THE MINIMUM ENERGY HYPOTHESIS: A UNIFIED MODEL OF FIXATION RESOLUTION

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ABSTRACT

Objective: To present a new theoretical construct, the Minimum Energy Hypothesis, which explains structural changes observed in the spine concomitant to spinal joint fixation resolution in initial investigations.

Design: Theoretical analysis.

Hypothesis: A unified theory of manipulative effectiveness is proposed that integrates the fixation and sensory tonus models of manipulation. The theory is based on the fact that the spine will assume a position of minimum internal energy when mechanical equilibrium is achieved. By using a simple mathematical model, it is shown that the fixation model and the sensory tonus models are 2 different aspects of the same theoretical construct. The Minimum Energy Hypothesis predicts that the spine will seek an optimal minimum energy configuration if the constraints preventing it from doing so are removed. Constraints are hypothesized to be joint fixations caused by inflammation in and about the spine and its sequella, muscle spasm, fibroadipose and scar tissue, and ultimately, degeneration. It is further hypothesized that the use of a computerized mechanical manipulative device may resolve such fixations, an example of which is radiographically demonstrable cervical hypolordosis.

Conclusion: A unified theory of manipulative effectiveness based on the concept of minimum energy to attain mechanical equilibrium is brought forward to explain the results of initial investigations. (J Manipulative Physiol Ther 2002;25:105-10)

Key Indexing Terms: Chiropractic Manipulation; Compliance; Spine

INTRODUCTION

This article proposes a theory to explain the clinical observation of structural change of the spinal system as a result of manipulation.1-5 The function of the skeletal structure is to provide support and mobility to the body.6 Each joint transmits supportive loads through the joint and, depending on the location of the joint in the structure, enables the structure to move about one or more axes. Fixations of spinal joints that reduce the mobility of the system lead to spinal dysfunction and may produce structural changes in the spine that correlate with patient symptoms such as muscle pain.

General considerations of complex systems result in the formulation of a theory of spinal positioning based on the spine achieving mechanical equilibrium (the equivalent to achieving a minimum internal energy state) with the loads imposed on it. Structural and/or mechanical changes that perturb the conformation of the spine are assumed to be fixations that result from inflammatory changes, along with associated muscle spasm, ligament shortening or thickening, facet locking, and ultimately, degeneration.

A common clinical example of this process is seen in cervical hypolordosis, or cervical kyphosis, in which a lateral cervical spine film shows loss or reversal, respectively, of the normal cervical lordotic curvature.7 This loss of normal curvature is often associated with whiplash disorder and is a requirement for the diagnosis of cervicogenic headache.8 It is hypothesized that loss of the normal curvature is associated with muscle spasms or more permanent changes in the joint, and there is some evidence that this promotes degenerative changes, although this remains to be proven.9,10

Evidence for the new hypothesis includes previous work in which a patient with radiographically demonstrable cervical hypolordosis had complete resolution of the fixation (measured both radiographically and with computerized measures of tissue compliance) after analysis and treatment.
with a PulStarFRAS (Sense Technology, Pittsburgh, Penn) computerized adjusting device, which uses multiple high-velocity, low-amplitude impulse percussive therapy for treatment.4

The results of this and other investigations with “lighter” techniques, including “mirror image” postural retraining and cervical extension distraction, challenge the concept of adjustment as a method of aligning individual spinal segments on the basis of deviations observed on static x-ray film. An alternative hypothesis is presented here to further explore the concept that the spine can reposition itself in space to a more optimal position if the constraints (fixations) that prevent the spine from achieving this position are reduced or removed.

Discussion

Historic Perspective

According to Leach,8 the earliest model of chiropractic practice, which was formulated in the early part of the twentieth century, was to normalize the nervous system and restore homeostasis by “removing nerve interference” through spinal adjustment and manipulation. It was believed that subluxations caused occlusion of the spinal nerves at the intervertebral foramen.11 In following this model, the practice of manual medicine has focused on the detection and correction of vertebral subluxations. Methods were developed for radiographic analysis that measured small displacements of vertebrae. Techniques were developed for moving the vertebrae back into normal alignment. The displacements of vertebrae. Techniques were developed for radiographic analysis that measured small displacements of vertebrae. Techniques were developed for moving the vertebrae back into normal alignment. The reliability and validity of such analytic and treatment approaches are under careful scrutiny at this time by chiropractic scientists and have been seriously questioned, if not totally discredited.12-15

With the publication of the work of Gillet and Liekens16 in 1973, the focus of manual medicine was broadened by the introduction of the concept of restricted joint mobility caused by joint “fixation.” (It should be noted that the fixation concept was originally proposed by Langworthy, Smith, and Paxson in Modernized Chiropractic, published in 1906.8) In this model, expanded by others,17,18 joint dysfunction is caused by the following:

- Inflammation and its sequella, including muscular fixation, in which joint motion is restricted by muscle spasm or hypertonicity;
- Ligamentous fixation, in which joint mobility is caused by shortened or thickened ligaments;
- Osseous fixation, in which joint mobility is caused by ankylosis, congenital deformity, or surgical arthrodesis.

Under this second model, treatment of joint dysfunction was given by means of a manipulative thrust that would re-establish normal motion by moving the joint through the restricted range of motion. The fixation model has gained widespread acceptance and has even appeared in medical texts19 as the currently accepted rationale for mobilization.

A third model, “receptor tonus,” was first advanced in 1957 by Nimmo.20 It focused attention on the role of sensory receptors as an explanation of neuromuscular dysfunction. Nimmo’s followers have advocated treatment of musculoskeletal dysfunction by stretching or compressing the involved musculature.

The fixation and receptor tonus models appear to have considerable overlap. In fact, these models will be shown to be different aspects of the same theoretical construct, which we will refer to as the Minimum Energy Hypothesis. The Minimum Energy model forms the theoretical basis for this article.

Mechanical Equilibrium

All structures assume a position in space dictated by equilibrium considerations. All forces acting on a structure must be in balance (ie, the resultant sum of all forces acting on the structure must equal 0) for the structure to be in mechanical equilibrium.21 An example is a string supported at each of 2 fixed endpoints. Given the length of the string and the distance between the 2 supports, the position in space of every point on the string may be determined with the assumption that the string will position itself between the end supports such that it is in mechanical equilibrium. The position of the string may be expressed mathematically and is referred to as a “catenary” (Fig 1). It can be shown that the mechanical equilibrium position is equivalent to the position of minimum internal energy given the physical constraints of the system.22

If the potential energy of one point on the string is increased, for example, by elevating its position in space, the position of the string in space is changed (Fig 2). In fact, the energy level and position of all points in the string (with the exception of the end points) have been changed. This example illustrates a very important and fundamental point that a minor change in the energy level at one point in a complex system potentially affects the entire system, not just the immediate neighborhood of the point.

Elevating one point of the string imposes an additional constraint on the system. Although the string attempts to minimize its potential energy, it is prevented from doing so. The additional constraint imposed by elevating the string at one point changes the position of the string in space. In fact, because the elements of the string are connected to one another, changes in the position of one element affect the position of all elements. If the elements of the string were not connected (uncoupled), changes in one element would have no effect on other elements. These concepts apply to complex coupled systems.

Coupling within complex systems composed of discrete elements may be achieved (or simulated) by connecting the elements of the system with springs, dashpots, combinations of springs and dashpots, or fields such as magnetic or electrical. In physiologic systems such as the spine, cou-
pling between vertebral segments is provided by intimate contact, muscles, ligaments, and fluids, as well as fibrous growth caused by injury or bony growth as a result of the disease process.

**Minimum Energy Model**

Considerable understanding of the physical situations described by the fixation and receptor tonus models can be achieved by considering a simple linear elastic model of the spine. The spinal column is modeled as a stack of rigid vertebrae that are connected by elastic springs. Each vertebra is allowed to translate and rotate relative to its neighbors, which exert forces proportional to the relative translation or rotation. Three translational degrees of freedom (df) and 3 rotational df describe the state of each vertebra. If there are N vertebrae, then the model has 6(N-1) df. The following equation describes this situation:

\[ F = KX \]

F is a 6(N-1) dimensional vector of the forces and torques on the vertebrae, X is a 6(N-1) dimensional vector of the translations and rotations of the vertebrae, and K is a 6(N-1) by 6(N-1) matrix of elastic constants. This equation relates the response in mechanical equilibrium of the model spine to the set of external forces and torques specified by F. Alternatively, we can write the following equation for the energy of the model:

\[ E = X^T KX \]

In mechanical equilibrium, the conformation of the model, X, is that which minimizes E. The vector X describes the conformation or shape of the model spine. The following situations can be identified:

- \( X = 0 \): zero force reference state
- \( X = X_0 \): the ideal functional conformation (IFC) state
- \( X = X_p \): a perturbed conformation

The zero force state is an imaginary conformation in which the model is not subjected to external loads. The IFC state corresponds to the conformation of the model when nominal physiologic loads are applied. This state is taken to be that of a normal and healthy spine, and the relationship between the loading of the model and its conformation in the IFC is:

\[ F_0 = KX_0 \]

Perturbed states can arise from 2 causes: (1) changes in the elastic constants in the K matrix, and (2) changes in the loading:

1. \( F_0 = (K + dK) X_p \)

In this case, the load is held constant and the K matrix is altered by dK. Such a perturbation in the K matrix can be understood as the result of changes in the structural/mechanical properties of the spinal system.

2. \( F_0 + dF = KX_p \)

In this case, a change in the load results in the perturbed state.

Case 1 corresponds to the “fixation” model, in which a change in structural/mechanical properties of the spinal system produces deviations from the IFC. Case 2 corresponds to the “sensory tonus” model, in which changes in the force and position sensors of skeletal muscles produce a change in the nominal loading of the spinal system and thus produce a deviation or deviations from the IFC. Theoretically, inflammation and repeat stresses (including abnormal loading) promote aging and alter Case 2, which may in turn further impact Case 1.

It should be noted that the materials that constitute the skeletal system are not well described by linear elasticity; they are highly nonlinear. However, the simple linear elastic model discussed previously is sufficient to understand the issues on which this article focuses. The conclusions reached are valid for the case of a nonlinear elastic model of the skeletal system as well as the linear model.

**Fixations and Minimum Energy Model**

The string in a gravitational field, as described previously, may be thought of as analogous to the spine under load. Although the spinal system is more complex, the same fundamental principles apply. We therefore propose a new hypothesis based on these assumptions. The Minimum Energy Hypothesis predicts that the spine will seek an optimal minimum energy configuration if the constraints preventing it from doing so are removed. Constraints are hypothesized...
to be joint fixations caused by inflammation in and about the spine and its sequella, muscle spasm, fibroadipose and scar tissue, and ultimately degeneration.

The position of the spinal system in space will correspond to the minimum internal energy that may be achieved by the system (given system constraints), and a change in the energy level at one point will change the energy levels and corresponding positions of all points in the system. Conditions (referred to as “fixations”) such as inflammation and subsequent muscle spasm within and around vertebral segments, fibrous growth between facets, and degenerative changes about the facets (referred to as “osteoarthritis”) may act as system constraints, preventing the achievement of minimum energy by the system.

Constraints imposed by fixations may cause positional change in the spinal system too small to be observed on radiographs but observable by pressure algometry,\textsuperscript{23} electromyography,\textsuperscript{24} or by measures of tissue compliance\textsuperscript{5,25} and are characterized clinically as tenderness or palpable “knots” in the muscles and termed \textit{spasms or trigger points}.\textsuperscript{8} Other fixations may cause gross changes in spinal structure that are obvious to the casual observer, such as the radiographically demonstrable cervical hypolordosis mentioned previously.\textsuperscript{1,2} This by no means implies that small system constraints are unimportant. Even small changes in the minimum energy level at one point may result in compensation in other segments of the spinal system, a phenomenon termed \textit{somatosomatic reflexes}.\textsuperscript{3} These compensations are made by the body to maintain static and dynamic spinal equilibrium. It has been hypothesized that compensations themselves may result in impaired spinal function.

Within the past 4 years,\textsuperscript{4} sensitive instrumentation has been developed that allows the clinician to reproducibly measure differences in compliance that show the location of even very small fixations. In addition, methods for releasing fixations with multiple impulse percussive therapy have been developed in parallel.\textsuperscript{5} Included in these methods are the Kinetic Technology Precision Adjustor (Pittsburgh, Penn), which applies a precisely controlled repetitive impulse at 5 Hz, and the PulStarFRAS (Sense Technology), which applies impulses at a rate that varies between 2 to 20 Hz. These techniques allow testing of the validity of theories of clinical practice as well as the effectiveness of specific therapeutic modalities.

Theoretically, resolving or releasing fixations of spinal joints should enable the spinal structure to return to a position of lower internal energy. Assuming that the optimal position of the spine represents the position of lowest internal energy that may be achieved under normal physiologic loads, resolving joint fixations would enable the spine to return toward a more optimal position. Hence, releasing fixations in the cervical spine of a patient with hypolordosis or kyphosis, for example, might be expected to promote restoration of the normal cervical lordosis.

The hypothesis presented here is that release of fixations of the spinal joints would allow the spine to return to a position of lower internal energy. This is a “unified” model in that it explains the relationship between the fixation model of manipulation and the sensory tonus model. This model, based on restoration of normal motion and not on realignment of vertebrae, might explain results gained by regular “diversified” chiropractic adjustment techniques (eg, supine and prone cervical and rotary break maneuvers) as well as lighter techniques, such as the multiple impulse method of therapy performed with the PulStarFRAS instrument.\textsuperscript{4}

These results can be explained in terms of mechanical equilibrium and minimum energy concepts; that is, generally accepted physical principles. This is extremely important for increasing the acceptance of manipulative therapy by the general public as well as other health professions and may also serve as the basis for improving clinical therapy.

Others have addressed the concepts of equilibrium and postural loading that are similar but not strictly analogous to the Minimum Energy Hypothesis presented here. Harrison et al\textsuperscript{26} propose the use of “average” spinal curvatures observed under conditions of static equilibrium as a standard by which to measure the effectiveness of manipulative procedures.

The technique associated with their work involves both manual chiropractic and instrumented adjustments, as well as “mirror-image” postural exercises and extension traction to effect improvement in fixations such as those observed with radiographically demonstrable cervical hypolordosis.\textsuperscript{3,26,27} Although others have provided earlier blinded pretreatment and posttreatment radiographic evidence for improvement in cervical hypolordosis\textsuperscript{28} and in cervical hypolordosis and kyphosis\textsuperscript{1} after chiropractic diversified adjustments, Harrison et al\textsuperscript{3} showed in a randomized controlled trial that even “lighter” interventions, such as the addition of cervical extension traction to adjustments, could have a significant treatment effect. Although no conclusions can be reached regarding effectiveness, from the initial evidence presented, the light (approximately 20 lb) instrumented impulse thrusts from the PulStarFRAS device represent a potentially less invasive adjusting technique for these spinal fixation types.\textsuperscript{4}

The clinical implications of this hypothesis are very important. If so-called “lighter” techniques, such as the cervical extension-traction component of Dr Donald Harrison’s Chiropractic Bio Physics technique,\textsuperscript{3} Dr Arlan Fuhr’s Activator technique,\textsuperscript{29} and Dr Joseph Evans’ PulStarFRAS\textsuperscript{5} can be shown to have clinical value for the amelioration of clinical symptoms, signs, and disorders, then the clinician will have other options to the standard diversified adjusting procedures used in the profession. This may be important, especially in cases for which standard technique may be contraindicated and those for which lighter procedures are acceptable, such as those involving patients at risk for stroke, some of the elderly, and infants or children.\textsuperscript{30} This hypothesis is promulgated, then, as a construct that should warrant further clinical research.

Although there is no direct support of this hypothesis in the literature, there is certainly a broad base of initial
evidence now pointing to the existence of fixation or segmental dysfunction as the clinical entity most likely to explain the clinical effectiveness of chiropractic adjustments for neck and back pain, as well as for specific musculoskeletal disorders such as cervical hypolordosis. The Minimum Energy Hypothesis is an attempt to explain this clinical lesion through basic principles of physics and the response to fixation resolution observed after a diverse array of treatment approaches, from more firm rotary and cervical break procedures to cervical extension traction and light instrumented adjusting techniques. Clinical research is warranted to determine the validity of this hypothesis.

CONCLUSION

The Minimum Energy Hypothesis unifies the fixation and sensory tonus models of the manipulable lesion and offers an explanation of fixation resolution. By using the simple linear model of a catenary and basic principles of physics, a theoretical construct was developed that may be applied to nonlinear models such as the human spine, with its complicated system of constraints.

The Minimum Energy Hypothesis predicts that the spine will seek an optimal minimum energy configuration if the constraints preventing it from doing so are removed. Constraints are hypothesized to be joint fixations caused by inflammation in and about the spine and its sequella, muscle spasm, fibroadipose and scar tissue, and ultimately degeneration.

An understanding of this hypothesis and its clinical implications points to the need for further research of “lighter force” mechanical instrumented techniques that may offer a safe alternative to regular chiropractic adjustments, especially in certain patients for whom regular technique is contraindicated. Further research of this hypothesis is warranted.

REFERENCES


Incidence of Foot Rotation, Pelvic Crest Unleveling, and Supine Leg Length Alignment Asymmetry and Their Relationship to Self-reported Back Pain

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ABSTRACT

Objective: To determine the incidence of pelvic unleveling, foot rotation, and supine leg length alignment asymmetry in a nonclinical population and to examine the validity (sensitivity, specificity, positive and negative predictive values) of these visual tests and their relationship to self-reported back pain.

Design: Volunteers answered a questionnaire regarding back pain and were then examined by a chiropractor who was unaware of the status of their back pain.

Participants: Seventy-four unscreened volunteers answered the questionnaire.

Main Outcome Measures: The association of visual tests with back pain and their validity indices; Visual Analogue Scale ratings.

Results: Fifty-one percent (n = 74) of volunteers examined had supine leg length alignment asymmetry (LLA). Pain intensity on a Visual Analogue Scale was significantly higher (P < .001) for those demonstrating supine LLA than for those without LLA. Those with back pain and recurrent back pain were significantly (P < .001) more likely to have supine LLA. The validity indices of the supine leg check showed acceptable levels for sensitivity (87%), specificity (84%), and positive predictive value (73%) in recurrent back pain. Findings also indicated a high incidence of supine LLA in volunteers with chronic back pain (85%).

Conclusion: The results indicated that, in this group of volunteers, the supine leg length alignment check had clinical validity as a stand-alone test for recurring back pain. Further testing on a larger, statistically defined cross-section of the population is recommended. (J Manipulative Physiol Ther 2002;25:e1)

Key Indexing Terms: Leg Length Inequality; Chiropractic; Back Pain; Incidence; Validity

76/90/121414