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A LITERATURE REVIEW OF THE INFLUENCE OF THE STOMATOGNATHIC
SYSTEM ON BODY POSTURE

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A THESIS

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ABSTRACT

INTRODUCTION: The stomatognathic system (SS) is a functional unit made up of the jaws, dental arches, masticatory muscles, and associated structures. The components of the SS act in unison to influence or control functional activities such as phonation, deglutition, mastication, and respiration. The aim of this literature review was to determine the impact of functional activities of the stomatognathic system on overall body posture based on available research studies.

RESOURCES: A thorough literature review of scholarly publications from peer reviewed journals was conducted.

DESCRIPTION: The review included available research material dealing with the functional impact of the SS on body posture. Emphasis was placed on similar findings and correlations to dental occlusion.

SIGNIFICANCE: A proven causal link or predictable relationship between stomatognathic function and positioning of the spine, ribcage, or pelvis would influence clinical treatment methods for a wide range of orthopedic issues such as scoliosis and low back pain. The literature has shown that body posture appears modifiable under experimental conditions, however, these findings seem limited to the head and neck region and in the case of occlusal interference evidence points to predominantly transient changes. A causal link or predictable relationship between dental occlusion and body posture did not emerge from the studies included suggesting low clinical significance of findings.
Table of Contents

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title Page</td>
<td>i</td>
</tr>
<tr>
<td>Abstract</td>
<td>iii</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>iv</td>
</tr>
<tr>
<td><strong>1 – Introduction</strong></td>
<td>1</td>
</tr>
<tr>
<td>1.1 – Background</td>
<td>2</td>
</tr>
<tr>
<td>1.2 – Equilibrium</td>
<td>2-3</td>
</tr>
<tr>
<td>1.3 – Posture</td>
<td>3-4</td>
</tr>
<tr>
<td>1.4 – Measurement of muscle action</td>
<td>4-5</td>
</tr>
<tr>
<td><strong>2 – Methods</strong></td>
<td>5-6</td>
</tr>
<tr>
<td><strong>3 – Results</strong></td>
<td>6</td>
</tr>
<tr>
<td>3.1 – Mandibular depression</td>
<td>6-8</td>
</tr>
<tr>
<td>3.2 – Head posture and occlusion</td>
<td>8-9</td>
</tr>
<tr>
<td>3.3 – Cervical spine</td>
<td>9</td>
</tr>
<tr>
<td>3.4 – Posture affected by respiration</td>
<td>9-12</td>
</tr>
<tr>
<td>3.5 – Altered occlusal effects on cervical spine and head posture</td>
<td>12-15</td>
</tr>
<tr>
<td>3.6 – Dental occlusion affects body posture</td>
<td>15-19</td>
</tr>
<tr>
<td>3.7 – Dental occlusion, scoliosis, and reciprocal connections</td>
<td>19-21</td>
</tr>
<tr>
<td>3.8 – Dental occlusion does not alter body posture</td>
<td>21-24</td>
</tr>
<tr>
<td><strong>4 – Conclusions</strong></td>
<td>24-26</td>
</tr>
<tr>
<td><strong>6 – References</strong></td>
<td>27-41</td>
</tr>
</tbody>
</table>
1 – Introduction

The stomatognathic system (SS) is considered a functional unit regulating deglutition, speech, chewing, and respiration. The SS consists of the maxilla and mandible and their associated dental arches, muscles of mastication (MM), temporomandibular joint (TMJ), and the associated neural and vascular supply. The current literature and studies reflecting the effect of the SS on overall body posture displays both promising connections between the two (4, 6, 7, 9, 11, 13, 14, 19, 20, 22, 23, 24, 29, 30, 31, 32, 36, 37, 38, 40, 42, 44, 45, 47, 49, 51, 55, 57, 63, 73, 74, 76, 77, 78, 79, 87, 88, 89, 91, 93, 94, 96, 97, 100, 101, 103, 104, 105, 106, 108, 113, 117, 118) as well as studies that show no correlation and further question the clinical significance and connection made by other researchers (2, 5, 33, 35, 64, 66, 67, 70, 71, 80, 81, 82, 83, 95). The subjective nature of body posture as well as conflicting results from research studies has made forming concrete conclusions difficult for authors reviewing the literature (19, 81).

The consequence of proving connections between the functional activities of the SS would have great clinical significance in the treatment of musculoskeletal disorders affecting the rest of the body, such as scoliosis, orthopedic dysfunctions, and low back pain.

My hypothesis is that mechanical dysfunction (tension/dysfunction in MM) or altered neural/proproroceptive input to the SS will cause postural deviations (adaptive responses) in the head and neck which leading to compensatory changes in overall body posture. The goal of this literature review is to specifically address the following questions/topics:

1) Can the SS cause a compensatory change in head and neck posture due to altered/faulty proprioceptive input or mechanical stresses?
2) Can alterations in the SS system cause alterations in other body segments (thoracic spine, ribs, pelvis) and thus affect overall body posture?
3) Why there is such conflicting research/conclusions on the topic of body posture and the SS.
1.1 - Background

The mandible, maxilla, palate, pharynx, and oral cavity along with the associated muscles and vascular/nervous innervation form one functional unit making up the head and neck. Embryologically this functional unit originates from bilateral swellings on the sides of the rudimentary pharynx called the pharyngeal arches. Neural crest cell migration from the mid and hindbrain leads to proliferation of ectomesenchyme (germ layers) from which all the bone/cartilage and connective tissue of the SS develop separately from the skeletal system/connective tissue of the rest of the body. The muscles of mastication (MM) develop from paraxial mesoderm much like the rest of the skeletal muscle in the body. The neck serves to structurally communicate the trachea, esophagus, vascular structures, and spinal cord from the head to the body, all of which are vital for survival. There are also key structures that connect the muscles of the head, cervical spine, and neck as a functional unit, namely the hyoid bone with supra and infra hyoid muscles, sternocleidomastoid (SCM), suboccipital muscles, semispinalis capitus, splenius capitus, trapezius and the stylopharangeas muscle.

1.2 - Equilibrium

Human bipedal stance is characterized by an inherent instability known as body sway, that necessitates continuous corrective muscular activity be taken to counteract the constant destabilizing effects of gravity on humans (50). Static gravitational forces affect the human body at rest and during equilibrium (56). Static gravitational forces can also alter the interaction of agonists, antagonists, and stabilizers in voluntary or involuntary kinetic movements. (56). Humans have an inherent passive instability and must continually search for active postural stability through muscular coordination resultant from a constant barrage of visual, vestibular, and somatosensory peripheral inputs (46).
Biologically dynamic systems such as humans will naturally revert toward the most efficient and metabolically cost effective way to perform mechanical work. The postural system of the bipedal human body is tasked with maintaining equilibrium which is characterized by balanced forces and torques among a set of interlinked segments and the applicable forces acting on these segments (46). This static equilibrium is best achieved by keeping major body segments (head/shoulders/spine/pelvis/knees) and the center of mass in line with the base of support (over the feet). This posture would signify the most metabolically efficient linkage of these biomechanical segments for optimal functioning and represents equilibrium among body structures (56).

1.3 - Posture
Balance can be characterized as the ability to control equilibrium. Body posture from a clinical viewpoint is viewed as the biomechanical linkage of symmetric relationships between musculoskeletal segments and can be measured somewhat subjectively by the plumb line (56). A more objective way to measure posture is through the human body’s response to gravity. This method assesses balance, which is based on measuring the vertical projection of a body's center of mass (CoM). We can also refer to CoM as center of gravity (CoG) since all masses on earth are subject to gravity.

Measurement of CoG over the base of support (BoS) is defined quantitatively by center of pressure (CoP) (50). In human two feet standing CoP is defined to a limited area due to the fact the BoS is equal to the area below and between the feet, due to the fact the force vector of gravity is located at the CoM pointing straight downward (50). Velocity can affect CoM by being directed toward the CoM or away from the CoM. This is due to bipedal ability to voluntarily manipulate our CoM as well as the CoP via muscular action in the sagittal plane by the ankle plantar flexors and dorsiflexors and in the frontal plane via the hip abductors.

Stability can be defined as a resistance to disruption of equilibrium (46). Multi-segmented bodies can change configuration, and thus change weight distribution causing CoM as a whole to be shifted (46). Alterations in bipedal CoM can also occur during respiration and normal physiologic functions (12,
16, 25, 41). Changes in foot position have also been found to alter CoM, with researchers showing decrease in frontal plane “sway” upon widening the BoS. Research has also shown that standing with one foot in front of the other increases sagittal plane sway as well as frontal plane sway (46). The COG is the point on a body where the sum torques (rotary force), which are created by weights (amount of gravitational force exerted on a body) on opposite sides of the center of gravity, are equal (46).

1.4 - Measurement of muscle action

Skeletal muscle produces a detectable current (voltage) when the muscle develops tension, even if the stimulus is just a nerve impulse. Skeletal muscle also develops tension when electrically stimulated (46). The technique used to record the myoelectric activity of skeletal muscle is electromyography (EMG). An EMG is useful in identifying which motor units respond to central nervous system commands and which muscles develop tension as a result of specific movements. Transducers (electrodes) are either positioned on the skin directly over a specific muscle or muscle group to pick up global myoelectric activity (surface electrodes, sEMG) or fine wire electrodes are injected directly into a muscle to detect more localized electrical activity of specific muscles (46).

Stomatognathic influence on total body posture is mainly evaluated quantitatively by measurement of ground reaction forces generated by the natural postural sway of the body through the pressure and forces on the planter surface of the foot.

Force platforms (force plates) measure ground reaction forces resulting from the point of application (the CoP or the feet) in vertical, lateral, and anterior posterior directions by specifically placed load cells. Pressure platforms measure pressure changes across the planter surfaces of the feet (46).

Body posture can be measured by different methods. Dynamic methods such as the stabilometric platform, measures the position of body planes relative to a reference point. An individuals center of
foot pressure on a force plate is used to approximate shifts in the body's center of mass in the frontal and sagittal planes (body sway) (33). Body sway is thought to be inherent to human beings due to our bipedal nature resulting in inherent instability requiring constant small postural adjustments via neuromuscular corrections due to the effects of gravity (46).

Electromyography (EMG), on the other hand, does not directly measure body sway or even body positions in space but measures the electrical impulses of muscles (46). Most studies focusing on the SS and posture involve EMG of the anti-gravity muscles, thus EMG is an indirect measure of postural positioning. Taking the above into account, instability would be characterized by greater energy expenditure and thus more muscular activity/higher EMG readings due to increased muscular activity compensating to maintain body position. Stability would be characterized by minimal muscular activity. Thus, if an occlusal device/blockage/opening device resulted in greater EMG of the cervical or muscular masticatory activity, there would potentially be greater instability locally or more postural sway/changes in center of foot pressure (CoP). This would represent the overall change in body posture via a possible effect of the malocclusion on distal musculature.

Head position is a component of overall body posture with the spine directly connecting the skull and pelvis. In theory, this linkage should transmit asymmetrical forces and loads resulting from the SS through distal segments with the capability to alter overall body posture.

2 –Methods

Scholarly publications from peer reviewed journals were selected from the Creighton University library online database search programs including but not limited to: EBSCOhost, PubMed, and MEDLINE. The search terms and phrases included: scoliosis dental occlusion posture, cervical spine dental occlusion, stomatognathic system body posture, and cervical spine airway. The review included available research material dealing with the functional impact of the SS on body posture.
with emphasis placed on similar findings and correlations to dental occlusion. References from select studies were also pulled and reviewed for further clarification of findings.

3 – Results

3.1 - Mandibular depression

The concept of a close functional relationship between the mandibular and head/cervical (cranio-cervical) neuromuscular motor systems has been documented. Ericksson studied subjects performing two single maximal jaw opening and closing tasks at a 12 second period, one “as fast as possible” and one at a slow pace, as well as a cycle of continuous jaw opening/closing movements at a standard speed (30). The subjects were monitored by sEMG in the masseter, suprathyroid, sternocleidomastoid, and upper trapezius muscles. Ericksson found that jaw opening was always accompanied by head-neck (cranio-cervical) extension and that jaw closing was always accompanied by head-neck flexion. Ericksson noted simultaneous activity of the suprathyroid and neck muscles during jaw opening and a decrease in neck and suprathyroid muscle activity with an increase in the masseter upon jaw closing. Ericksson also observed that irrespective of the speed of jaw movement or gender, at the time the jaw closing phase was completed the head had not returned to its original starting position, differing the amplitude between jaw opening and closing suggesting differing neuromuscular mechanisms controlling the action of jaw opening vs jaw closing. Ericksson confirmed the functional linkage between the cranio-cervical linkage and mandibular neuromuscular system during natural jaw activities (31). The results again showed co-ordinated head extension-flexion movements during each maximal continuous jaw opening-closing cycle in all subjects. In addition it was shown that for the self paced and paced continuous jaw tasks, the head movement (extension upon mandibular opening) preceded the mandibular movement.

Haggman hypothesized that restricted head-neck mobility can impair jaw function (44). They tested the effect of fixation of the head on rhythmic jaw activities in healthy subjects. The restriction of
head movements experimentally, showed that reduced head and neck mobility can impair jaw function. In the sessions with head fixation, head and neck movements were registered at smaller amplitudes and the mandibular movements were significantly reduced. This resulted in shorter mandibular cycle duration times, especially in the self-paced maximal jaw opening-closing cycle where the average reduction of the test group in amplitude was 22%. In other tasks such as gum chewing there were no associated reduced mandibular movements during head fixation. These findings suggest a proportional involvement of head movement with mandibular opening (larger mandibular opening more head movement) specifically at the atlanto-occipital joint and cervical spine. The finding of trapezius and SCM (sEMG) activity occurred along with smaller head and neck movements in the head fixed position suggest head neck movements and musculature are an integral part of natural jaw function in humans. Catanzariti’s findings also show masticatory muscle connections with the neck. Contraction of the masseter muscles is associated with increased electrical activity of the trapezius and SCM (17). Masticatory musculature EMG was also found to be influenced by cervical spine position. Ballenberger found that differing head postures and orientations of the cervical spine provoked changes in the EMG of the masseter muscle (9). A decrease in EMG activity of the masseter muscle was shown during c-spine flexion, ipsilateral lateral flexion, and contralateral rotations with the anterior temporalis muscle not being significantly affected (9).

The above studies illustrate experimentally that when subjects were asked to perform normal functional jaw activities, they were ALWAYS associated with paired head movements which in general preceded the start of the mandibular movement (9,17,30,31,44). Data suggests that cranio-cervical movements are functionally interlinked and integral to mandibular movements of the stomatognathic system. Additionally, jaw opening should be considered an inerrant and innate motor program encompassing the trapezius and sub-occipital muscles that allow cranio-cervical extension at the atlanto-occipital joint as well as extension of the cervical spine via pre-programmed neural
commands common to the jaw and neck muscular systems (30).

3.2 - Head posture and occlusion

Altered head posture itself has also been found to effect mandibular kinematics. Visscher found that head posture in both the sagittal and frontal plane significantly influenced the opening movement path of the incisal point and thus the position of the mandibular condyles in the TMJ (111). Compared to neutral head posture, the movement path was shifted posteriorly in forward head posture and anteriorly with the head held in military posture, and deviated to the side the head moved to in lateroflexion (ipsalateral movement).

Ohmure also found that the position of the mandibular condyle in deliberate forward head posture was more posterior in the TMJ than in natural head posture (77). Initial tooth contact was also found to vary with different head postures, with FHP providing the initial contact on the initial majority contact on the anterior teeth (47). Mandibular muscles that protrude the mandible were also found to display differing EMG activity based on body posture. As the body changed from the erect to semi reclined position the four mandibular protruder muscles displayed increased EMG activity, suggesting their effects of preventing passive mandibular retrusion and corresponding airway obstruction in the supine position (45).

In addition, studies also showed that head posture had an affect on genioglossus muscle activity, with statistically significant greater EMG activity in FHP vs neutral head posture (72). Makofsky demonstrated experimental head alterations in subjects over 30 years of age and older extension of the head shifted the Initial occlusal contacts posteriorly and flexion shifted them anteriorly (65). Makofsky also examined the influence of FHP on initial occlusal contact pattern (IOCP) recorded in four different postures and found no correlation between occlusal contact and FHP, However there was a correlation between IOCP and age. The IOCP moved posteriorly with increasing age.
supporting the findings in his earlier work (64) (65).

3.3 - Cervical spine
Tahara concluded that cervical curvature was greater in older adults with good occlusion and many remaining teeth versus a control group of younger subjects (98). The lordosis in the aged sample population was greater in women than men. (98). Tahara’s findings are supported by Ando, who also showed a significant positive correlation between cervical curvature and age (5). Ando also found strong positive correlations between age and cervical lordosis in the control group with only a very weak correlation between cervical spine posture and infraocclusion. However, Tahara studied subjects with good occlusion and many remaining teeth. The sample of aged women having more cervical lordosis than men as well as more teeth and better occlusion challenges the impact of occlusion on cervical spine posture over the lifespan of an individual suggesting mostly degenerative changes cause increased cervical spine curvature. Increasing age changes in other spinal districts are associated with dehydration of intervertebral disks loss of muscular strength of spinal erectors and postural muscles which result in exaggeration of the natural curvature of the spine (68). This loss of natural S shaped spinal curve could cause a shifting of the body mass requiring postural compensation at levels of the pelvis, hips, and ankles in order to maintain eye level gaze and body center of mass. All of the following suggest age is a strong predictor of postural changes.

3.4 - Posture affected by respiration
Evidence for the support of stomatognathic function and head posture contribute to airway patency (1, 43, 52, 58, 66, 75, 86, 92, 95, 102, 109, 110,111). Gonzalez and Mann studied the consequences of adopting a forward head posture (FHP) which is characterized by a dorso-extension of the head and upper cervical spine (C1-C3) with accompanying flexion of the lower cervical spine (C4-C7) (4). This increase in the normal concave cervical lordosis (hyperlordosis) and mandibular angle was proposed to be a result of altered respiratory function, specifically obstructed nasal
breathing (43). Vig showed experimentally an increase in craniocervical angulation when he totally obstructed nasal breathing in individuals. This manifested within fifteen minutes and peaked after one and a half hours (111). Studies have shown that extension of the head and neck increased the diameter of the pharyngeal airway in individuals showing an airway obstruction and individuals with no obstruction (43, 53, 75, 92, 102, 110, 111).

Gonzales and Mann proposed that when breathing is restricted by anatomic or allergic factors there will be a physiological change of cervical posture to facilitate breathing. Any restriction in normal nasal breathing would facilitate a physiological shift to oral breathing to open the airway, and would be the most efficient method of respiration in the presence of nasal obstruction. This proposed shift to oral breathing lowers the mandible, decreasing tension on the suprathyroid muscles resulting in the hyoid bone moving posteriorly and inferiorly, which reduces the pharyngeal air passage. This reduction in the pharyngeal air space would necessitate the head and neck to assume a more extended position (FHP) in order to passively move the hyoid bone anteriorly and superiorly, thus restoring the original airway space as much as possible (14, 102, 1, 92, 58).

Vig investigated adaptations of head position with total nasal obstruction in total deprivation of visual feedback and a combination of both visual deprivation and nasal obstruction groups (111). Vig found that total nasal obstruction resulted in progressively more extension of the head with corresponding jaw separation. Extension peaked 1 to 1.5 hours into the experiment after introduction of the stimulus. Visual deprivation did not have a significant effect on changes in head posture. Thus Vig, Gonzalez, and Mann demonstrated craniocervical dorsoextension (FHP) as an adaptive response to airway alteration.

The genioglossus, sternohyoid, and sternothyroid muscles also contribute to airway patency. Specifically, during non REM sleep the genioglossus, sternohyoid and sternothyroid muscles exhibit
inspiratory activity and contribute to the patency of the upper airway. The sternohyoid is also responsible for rib cage fixation during sleep states optimizing diaphragmatic function (68).

Inspiratory and expiratory activity of the genioglossus were both augmented in the supine and upright body positions with protrusion of the mandible, suggesting posture can reciprocally effect the activity of the muscle. Collapse of the posterior pharyngeal wall (airway) is prevented with respiratory induced inspiratory activity of the genioglossus muscle opposing the negative thoracic pressure during inspiration. Both expiratory and inspiratory genioglossus activity were found to be augmented in parallel with advancement of the mandible resulting in maximum EMG activity of the genioglossus inspiratory action and expiratory action shown at the maximal mandibular position in both body positions (109). The fact that the genioglossus muscle acts as a dilator of the pharynx and that mandibular position influences genioglossus activity, further strengthens the anatomical and biological association between stomatognathic function and airway patency (60).

Due to the findings of Markofsky and Vig, the respiratory/process musculature warrants further investigation in the effect of respiration having a causal effect on faulty postural alignment. Specifically, the SCM muscle, which can function as an accessory muscle of respiration (52). Ribeiro found a significant difference in the trapezius and SCM during nasal inspiration by a classified “mouth breather” study group that presented with a medical diagnosis of airway obstruction, other respiratory diseases, or whose lips did not show contact while resting (86). The study showed a larger electrical potential in the trapezius and SCM during nasal inspiration in the oral breathing group, suggesting a greater respiratory effort in general which recruits the accessory respiratory muscles to a greater degree (86). In its roll as an accessory muscle of respiration, the SCM functions to elevate the first rib, the sternum, and the diaphragm (52). Diaphragmatic dysfunction such as hypertonicity or other muscular trauma would thus in theory, cause functioning similar to nasal obstruction and force the accessory musculature of the scalene and SCM to contract more to lift the ribcage. Hruska proposed the diaphragm be viewed as two hemidiaphragms based on their differing
attachments to the lumbar spine as well as distribution of the organs asymmetrically in the abdominal cavity with situs solitus. Hruska proposed a mechanism of compensatory patterns leading to craniofacial pain, headaches, and forward head posture resulting from diaphragmatic dysfunction and altered abdominal muscle resting tension (weakness) (52). Hypertonicity of the diaphragm, asymmetric tone between hemidiaphragms, large lung volume (hyperinflation) or weakness of anterolateral abdominal muscles, would result in “decreased descent of the diaphragmatic dome” upon contraction. This places greater demand on accessory respiratory muscles such as the SCM and anterior cervical musculature to lift the ribcage, leading to postural compensations as a result of the fault breathing patterns: increased lumbar lordosis, decreased thoracic kyphosis, posterior cranial rotation, and FHP. More research needs to be done in this area. Determining if the root of the problem would be diaphragmatic dysfunction via weakened trunk musculature leading to FHP in absence of nasal obstruction. With the diaphragm attaching to the lumbar spine and the ribs attaching to the thoracic spine, plus scalene attachment to the cervical spine, theoretical postural adaptations via respiration dysfunction should be further investigated. The SCM and other accessory cervical musculature (scalenes) contribute to respiration, and in the presence of excessive use of these muscles due to faulty respiratory patterns the possibility of adaptive shortening leading to postural alteration of the head seems plausible. Overactive SCM muscular function has been shown to cause postural deviations in facial and head posture (18).

3.5 - Altered occlusal effects on cervical spine and head posture

Dental occlusion has been shown to affect cervical spine and head posture (14, 22, 23, 29, 30, 31, 32, 38, 39, 42, 44, 45, 47, 57, 77, 78, 93, 102, 105, 106, 111, 112). Shimaziki used 3D models to investigate mandibular lateral displacement and lateral inclination of the occlusal plane with differences between the right and left masticatory muscles (93). The models simulated standard occlusion, higher masticatory muscle strength on one side to stimulate unilateral chewing imbalances, symmetrical masticatory strength on each side but an inclined occlusion plane unilaterally to stimulate
a poor restoration, and unilateral occlusal plane inclination coupled with contralateral masticatory muscle strength. Shimaziki found that asymmetrical masticatory forces as well as an inclined unilateral occlusal plane caused variable asymmetrical stress distribution on the cervical spine as well as lateral displacement of the mandible in all but the model with symmetrical occlusion. Shimaziki’s study is representative of the possible effects of mechanical stressors on the stomatognathic system and cervical spine resulting from occlusion. However, the study does not take into account the complexity of the human nervous system and its ability to physiologically adapt and compensate. Shimaziki does bring to light mechanical forces such as malocclusion, as having an affect on the cervical spine.

D’Attillio altered the dental occlusion on rats to see if experimentally induced malocclusion could alter spinal alignment measured by total body radiographs. He found that a scoliosis curve developed after one week and that the curve diminished and the spinal column returned to normal in 83% of the rats after occlusion was normalized (24). The study proved the alignment of the spinal column in rats could be influenced by dental occlusion. However, due to the differing postural demands on quadruped rats vs bipedal humans, the study is limited in scope and clinical application. The study does bring to light the possible effect of malocclusion on head posture in human subjects.

Kibana experimentally examined the influence of unilateral and bilateral occlusal support on head posture via EMG (electromyography) of the masseter, temporalis, and sternocleidomastoid muscles (57). Kibana examined MVC (Maximal Voluntary Clenching) in the presence of a bilaterally/unilaterally placed intraocclusal splint designed to increase occlusal elevation by 4mm in both the eyes closed and open position. He found that when the splint was placed unilaterally resulting in lateral imbalance of occlusal support, the EMG of the masseter/temporalis and sternocleidomastoid of the occlusal support side was greater and the neck was bent toward the side with unilateral occlusal support, regardless of the eyes closed/open position. Kibana also observed
that under VMC with any type of occlusal support (unilateral/bilateral), the head flexed anteriorly when compared with the mandibular rest position regardless of the eyes open/closed position, noting statistically greater flexion in the eyes closed position.

Thus, Kibana experimentally produced a positive correlation between the asymmetrical activity of the sternocleidomastoid muscle and lateral bending of the neck. He also noted that initiation of EMG activity of the SCM was behind that of the masseter/temporalis muscles. These results implicate a relationship between occlusal support, the cervical spine, and head posture, as well as a relationship between the jaw closing muscles and the SCM.

Ferrario found that a previously symmetrical SCM contraction of maximum voluntary clench without occlusal interference became asymmetrical upon MVC in the presence of an asymmetrical/unilateral occlusal support (32). The MVC with unilateral occlusal interference showed alteration in the contraction pattern of the subjects SCM. Thus Ferrario demonstrated experimentally, how a symmetrical pattern could become asymmetrical in the presence of occlusal interference. Interestingly, Tecco evaluated masticatory, neck and trunk muscle activity in patients with unilateral and bilateral posterior crossbite and found no difference in MVC of the masseter muscle in the groups with crossbites or the control groups without crossbite (106). Tecco also observed no significant difference in unilateral functioning of neck muscles such as the SCM or trunk muscles. However, there was increased sEMG activity bilaterally of the SCM in both mandibular rest position and MVC positions. This test group differs from that of Ferrario or Kibana in which they experimentally produced a malocclusion and found differing levels of muscular activity and asymmetrical patterning in the SCM, namely, in the test group used by Tecco there was no experimental induced malocclusion as the subjects presented with biological deviation of the mandible. This suggests the adaptability of the SS to functional deviations from the proposed “ideal” normalized functional parameters.
Compensatory mechanisms in the presence of occlusal alteration were also noted in a longitudinal study where masticatory sEMG changes at the onset of occlusal insertion were noted but dissipated and returned to normal after 14 days, even with presence of the occlusal interference (67). These findings cast doubt on the clinical significance of experimentally induced alterations in masticatory muscle activity suggesting they are transient.

3.6 - Dental occlusion affects body posture

The preceding discussion illustrates that functional aspects of the SS have experimentally induced modifications in head and jaw posture as well as altered muscular activity (EMG) associated with the SS (14, 22, 23, 29, 30, 31, 32, 38, 39, 42, 44, 45, 47, 57, 77, 92, 101, 104, 105, 110, 111, 112). Correlations between dental occlusion and overall body posture have also been experimentally shown. Evidence showing connections between the SS and distal musculature shows increased EMG activity in neck and trunk muscles during an occlusal clench (29). Patients suffering disk herniation have also displayed alterations in mandibular opening and velocity compared to a control group (97). Specific mandibular position seems to have an effect on appendage muscular endurance and strength (34). D’ermes found that the percentage of postural load is modified with the occlusal splint insertion in elite athletes, changing the load distribution to within .4% of ideal balanced 50% load distribution on both sides (27). This was also associated with improved athletic performance. An occlusal splint appeared to balance occlusal loads and result in better postural control and increased quadriceps muscular force (6, 27, 28, 34, 61, 115). It has also been shown that head and shoulder posture can affect scapular mechanics, specifically shoulder flexion and extension in functional tasks (107, 114).

Dental occlusion has also been associated with increased postural control in the elderly. A test group with maintained natural dentition performed better than a test group wearing dentures in one or both
dental arches on postural tests, showing experimentally with hand grip and leg extensor strength being equal tooth loss is a risk factor for postural instability (117). It was also shown that dental occlusion plays an important role in the postural reflex among the elderly in mitigating falls and that a decrease in occlusal functions in the elderly resulted in postural instability (96). Okubo’s findings show unclear causal factors in edentulous patients with regard to postural stability (79). This group demonstrated that dentures produce an effect on the stability of edentulous patients in both static and dynamic conditions as well as gait velocity. In the presence of external disturbances on balance control teeth clenching was found to decrease latency of corrective postural adaptation and lower the needed reaction force caused by perturbation. It was also show from EMG data of the masseter that in the presence of unexpected postural perturbation there is an unconscious effort to clench in order to maintain balance (51, 3, 28). Experimental malocclusion via horizontal mandibular deviation was also found to affect postural reaction to perturbation, negatively interfering with stability. These findings suggest dental occlusion is linked to reflex or motor control activity that influences dynamic balance (113). It's is not clear if the natural afferent feedback of the proprioceptors in the natural teeth are responsible for this stability in the elderly or if it is simply the increased TMJ stability provided by the act of clenching/biting in the case of dentures.

There is also evidence that oral motor functions can facilitate reflex motor responses in distal body segments. Miyahara found that voluntary teeth clenching increased the amplitude of the soleus H reflex (monosynaptic reflex) significantly during wrist extension (MVC of wrist extensors) or fist clenching (74). The increased amplitude positively correlated with the strength of teeth clenching which was monitored by EMG of the masseter muscle and was able to be experimentally decreased by electrical stimulation of the lip. Along with the electrical stimulation of the trigeminal nerve affecting masseter muscle activity in the study above, trigeminal stimulation was also found to inhibit the SCM as well as the masseter (14). The ability of the lip to decrease the EMG of the masseter muscle proves a connection between trigeminal afferent input and functional motor activity of the SS
system. This was also shown in the same experiment to exert influence on motor activity in other body districts via modulation of the soleus H reflex. The functional significance of these findings was explored and it was suggested that voluntary teeth clenching could contribute to stabilization of postural stance (74, 37).

Increased ability to maintain balance and smaller center of pressure (COP) displacement is how many of the studies review and quantified posture. In addition, many studies related these COP displacements to specific jaw positions in either static or dynamic conditions to determine the most stable occlusal position (if any was noticed). Under dynamic conditions such as gait, jaw relationships and planter arch control, loading between forefoot and back foot can be experimentally changed with cotton rolls placed between the dental arches. Voluntary tooth clenching can also increase surface area of contact as well as reduce the load on both feet in the absence of cotton rolls. These findings suggest the planter surface of the foot is able to be modified by dental occlusion (20).

Dynamic gait testing has also shown experimental changes in the spinal column via a 4m occlusal block inserted into the dental arch of healthy right handed individuals in both standing and walking (76). This resulted in a shift toward left lateral flexion, clockwise torsion, and extension in the cervical and thoracic regions suggesting upper body posture is modifiable due to dental occlusion. It should be noted these changes were in the measure of millimeters.

Experimentally induced occlusal imbalance via cotton rolls placed between the dental arches unilaterally resulted in a change in the percentage of load on the ipsalateral foot during walking vs walking in habitual occlusion (84). Although these studies suggest connections between dynamic posture and dental occlusion, the differing research methods, subjects, and sample sizes makes concrete conclusions or causal factors hard to discern.

Adding to the inconsistency of results, another study with similar methods measured differing jaw
positions on postural stability found myocentric position of occlusion to be the most stable (13).
The posturographic examination of the same study also found that out of 95 subjects tested ideal postural loading with regard to balanced distribution of weight on both feet was found to be present in centric relation in 26 subjects, in the rest position in 20 subjects, and in the myocentric position in 45 subjects. The remaining four cases there was no difference in weight distribution in the three mandibular positions. This study used a larger sample size than most studies reviewed. These results support the hypothesis that jaw relation and dental occlusion affect body posture, however, the high rate of individual responses within the sample needs to be addressed in order to draw any concrete conclusions. The fact that the study by Bracco is the only study reviewed that tested the myocentric position makes it difficult to validate their results, simply because making comparisons is impossible. Fink tested the influence of a mandibular imbalance via artificial occlusal interference on the functional activities of the body. Specifically, the functional mobility of the upper cervical spine and the sacroiliac joint (36). The results showed a functional interlinking between the altered occlusion and dysfunction in the sacroiliac joint and cervical spine with 90% of the test subjects testing positive for hypo-mobility at the sacroiliac joint after insertion of occlusal interference. However, there was a high degree of intra individual variability within the small number of subjects sampled with regard to specific affects. Hypo-mobility appeared in 55% of tests subjects at C0/C1 and 25% on the C2/C3 vertebral level on the left side after insertion of the occlusal interference 45% diagnosed with hypo-mobility at the C1/C2 level on the right side. The findings by Fink are supported with similar findings in relation to the cervical spine being affected by occlusion and support malocclusion playing a role in pathological gait, in theory, by negatively affecting the function of the sacroiliac joint (14, 22, 23, 29, 30, 31, 32, 38, 39, 42, 44, 45, 47, 57, 77, 92, 94, 101, 104, 105, 110, 111, 112). Along with the high degree of individual differences in physiological responses, the dysfunctional joint segments immediately returned to normal following the removal of the occlusal interference in all but one of the sample subjects, which returned to normal the following day. This suggests transient neurological adaptations and not long lasting structural physiological compensations. There is strong
evidence showing experimental changes in posture produced by Fink are transient and do not take into account the adaptability of the skeletal, neurological, and muscular systems to artificial stimuli, be that pathological or physiological.

Marini in the seemingly only longitudinal study to scientifically investigate the effects of experimental occlusal interference on body posture, proved experimentally that no postural changes were present after leaving an occlusal interference in the subject for 14 days (67). Only a transient modification of masticatory muscle EMG, which again, dissipated and returned to normal even in the presence of the occlusal interference after 14 days were shown. Among studies experimentally showing the impact of occlusal and mandibular function on body posture, there is no concise agreement on the mandibular position that provides the smallest deviation from the COP and thus provides the most stable postural stance (39, 91, 13). There is even disagreement among researchers as to the ability to quantify a specific jaw position to the most stable body position due to the fact studies have shown force controlled biting motor tasks have a greater effect on body oscillation, postural sway reduction, and EMG activation patterns than maximal clenching in a fixed jaw position (49, 90, 87). These findings suggest that postural sway reduction is a motor reaction, independent of a specific jaw position or symmetric jaw muscle activation. The frontal plane COP was not shown to be experimentally affected by unilateral biting, suggesting that short term asymmetric loading of the SS does not affect postural balance control (49).

3.7 - Dental occlusion, scoliosis, and reciprocal connections

Several studies propose postural imbalance from asymmetric occlusion and loading on the masticatory system (10, 54, 59, 61). When looking at the occlusal patterns of patients with scoliosis, the available research is again inconclusive in human subjects. However, alignment of the spinal column does seem to be influenced by altering dental occlusion in rats (24). Korbmacher found an increased occurrence of frontal plane orthopedic parameters such as an oblique shoulder or pelvis,
scoliosis, and functional differences in leg length in children with a unilateral crossbite and asymmetrical cervical spine but no pathological orthopedic variable was necessarily combined with unilateral crossbite (59). Occlusal patterns in patients with idiopathic scoliosis were shown to have more asymmetrical occlusal features such as anterior-posterior crossbite and canine relationships, however, no association between scoliosis or specific malocclusion was able to be concluded (10). The findings of higher prevalence of asymmetrical occlusal relationships in subjects with scoliosis was also supported (10, 54, 59, 61). Interestingly, in a six month longitudinal study the treatment of scoliosis with a functional brace was shown to alter the muscular tone and correct asymmetry of trunk, neck (SCM), and masticatory muscles (anterior temporalis and masseter) as well as increasing their contractility. The control group in the study received no functional brace for scoliosis treatment and did not register any of the changes the test group did over the six month treatment with the brace (103).

Abnormal SCM muscle function and downward tension has been shown in case studies of congenital muscular torticollis to cause postural adaptations of the head by mandibular deviations leading to unilateral crossbite and facial scoliosis. The abnormal SCM function results from bony changes to the mastoid process on the affected side. The positioning of the mandibular condylar head on the unaffected side was also shown to be affected by the contralateral abnormal sternocleidomastoid tension. The malocclusion and facial scoliosis improved in the case subject suffering from the above pathology after surgical release of the SCM and cervical fascia, this suggests that the SCM muscle plays an important role in head posture (18, 62). It was also shown that unilateral chewing did not alter frontal plane COP nor did asymmetrical malocclusion (unilateral posterior crossbite) influence postural stability, nor is associated with leg length inequality (49, 70, 71, 82). These findings are supported in a randomized clinical trial of preadolescents where orthodontic treatment of posterior crossbite was not found to alter lumbar, thoracic, or pelvic positions (61). Unilateral chewing is a habitual physiological process of mastication. Linear increases in disorders of the masticatory system
would seemingly parallel other self imposed metabolic disorders that are on the rise due to increased food consumption in the United States if asymmetrical chewing was able to cause a pathological state. After all, the human body itself is not symmetrical with regard to spinal or muscular tonus in habitual stance or with distribution of the organs and organ systems in the body (76, 52). The biological asymmetrical makeup of the human body proves in many well functioning individuals asymmetrical forces/influences do not necessarily lead to dysfunction due to our highly adaptable nature as human beings. These experiments above showing correlations between asymmetrical occlusion and orthopedic variables lack causal factors to illustrate that imbalances of the masticatory system or asymmetric loading directly cause asymmetry in the frontal plane. Studies showing positive correlations are devoid of longitudinal follow ups with subjects. Any correlations derived from these studies and need not be ignored but consideration of the adaptability of the masticatory muscles/SS to the asymmetric disturbance over time needs to be considered in the current literature and implemented in further studies (48, 67).

Sakaguchi evaluated changing mandibular position on body posture as well as the influence of altered body posture on mandibular position and occlusion (91). He found that centric occlusion was the more stable mandibular position and also found occlusal force was altered when a heel lift was placed under the right foot occlusal forces shifted toward the right side. These results showed a reciprocal connection between body posture and occlusion, and were also observed by Maeda when use of heel lifts of differing heights shifted weight or occlusal force to the ipsalateral side compared to the controls (63).

3.8 - **Dental occlusion does not alter body posture**

In addition to the questioning of the clinical and practical relevance of the studies showing experimentally induced transient changes in postural orientation, many studies reviewed showed no changes at all in body posture or functional activities due to experimental occlusal interference. In
what can objectively be referred to as the most thorough study reviewed, Marini investigated the long
term effects of an experimental occlusal interference on body posture (67). The strength of this
study lays in the evaluation of the test subjects postural reactions to the occlusal interference using an
integrated and sophisticated system of instruments. The evaluation consisted of a high number of
measured exteroceptive conditions leading to large amounts of data collected, a built in
intraindividual control, and its longitudinal design that would allow for any physiological
compensations to manifest due to the interference not being removed until 24 days following
insertion. The study revealed no significant differences in gait and only random and insignificant
changes in the frontal and sagittal parameters in relation to the measurements taken directly before
insertion of the occlusal interference (T1). This leads to the conclusion an experimental occlusal interference does not modify static or dynamic body posture.

Marini’s differing exteroceptive test conditions did not find differences in frontal or sagittal
parameters with teeth in occlusion and subjected to the occlusal interference, or with teeth out of
occlusion and thus not subjected to the interference. This comparison further strengthens the
conclusion that dental occlusion has no affect on body posture. Masticatory muscles did show a
significant sEMG increase between T1 (directly before occlusal interference inserted) and T3 (7 days
after occlusal interference inserted). However these changes normalized at (14 days after insertion of
occlusal interference) T4. The sEMG of the trapezius muscle showed no significant differences
between measurements (T1-T4) challenging the notion the masticatory muscles and muscles of other
body districts being functionally linked (67). Ferrario also concluded experimentally a lack of
significant difference in postural control between subjects with TMD, malocclusion, or a control
group when COP was tested in differing occlusal positions (33). The results obtained by Marini and
Ferrario concluding no predictable relationship between occlusion and body posture are supported
by the following findings (2, 5, 35, 64, 66, 70, 71, 80, 81, 82, 83, 95).
Patterns emerged from the reviewed literature that postural control is negatively affected by deletion of visual input (4, 7, 8, 39, 40). Tardieu showed that dental occlusion affects postural control differently depending on static or dynamic conditions (101). The only influence dental occlusion had on postural control was modifying postural sway in dynamic condition in the absence of visual input. Tardieu's findings suggest the contribution of dental occlusion, in terms of the afferent feedback from the trigeminal nerve via dental structures such as the PDL, would increase in the absence of visual input (26). Tardieu’s findings suggest a hierarchy of sensory input whereby, in absence of certain afferent input other sensory systems have a greater impact on postural control and “pick up the slack” for the others.

Gangloff further tested the impact of occlusion on the visual and vestibular system using a test group of highly skilled shooters to test gaze stabilization with mandibular positions previously tested on a group that was only evaluated on postural relations to mandibular position (39). Experimentally, Gangloff found that COP displacement was lowest (postural position most stable) in centric relation in the eyes open position for the group that underwent postural evaluation (P group), this supports the findings of Sakaguchi (91). Shooting performance measured in accuracy as well as shot dispersion was also significantly improved in the centric relation position. These experimental findings suggest occlusal alteration can influence visual tasks requiring high postural stability and balance control suggesting interlinking of the SS with the vestibular system, which is supported in the research (15, 21, 84, 85).

Gangloff also experimentally found in one group the physiological (ipsalateral) side lateral position, not the centric relation mandibular position was the most stable in the eyes closed test position. This further suggests that altering visual input changes sensory channel involvement of postural control and that visual input has a greater impact on postural control than dental occlusion (4, 7, 8, 26, 39, 40). Findings of vertical dimension of occlusion having a relationship with the proper dominant eye
have also been shown in an epidemiological study of school children (94). Interestingly every study that measured altered mandibular positions and balance in both the eyes closed and eyes open exteroceptive positions, postural control largely deteriorated in the eyes closed position.

4 – Conclusions

1) Can the SS cause a compensatory change in head and neck posture (craniocevical angle) due to altered/faulty proprioceptive input or mechanical stresses?

Alterating input to the SS does seem to modify head posture as well as masticatory muscular activity experimentally in select studies. The immediate changes shown in head posture as well as mandibular position due to the occlusal interference need further study to determine any lasting impact on SS function, thus clinical significance of these findings are low. Functional adaptations with regard to respiration are suggested to be normal physiological changes occurring due to the fact respiration is vital for all living creatures. In the instance of airway obstruction, postural compensation to increase respiration benefits the organism in the short term and does not qualify as a pathological change. However, It is suggested that prolonging this postural compensation would alter the entire organismic system leading to a pathological development.

2) Can alterations in the SS system cause alterations in other body segments (thoracic spine, ribs, pelvis) and thus affect overall body posture?

Debate currently continues with regard to the affect of specific effects of dental occlusion on overall body posture. The research reviews shows conflicting results. In summary, some researchers found that an occlusal interference experimentally influenced overall body posture when posture was measured either in terms of COP displacement or by manual methods. No causal link was found in any of the research studies showing correlations.
3) Why the conflicting results

The results from the reviewed literature are overwhelmingly conflicting, with some researchers citing strong correlations and other researchers citing none. Many researchers used small sample sizes lacking control groups and targeted a specific demographic, which make any experimental findings population specific. Postural sway and the use of posturography itself has shown to be affected by the autonomic nervous system (ANS) and by stimulation of the carotid sinus baroreceptors as well as ventilation. Local muscular fatigue in the planter flexors was also shown to alter postural sway, specifically in the sagittal plane. Lumbar extensor fatigue and ankle sprain were also shown to increase postural sway. The first 20 seconds of measurement upon the subject standing on the platform itself were also shown to be very random and individual, not necessarily due to any other variable than establishing individual postural stability. No study disregarded the first 20 seconds of measurement except for two, which could contribute to the conflicting findings among researchers. Due to the many variables affecting postural balance control described above it is suggested that any causal findings between dental occlusion and postural control are limited to the specific variables of the group studied and are not transferable to populations of differing age, height, or muscular strength levels. In addition, a causal link must then be identified with no differing intra-individual variability among study participants. Specifically, high rates of individual responses within the sample need to be addressed in order to draw any concrete conclusions. Among studies experimentally showing the impact of occlusal and mandibular function on body posture, there is no concise agreement on the mandibular position that provides the smallest deviation from the COP and thus provides the most stable postural stance.

According to the reviewed literature there are promising connections between the SS and the distal musculature, specifically with regard to the affect of teeth clenching on muscular performance as well as reflex activity and dynamic balance. Modifying dental occlusion in the form of occlusal
interference does experimentally affect mandibular position, which can be accompanied by changes in EMG activity of masticatory muscles and cranio-cervical posture. However, these changes seem to be transient in nature with low clinical significance. There are too many inconsistent results and experimental parameters to conclude that dental occlusion has an affect on body posture. Longitudinal studies with appropriate follow-ups are needed to scientifically confirm clinical significance and not just experimental results; these experimental studies are absent in the literature.
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