal roots along with somatic sensory fibers. The facilitation thus produced extends to the neurons supplying to somatic structures, producing muscular spasm, vasomotor and sudomotor changes, "referred" pain and tenderness. There is apparently no fundamental difference in mechanism or response whether the disturbing input arises in visceral or in somatic structures. Both are disruptive to spinal patterns, and each soon invokes into the disturbance other structures, the innervation of which courses in the same spinal roots and enters through the same foramina.

2. Physicochemical disturbances of excitation and conduction

a. The kinds and origins of insults to nerves and neurons. The concern in this section is with the effects of various types of direct biomechanical insult to nerves, axons, and nerve cells, and of the secondary metabolic disturbances. These insults have a high incidence in man because of the compressive forces associated with the upright stance, and because of some of the motor and postural demands of various occupations, athletic activities, habitual postural faults, muscular tensions, et cetera. But nerves, in general, are vulnerable to deformation, with structural and functional consequences, along their entire length, especially where they pass over bone, through bony canals, across tissue interfaces, and so forth. As a result, nerves may be subject to stretch, constriction, compression, torsion, angulation, and ischemia.

In man, the spinal roots, spinal nerves, and the primary divisions are especially vulnerable not only because of the hazards associated with the intervertebral foramina, but because of the hazards associated with structures on which segmentation has also been imposed by the spinal column, namely, the meninges (dural pouches, root sleeves) and blood vessels (spinal and radicular arteries and veins).

Detailed examination of the specific kinds of mechanical hazards common to each structure is not appropriate to this preliminary article. One need only mention such factors as the following: compression by narrowing of the foramen; adhesions between roots and sleeves, causing angulation, shearing and constriction; shearing forces acting upon nerves passing through fascia; compression (for example, of posterior rami of spinal nerves) by sustained contraction of the paravertebral muscles through which the nerves pass; constriction at duroarachnoid junctions of root pouches; compression within foramina secondary to venous congestion (compression of spinal and radicular veins). Hypoxia, pH shifts, and other chemical changes in the environments of the nerves due to ischemia (compression of spinal arteries, sustained contraction of muscles through which nerves pass, et cetera) are also important factors in the alteration of axonal excitation and conduction.

Separate consideration must be given to the paravertebral sympathetic ganglia. The cervical ganglia are subject to frequent microtrauma because of their location in a highly mobile part of the body and their proximity to powerful muscles. The thoracic and lumbar ganglia are vulnerable because of their close relation to bony structures (vertebrae, ribs) and compression by, and possible adhesion to, parietal pleura or peritoneum. Compression, as has been demonstrated, may block lymphatic drainage of parts of the ganglionic chain, with severe edema and swelling of the affected ganglia. The ganglia, of course, contain the cell bodies of postganglionic neurons that innervate various vascular, glandular, and visceral structures.

b. The changes in neuronal function resulting from direct insult. In considering the effects of deformation of musculoskeletal origin on nerves and nerve cell bodies, it is important to emphasize that our

concern is not with catastrophic situations in which whole nerves or roots are crushed or even in which conduction has been blocked in all or most of the axons. In the extreme case, of course, involving wholesale interruption of axoplasmic continuity, there would be total loss of neural function, with wallerian degeneration distal to the insult. In the more moderate situation of conduction block in some of the fibers in a nerve, there would be corresponding loss of sensory and motor function, which might be transient or fluctuating. In such cases, the sensory or motor deficits would not even be perceptible. However, since some types of fibers are more susceptible to deformation block than others, garbled sensory input and incomplete and uncoordinated efferent output may be the clinically more significant consequences.

The predominant consequence of the more common and more subtle deforming forces which were the subject of the foregoing section is quite different. They cause not the loss of excitability, but, on the contrary, hyperexcitability and the hyperirritability syndromes that it engenders. The hyperexcitability, localized at the sites of deformation, is manifested in several ways, which have been studies in nerves and roots during surgical exposure and which can be simulated experimentally. In reviewing these manifestations, it is important to remember that, ordinarily, nerve impulses are launches at the *ends* of nerve fibers - at the central or cellular ends in efferent fibers and at the peripheral ends in sensory fibers - and that impulses pass in only one direction, either toward the CNS or toward the periphery. The following are the manifestations of hyperirritability at sites of deformation:

1. Impulses are generated at the deformation site, for example, at a constriction or angulation or at the edge of a longer compressed area, and they are propagated in both directions. These, of course, are "supernumerary" impulses superimposed on those being generated in the usual way, centrally or at the peripheral ending.

2. Trains of impulses are triggered by "normal" impulses as they pass through the deformed locus. Each normally generated impulse, therefore, has a grossly amplified and prolonged effect centrally or peripherally.

3. Cross-talk between fibers may take place. Under normal circumstances each fiber is, in effect, a private line, effectively "insulated" from it neighbors in the nerve or root, and only end-to-end (synaptic) transmission occurs. At the hyperirritable foci, however, the small electrical fields that accompany each impulse as it moves along a fiber may be sufficient to trigger impulses in neighboring fibers. This lateral, side-to-side (ephaptic) transmission is usually from large fibers to small fibers.

4. Pain and possibly other endings in the epineurium may be additional sources of impulses provoked by some types of deformation, especially stretching or swelling of nerves. They may be responsible for the pain and tenderness along the course of a nerve in some peripheral neuropathies.

5. Cells in the paravertebral sympathetic ganglia, which are ordinarily excited only by presynaptic impulses delivered by preganglionic fibers, fire spontaneously under conditions of ganglionic deformation, edema, or other, secondary changes in their environment.

6. A significant degree of narrowing of axons by constriction or compression is known to impede the axonal transport of nerve cell cytoplasm. Considerable swelling, due to the damming of axoplasm, occurs proximal to the obstruction, while distally the axon becomes quite attenuated. Since various proteins and other complex substances in a given axon are transported at two or more rates varying from approximately 1 mm. per day to approximately 400 mm. per day, and by different mechanisms, changes in composition of the axon distal to the obstruction and in the mixture of substances reaching the terminals are almost certain. If attenuation surpasses a critical degree, axoplasmic continuity is interrupted and the distal axon undergoes wallerian degeneration.

The behavior of "segments in view"

How do the disturbances in afferent input and in neuronal excitation and conduction alter the function of the affected segments? Since disturbed excitation and conduction inevitably disturb afferent input, it is not possible to examine their respective impacts on cord function entirely separately. Only the first four items in the following sample of impacts are strictly related to aberrant neuronal excitation and conduction; the others represent inseparably combined impacts.

1. Ectopic impulses in afferent fibers, arising as they do somewhere along the axons rather than at the endings, present false sensory information to the cord--situations that have no basis in the peripheral tissues in which the affected fibers end. The total afferent input pattern, therefore, is deceptively intensified, imbalanced, garbled. If the nerve deformation has simultaneously produced conduction block in large, fast myelinated fibers (which convey signals from skin receptors and proprioceptors) causing small-fiber dominance, then the sensory chaos in that part of the cord would be even worse. Only nonsensical responses can be made to nonsensical information, and all total-body patterns in

which the dysfunctional segments participate would be in disarray to some extent.

2. Similarly, ectopic impulses in efferent fibers are meaningless commands which "jam" the real, centrally issued commands, convert them to gibberish, and result in uncoordinated motor and autonomic responses.

3. Since, under conditions in which "cross-talk" occurs, the direction of lateral transmission is from large fibers to small fibers, excessive activity is provoked in the pain fibers and in sympathetic fibers. Under these circumstances, the passing of impulses in large A fibers, such as those mediating touch or proprioception or those innervating skeletal muscle, may be expected to produce pain that has no basis in the periphery, accompanied or not by paresthesia of various kinds. It may also produce, via the sympathetic innervation, such manifestations as vasoconstriction, sweating, visceral activity, or visceral inhibition that was not centrally ordered.

It is possible, though not established, that among the small fibers victimized by cross-talk are the gamma fibers controlling the sensitivity of the muscle spindle. The effect would be exaggerated tension in the affected muscles and resistance to changes in length.

4. Since impulses that arise ectopically somewhere along the length of the axon are propagated in both directions (ortho- and antidromically), we need also to consider the effects of the antidromic, or wrong-way, impulses. Those in motor fibers, on reaching the cell bodies in the ventral horn, are known to alter the excitability of those neurons in the inhibitory direction. The effect, of course, would be to confuse the motor activity in which those neurons participate. A similar influence, though not yet demonstrated, may also be expected in sympathetic neurons.

Antidromic impulses in sensory fibers have been shown to produce profound vasodilation and hyperemia (at least in skin), somewhat in the manner of and "axon reflex."

5. The chaos in afferent input and efferent output causes the affected segments and the organs, tissues, processes, and activities that they control to be "out of step," with disruption of the (vertically organized) activity patterns in which they participate.

6. Somatosympathetic integration, so essential to musculoskeletal function, would also be disrupted.

7. As has been shown for segmental somatic dysfunction, the associated facilitation, for reasons presented above, extends to the sympathetic outflow. The effects of the sympathetic hyperactivity depend on which of the fibers are involved, that is, on what cells, tissues, and organs are victimized by the exaggerated sympathetic bombardment. Each organ or tissue responds according to its own inherent nature. The clinical impact - the syndromes that may be produced given sufficient time and other contributory factors in the person's life - depend, therefore, on the segmental level, since that determines which organs and tissues may be in the line of fire.

Further examination of this most important aspect of segmental dysfunction is far beyond the scope of this article, but it is important to point out that there is a significant sympathetic component in many, possibly most, syndromes and diseases. Therapy directed at silencing or reducing impulse traffic in the affected sympathetic pathways is often ameliorative. Furthermore, many of the most serious manifestations of sustained sympathetic hyperactivity, aside from the vasospastic ischemia so often present, are so diverse as not to be explainable by conventional views of the sympathetic nervous system, that is, solely in terms of altered contractile (smooth and cardiac muscle) and secretory activity. The sympathetic outflow exerts influences on many other kinds of cells and cellular processes which, in sustained sympathetic hyperactivity, become pathologic and aberrant. The nature of the changes varies with the tissue and organ in question. The sympathetic impulses merely modify the *inherent* cellular functions and processes. In other words, the diversity of clinical manifestations of local or segmental sympathetic hyperactivity is in the diversity of the cells, tissues, and organs innervated by the sympathetic nervous system.

This aspect of segmental dysfunction will be the subject of another article.

8. Since at least several organs and tissues, somatic and visceral, innervated from a given segment or group of segments may be affected by segmental dysfunction, each becomes, in turn, a source of afferent bombardment. Each, therefore, contributes to the establishment and maintenance of a vicious circle of impulses, and each is victimized by the others' inputs.

9. Finally, the effects of somatic insult on nerves and nerve cells are not only on excitation and conduction. To the extent that deformation of axons impedes axonal transport, the trophic influence of those neurons may be profoundly impaired. Also, to the extent that driving a neuron to sustained hyperactivity alters it metabolism, it may be expected that the synthesis of proteins and other macromolecules that are axonally transported may also be altered, with trophic consequences to the innervated cells and tissues.

Relevance to osteopathic manipulative therapy

On the basis of the foregoing information and

perspectives, osteopathic manipulative therapy appears, empirically, to be designed: (1) to correct or ameliorate the biomechanical insults to nerves and nerve cells that lead to disturbances in excitation, conduction, and trophic function; (2) to alter the proprioceptive and other discharges from somatic tissues in such a manner as to restore balanced, intelligible, reliable patterns of sensory feedback to the spinal cord; and (3) to soften or silence the somatic input to the vicious circles initiated elsewhere, thus contributing to arrest or retardation of impulse traffic in the circular party lines.

To a large extent, it may be said that much of the basis for the osteopathic emphasis on the spinal column lies in the segmentation that, in dysfunction, the spinal column imposes on the function of the spinal cord, on the patterns that the spinal cord organizes, and on the neural structures through which it expresses that organization. No other system of therapy appears to address itself adequately to the role of the spinal cord as organizer of disease processes.

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