RON, Propriception is found on pages 7 through 17 of this reprint. Notice that I published it in Clinical Dentistry in 1981. I think that the principles in this paper have not been altered in substance since that time. Hope it helps with your questions on propriception.

[signature]

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INTEROCCLUSAL DISTANCE AND MOVEMENT FROM REST POSITION TO INTERCUSPAL POSITION

Bennett demonstrated that the center of rotation of his mandible from maximum intercuspation to rest position was located in the region of the mastoid process (19). Nevakari studied this movement in 75 dental students (20). He was interested in finding out if this movement was a pure hinge movement with its center in or near the condyle. He found the average location of the center of rotation of this movement to be also in the region of the mastoid process. His study demonstrated that the condyle moves up and back approximately 1 mm during this movement so that both translation and rotation occur simultaneously. He found that lower canines move up and forward at an average angle of 11° to a perpendicular to the Frankfort plane in the movement from rest to maximum intercuspation. Posselt demonstrated (Fig 33-1) that the rest position in the average patient is not a border movement but lies within the movement space on the free opening-closing path. These data indicate that the mandible is not back in the centric relation closure arc when it is in rest position in most patients. This study disproved the concept that the normal closing path from rest to intercuspal position was a simple rotary type with the condyle acting as the center (21).

Niswonger measured the interocclusal distance in 200 patients with natural teeth (22). His measurements were taken between dots on the skin just under the nose and at the center of the chin. He reported that 87% of these subjects had an interocclusal distance of 3.1 to 3.2 mm. The other 13% had distances that ranged from 0.8 mm to 8.7 mm. Measurements on another 200 subjects between 37 and 78 years of age who had extremely worn or abraded natural teeth revealed that 83% of these subjects had an interocclusal distance of 3.1 to 3.2 mm. These studies led to the concept that the normal interocclusal distance should be 3.0 mm at the anterior teeth.

Many studies (23–28) have pointed out that even though a 3-mm interocclusal distance is an acceptable measurement for most patients, there is a hazard in considering that every patient should have a 3-mm distance. In addition to the normal biologic variation in this measurement, other factors may alter a patient's interocclusal distance. For example, it has been reported that the phonetic method of recording rest position gives consistently greater values for interocclusal distance than the swallowing method. With the extraction of all the teeth and their immediate replacement with a denture, both the occlusal vertical dimension and rest vertical dimension tend to decrease, while interocclusal distance tends to remain fairly constant. Interocclusal distance is highly variable after extraction of all the teeth. It may vary between different measurements within the same sitting, between different sittings, and between readings with and without dentures in the mouth. The rest position of the mandible is not a single position but a range of positions, and the width of that range varies in the individual at different times.

A number of electromyographic (EMG) studies of interocclusal distance have been reported (28, 29). It has been shown (29) that the posterior temporalis muscle usually demonstrates electrical activity when the mandible is in the clinically determined rest position. The distance between the teeth when the first elevator muscle shows electrical activity on jaw closure has been called the EMG interocclusal distance. The EMG interocclusal distance averaged 3.3 mm in a study of 20 subjects, while the clinically determined interocclusal distance averaged 1.7 mm. An EMG resting range of 11.1 mm was found instead of a specific rest position. Preiskel (28) studied the variations in interocclusal distance with different head positions. He found that when the head is turned down 35° from the horizontal orientation, the interocclusal distance decreases. When the head is turned up 35°, the distance increases. In each instance he found the EMG interocclusal distance to be greater than the clinically determined distance. It has not been practical to place electrodes on all of the mandibular muscles in these studies, but it has been shown on the muscles that are accessible for recording that the concept that the mandibular muscles are not active at the rest position is probably not true. It seems that at least the posterior temporalis is active, counteracting the pull of gravity on the mandible at the clinically determined rest position. With the advent of space travel, it will be interesting to see what effect weightlessness will have on the interocclusal distance.

The rest position in children with Angle's Class II malocclusions is different from that in children with normal jaw relationships (30, 31). The average rest position in 32 Class II, Division 1 girls was found to be down and forward of the maximum intercuspation position. In subjects with normal jaw relationship the rest position is located down and backward from maximum intercuspation (20). In 22 children with Class II, Division 2 malocclusions (31) it was found that the rest position is more inferior but not as far anterior as in the Class

II, Division 1 children. The Division 2 subjects, therefore, had a greater interocclusal distance (freeway space) than Division 1, or normal, children. Approximately 50% of these subjects had interocclusal distances between 4.0 and 7.3 mm. The Class II patient may "rest" his jaw down and forward for aesthetic reasons or to allow the muscles of the lips and chin to function adequately.

The addition of an acrylic palatal base plate to a patient's mouth has been shown to increase the resting height of the face.[32] This study of rest position in 13 dental students demonstrated a statistical increase in resting face height and greater variation in rest position of the mandible when the subjects wore a palatal base 2.5 mm thick. These subjects all had nearly full complements of natural teeth.

The interocclusal distance was reduced to zero over a 12-year period in a patient with a paralyzed right lateral pterygoid muscle.[33] In this instance, an imbalance between the elevators and depressors of the mandible in favor of the elevators established a new rest position at the occlusal vertical dimension. The occlusal vertical dimension and the rest position are established in any given patient by a dynamic balance between various factors that tend to close the jaws and those that open them. In some patients, the teeth, when taken out of occlusion by the occlusal reduction of full crown preparation, rapidly extrude into occlusion if very accurate temporary crowns are not placed on them. In other patients, the teeth that have been taken out of occlusion do not seem to extrude at all.

Measurement of the interocclusal distance is necessary when the dentist is contemplating increasing the occlusal vertical dimension in a patient. Increasing the vertical dimension in patients with small interocclusal distance is rarely successful.[34] Increasing the occlusal vertical dimension with fixed restorations or removable prostheses may not alter the opposing forces that establish the dimension so that the teeth intrude into the alveolar process and/or the condyle-fossa relationship of the TMJ may be changed.

In recent years, the studies of Farrar and McCarty have demonstrated that anterior displacement of the TMJ meniscus is responsible for changes in occlusal vertical dimension and interocclusal distance in many patients.[35, 36] In these patients, the condyle becomes positioned superiorly and posteriorly in the fossa against a degenerated bilaminar zone. These patients usually demonstrate a painful reciprocal click during opening and closing movements.

TMJ tomograms and profile radiographic films were taken on 27 complete denture patients before and after new dentures were seated.[37] The effect of increased occlusal vertical dimension in the new denture on TMJ intra-articular space was evaluated. The results showed that the width of the joint space was not affected by considerable increase in the occlusal vertical dimension. Forty-four percent of the patients had a narrow width of the joint space, with change in shape of the condyle and fossa indicating TMJ arthrosis, and these findings were not altered by the wearing of a new denture at increased occlusal vertical dimension.

In some patients with TMJ pain syndrome, "opening the bite" relieves the pain.[38] This relief is not uncommonly temporary, and in those patients in whom pain recurs after the occlusal reconstruction, the dentist is confronted with a most difficult problem. One should always carefully examine for TMJ pathology, vascular pain, cranial nerve pathology, muscle abnormality, interferences in the slide, nonfunctional (balancing) interferences, lateral deviations in the slide, and open or heavy centric stops at the patient's occlusal vertical dimension before a patient's bite is appreciably opened.

CENTRIC RELATION CLOSURE ARC AND THE HINGE AXIS

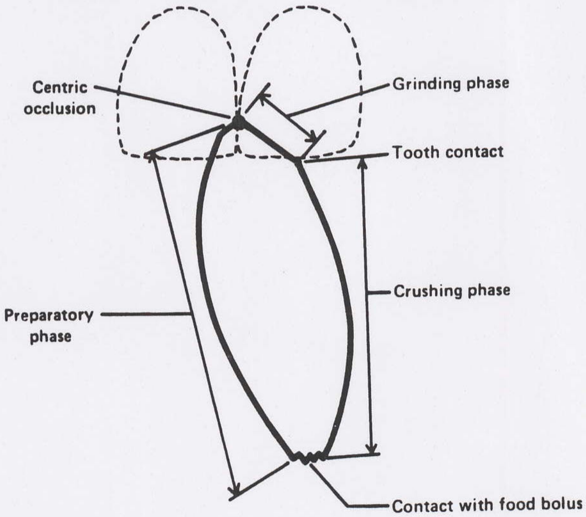
Zola has demonstrated a shiny facet in a depression in the medial wall of the glenoid fossa of an unspecified number of skulls.[39] He has also demonstrated that the meniscus may be only 0.2 mm thick over the medial pole of the condyle as it is positioned in these depressions. The seating of the right and left condylar medial poles in these depressions establishes a bony support for the mandible in its superior-posterior position and may establish an axis about which the mandible rotates. It is reasonable that this anatomic relatinship would establish a terminal hinge axis point on the face where the axis emerges from the head. This definite depression in the medial wall of the glenoid fossa cannot be demonstrated on many human skulls, so these findings do not explain the presence of a terminal hinge axis in all patients.

Beck located the terminal hinge axis on 12 subjects and studied its location relative to the image of the condyle on lateral cephalometric radiographs.[40] Disregarding the complicated distortion of the cephalometric radiograph, it can be seen from his study that the terminal hinge axis fell within the condyle in 7 of his 12 subjects. In the other 5 subjects it was located posterior to, anterior to, or within the neck of the condylar process. Fox has estimated that cementation of crowns produces occlusal errors of 0.05 to 0.08 mm.[41] He then calculated that an error of 1.00 mm in locating the terminal hinge axis does not result in greater occlusal discrepancy than 0.08 mm.

THE MASTICATORY CYCLE

The masticatory cycle has been examined in great detail in the aborigine (Fig 33-2) and has been described in six different phases.[42] The preparatory phase is the descent of the mandible, deviating initially to the nonbolus side and then to the bolus side of the mouth. The initial deviation to the nonbolus side of the mouth would place the teeth in a balancing or nonfunctional occlusal position on the bolus side of the mouth. Contact with the food bolus occurs at the bottom of the preparatory phase as the mandible is positioned to be elevated and crush the bolus. The crushing phase is the elevation of the mandible with deviation to the side of the mouth on which the food bolus is located. Tooth contact occurs at the top of the crushing phase when the buccal cusps of lower teeth contact the buccal cusps of upper teeth on the bolus side of the mouth. The grinding phase begins at tooth contact and ends when the opposing cusps have glided across each other into maximum intercuspation position. The final phase of the cycle has been called centric occlusion and is the point at which the teeth have closed into the maximum intercuspation occlusal position. Accurate timing of the cycle demonstrates that centric occlusion is the only point in the cycle in which the mandible makes a definite stop. From this point the cycle repeats itself as the mandible moves to the nonbolus side of the mouth in the next preparatory phase.

Fig 33-2. Frontal projection of masticatory stroke. (Redrawn from Murphy TR: Arch Oral Biol 10:981, 1965.)



The length of the grinding phase averaged 2.8 mm at the incisors in the aborigine but averaged one-half that length in modern man.[3, 43, 44] This indicates that the buccal-to-buccal or functional side contacts of the teeth are utilized in chewing. If the first 1.5 mm of the grinding phase is not accurately reproduced in occlusal restorations, excessive forces may be exerted on single teeth in chewing.

The replicator of Messerman and Gibbs has been used to study the chewing of various foods by 185 children and adults.[45] In this computerized method of studying mandibular function during mastication, a point on the hinge axis 20 mm medial to the skin in adults and 12 mm medial to the skin in children was plotted to represent condylar movement.

In the adult, on closure on a bolus of food placed between the posterior teeth, the working side (bolus side) condyle moved to an upward and posterior position before the teeth enter their intercuspal range. During final closure, the working condyle moved an average of ⅓ mm anteriorly and ⅕ mm medially. This movement may have a superior or an inferior component. The nonworking condyle moves posteriorly, laterally, and superiorly on closing in the masticatory stroke. It has no anterior component.

The working side condyle reaches its most superior position before the teeth enter the intercuspal area, and the nonworking condyle reaches its terminal position at the same time the teeth reach intercuspal position. There is no hinge-axis movement in chewing. Subjects with pathologic occlusion and mobile teeth are unlikely to reach intercuspal position or to demonstrate stoppage of jaw movement when intercuspal position is reached.

The harder the food bolus, the more lateral is the closing stroke. The opening stroke is usually symmetric except when gum is chewed, in which case the opening pathway is more laterally directed toward the nonworking side.

The child will open laterally to the bolus side of the mouth and close more medially, as do adults with an anterior open bite. The child's condylar pathway is more nearly horizontal, while the adult's pathway is steeper, reflecting the development of the articular eminence.

A study of tooth contact in American subjects during mastication has shown that the teeth contact an average of 1.3 mm lateral to IP, glide into maximum intercuspation, and continue in contact an average of 0.9 mm beyond intercuspal position on the opening stroke.[46]

Abraded occlusions tend to demonstrate greater lateral tooth contact. Persons with a prognathic mandible and denture wearers tend to demonstrate vertical closures.

There is looseness in the TMJ, which makes depression of condyles during the taking of interocclusal records possible. The operator or the patient's elevator muscles must maintain a superior position of the condyle during interocclusal records in order to prevent excessive occlusal vertical dimension on posterior teeth.

It is interesting to note that speech shows almost no lateral and little vertical jaw movement, and it does not reach the intercuspal position. However, there is considerable anterior-posterior movement during speech.[47]

TYPES OF OCCLUSAL FUNCTION

There are a number of ways to classify the relation of upper and lower teeth as they approach each other and occlude during jaw function. One simple way is to divide occlusal function into only three types, including balanced occlusion, functional side occlusion (group function), and cuspid-protected occlusion. All three are based on the assumption that opposing posterior teeth are in contact in a centric stop position when the jaws are closed in maximum intercuspation position. The type of occlusal function in a specific patient may not be bilateral. It is not uncommon, for example, to find cuspid-protected occlusion on one side and functional side occlusion on the other in young patients.

Balanced occlusion is that relationship of the teeth in which there is contact of buccal cusp to buccal cusp on the functional side of the mouth and at least one contact of an upper lingual cusp against a lower buccal cusp on the nonfunctional side in lateral movement of the mandible. This type of occlusion is considered ideal in full denture construction, because balanced occlusion provides stability of the denture bases against the alveolar mucosa during occlusal function.

Functional side occlusion (group function) is that type of occlusal function in which the canines and one or more posterior teeth are in contact, buccal cusp to buccal cusp, on the functional side, but in which there is no tooth contact on the nonfunctional side. Functional side occlusion is found in the Australian aborigines, who abrade their teeth excessively.[3] Nonfunctional (balancing) interferences are often associated with TMJ pain syndrome[9, 48] These interferences are not infrequently found in mouths with missing lower molars and mesial tipping of the more distal molar. They are also found in some postorthodontic patients when occlusal adjustment has not been accomplished after the band spaces have closed and the teeth have tightened up in the alveolar process.[49]

In cuspid-protected occlusion, there are even centric stops around the arch in the intercuspal position, but any lateral or protrusive movement of the mandible immediately discludes the posterior teeth, with the lower canine occluding against the lingual surface of the upper canine.

D'Amico pointed out the significance of this type of occlusal function when he noted that ancient California Indian skulls showed abraded canines and incisors with functional side occlusion, while the modern California Indian (eating a soft diet) has cuspid-protected occlusion.[50] Cuspid-protected occlusion would tend to put heavy forces on single teeth, the canines, in eccentric occlusal positions. The periodontal ligaments of the teeth, especially the anterior teeth, are richly innervated with sensory receptors whose primary cell bodies lie in the mesencephalic nucleus of the trigeminal nerve.[51–55] These receptors are directionally oriented around the tooth roots so that slight displacement of the canine inhibits the motor output to the jaw-elevating muscles and stimulates the anterior belly of the digastric muscle. These periodontal ligament receptors and their neurons constitute the sensory side of a jaw-opening reflex. There is evidence that this innervation may function to prevent the application of excessive forces to the canine periodontium in subjects with cuspid-protected occlusion.[55] Patients with cuspid-protected occlusion would have no grinding phase in their masticatory cycle. They could only contact their canines on the bolus side of the mouth on jaw closure. The posterior teeth would contact only at the intercuspal or centric stop position.

A number of studies have reported the incidence of different types of occlusal function in humans.[56–58] The subjects in one study had at least 28 natural teeth and ranged from 17 to 69 years of age.[56] An incidence of 19% cuspid-protected occlusion, 65% functional side occlusion, and 16% balanced occlusion was reported, with no indication of unilaterality or bilaterality. In another study of 1,200 men between 17 and 25 years of age, it was reported that 73% of the subjects had cuspid-protected occlusion on at least one side.[57] The incidence was highest in Angle's Class II patients (84%), next highest in Class I patients (73%), and lowest in Class III patients (33%).

The great difference in incidence of cuspid protection reported in these two studies could be due to the difference in the age of the subjects. The older patients in the former report may have abraded their canines so that posterior teeth made contact of the functional side.

In a study involving 50 subjects between 18 and 29 years of age, only 20% had cuspid protection on at least one side.[58] This study was different from the other two in that all the subjects had Angle's Class I occlusion, the subjects moved laterally exactly 3 mm, as indicated by a marking device fixed to the labial surface of upper incisors, and tooth contact was detected by placing alginate on the occlusal surfaces of the lower teeth. Only perforations in the alginate were reported as tooth contacts. In this study the incidence of nonfunctional (balancing) contacts was higher than that of the earlier reports. Eighty-four percent had a nonfunctional contact on at least one side. Only 8% of the subjects had nonfunctional interference in that these contacts prevented functional side contact. The low incidence of cuspid protection for young adults and high incidence of balanced occlusion, relative to the earlier reports, might be due to stronger biting force applied on the nonfunctional side, stimulated by the alginate between the teeth. The teeth on the nonfunctional side can be brought into light occlusion by conscious effort in many subjects. During the time required for setting of the alginate, the subjects may have momentarily applied strong biting force on the alginate. When fifty 11-year-old children were examined, 42% were found to have contact of a single tooth on the functional side; this single contact was usually between the first permanent molars. The permanent canines are not fully erupted in 11-year-old children, so functional side contact seems to shift from posterior to anterior as these teeth reach their occlusal position in the arch. There was the unexpected high incidence of nonfunctional side contacts in the children (84%), just as described above for the adults.

After considering possible reasons for the differences in these reports, it seems that the incidence of cuspid protection goes down in older adults; the incidence of nonfunctional (balancing) interference is very low; the incidence of cuspid protection is related to Angle's class of jaw relationship, being greatest in Class II and least in Class III individuals; and there is no difference in the incidence of cuspid protection between males and females in children and young adults.[58] Since biting force tends to be less in women, it would be interesting to study the incidence of cuspid protection in a large number of older men and women.[59] If tooth abrasion is a significant factor in establishing occlusal function, one might find a higher incidence of cuspid protection in women than in men in the older age-groups.

There is no agreement among the dentists most experienced in occlusal restoration as to whether cuspid-protected occlusion is healthy and desirable. Some feel that the lateral forces of occlusion should be distributed to as many teeth as possible, while others think that the canines can withstand these forces and the posterior teeth may show premature periodontal deterioration when subjected to the lateral forces of balanced occlusion.[60–65]

Mobility of the teeth in 30 maxillary quadrants of subjects with cuspid protection and 30 maxillary quadrants of subjects with functional side occlusion (group function) has been measured.[66] Analysis of statistics demonstrated greater mobility in the first premolars and first molars of the subjects with cuspid protection than in those with functional side occlusion. Even though there was no statistical difference in the average mobility of the other teeth, there was more overall mobility in the cuspid-protected subjects at the 0.05 significance level. All of these subjects had good gingival health with no alveolar bone loss. The investigators concluded that changing a patient's occlusal function from group function to cuspid protection may be deleterious to periodontal health.

PROPRIOCEPTION PHYSIOLOGY

There are three stretch-sensitive receptors in the striated muscle of man. Two are found in the spindles, which are located in the fleshy parts of the muscles, and the third is the Golgi tendon organs, which are located at the musculotendinous junction of the motor units in a muscle (Fig 33-3).

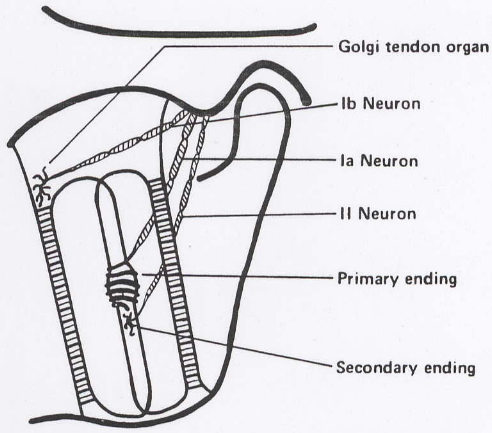


Fig 33-3. The three proprioceptors in striated muscle. The neurons that provide the spindle primary ending and the Golgi tendon organ are classified as Ia and Ib fibers, respectively. The neuron that provides the spindle secondary ending is classified as a group II fiber. Note that the spindle is "in parallel" with the extrafusal muscle, while the tendon organ is "in series" with the extrafusal fibers.

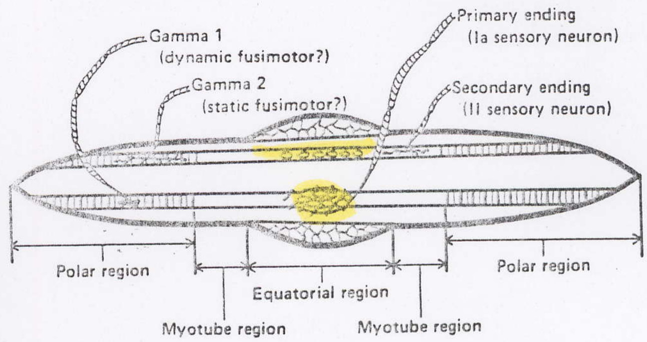


Fig 33-4. Muscle spindle with greatly shortened polar and myotube regions. Diameter of the capsular region ranges from 80μ to 200μ, while the overall length ranges up to 20 mm. The two types of intrafusal muscle fibers are represented with the nuclear bag fiber below and the nuclear chain fiber above.

The sensory receptors of muscle spindles detect both length and rate of change of length of its muscle fibers. They help ensure that muscle tension is proportional to stretch and allows smooth coordination of phasic (intentional) movement with posture.

The spindles contain thin muscle fibers that are arranged in parallel with the major fibers of the muscle. The thin fibers of the spindles are called intrafusal fibers, and the major fibers of the muscle are called extrafusal fibers. As many as one third of the motor nerves to a muscle may innervate the intrafusal muscle. Excitation of the intrafusal muscle fibers of a deafferentated muscle does not result in contraction of the muscle. That is, stimulation of the motor nerves to intrafusal muscle does not produce any detectable increase in tension in the muscle.

The central portion of the muscle spindle is called the equatorial region; the two slender ends are called the polar regions (Fig 33-4). The spindles may contain 3 to 12 intrafusal fibers. Most spindles however, contain 5 to 7 fibers, with 1 to 3 being nuclear bag fibers and the remainder being nuclear chain fibers. The bag fibers are enlarged in the equatorial region, where their nuclei are aggregated in a swelling. The chain fibers are not enlarged in the equatorial region, but their nuclei are lined up within the fiber. The intrafusal fibers are striated in the polar regions. The myofilaments run through the equatorial region within the bag and chain fibers but lose their striations at this site.

There are two types of sensory receptors in the spindles. The annulospiral endings (primary endings) are ribbon-shaped, spiral nerve endings, normally wrapping around the bag fibers in the equatorial region. Their axons are classified as Ia fibers (12μ to 20μ in diameter). The flower spray endings (secondary endings) are irregular-shaped endings usually associated with the chain fibers in the myotube region (where the polar region meets the equatorial region). Their axons are classified group II or A β-fibers (5μ to 12μ in diameter). A spindle contains only one primary ending but may have up to five secondary endings.

There are two types of motor nerves innervating the intrafusal muscle of the spindles. They are known as the static fusimotor fibers and the dynamic fusimotor fibers. Cinephotomicrography of isolated spindles shows that the nuclear bag and nuclear chain fibers may contract independently on stimulation of the different nerve fibers. Stimulation of the dynamic fiber causes the velocity response of the primary ending to be increased, while static fiber stimulation decreases the velocity response of the primary ending and increases the length response of both endings. It is now believed that the dynamic fusimotor nerves innervate the nuclear bag fibers and the static fusimotor nerves innervate the nuclear chain fibers (Fig 33-4). The dynamic fusimotor axons tend to end in discrete end plates, while the static fusimotor terminations are more diffuse, trail-like endings.

The Golgi tendon organ, unlike the muscle spindle, is positioned in series with the extrafusal muscle. It may be excited by the contraction of individual motor units, and it appears to play a continuous role in the central regulation of muscle contraction. The tendon organ signals tension of its muscle, the spindle secondary ending signals length of the muscle, and the spindle primary ending signals both length and velocity of shortening. These receptors do not make an important contribution to conscious proprioception but allow smooth coordination of phasic movement with posture.

Muscle–nerve experiments have demonstrated that the Golgi tendon organs and spindle receptors are constantly firing into the central nervous system.[67, 68] It has been shown (Fig 33-5) that when a muscle is stretched externally, the firing rate from both the spindles and the Golgi tendon organs increase with that stretch. When the muscle is stimulated to contact, the Golgi tendon organs, again, increase their firing while the muscle spindles may cease firing (demonstrate a silent period).

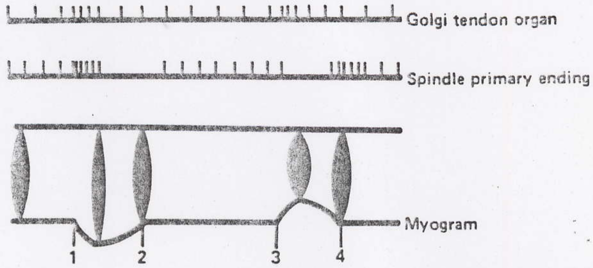


Fig 33-5. Activity of spindle ending and Golgi tendon organ elicited by external stretch and contraction of their muscle of origin. At 1 the muscle was stretched externally, at 2 it was placed back to resting length, at 3 the motor nerves were stimulated to make the muscle contract, and at 4 the muscle relaxed back to resting length. (Redrawn from Matthews BHC: J Physiol 78:1, 1933.)

The firing rate of spindle primary endings may be increased by stimulation of the fusimotor nerves to the intrafusal muscle.[68] In these muscle–nerve preparations, firing of the primary ending ceases when the muscle is stimulated to contract and lift a weight. If the fusimotor nerves are stimulated when the muscle shortens, the silent period in primary ending firing is eliminated. The fusimotor nerves therefore modulate the afferent impulses from the muscles to the central nervous system.

The secondary endings respond linearly to stretch (*i.e.*, doubling the length of stretch doubles the firing frequency). The primary ending does not respond linearly to stretch but is a very good detector of small perturbations. Its length sensitivity decreases with increasing amplitude of stretch. After a stretch of large amplitude, the primary ending "resets" itself so that high sensitivity is reestablished at the new length. The primary spindle endings are much more sensitive to vibration than the secondary endings.

In one study fusimotor nerves were shown to be activated simultaneously with the lower motor neurons during voluntary isometric contraction.[69] It is presumed that this fusimotor activity helps to maintain the contraction by preventing the decreased excitation from the spindle primary receptors when the muscle contracts. It seems that the cerebellum modulates the fusimotor activity during movement so that the spindle endings fire at a preset rate as long as the movement proceeds in the anticipated manner. Any deviation of the movement from its planned course would lead to an immediate change in spindle firing that would initiate appropriate correction in the movement.

The primary sensory nerves of striated muscle have their soma in dorsal root and cranial nerve ganglions, and their proximal processes make different connections in the central nervous system, depending on which type of receptor they serve. Since muscle spindle receptors do not contribute to conscious proprioception, they project to the cerebellum rather than to the sensory cortex.

The proximal process of the spindle ending neuron projects directly on the lower motor neurons to the extrafusal fibers of the muscle in which it is located (Fig 33-6). This connection provides a monosynaptic reflex arc. The reflex mediated via this arc is called the stretch or myotatic reflex. The stretch reflex is described as the contraction of a muscle in response to stretching of that muscle. The contraction is typically proportional in magnitude to the abruptness and extent of the stretch. If the pull on the muscle is maintained, the muscle responds with a steady contraction sufficient to balance the force of the pull and maintains this contraction for many minutes. The myotatic reflex may therefore be phasic or static, depending on the nature of the stretch applied to the muscle.

In addition to serving as the sensory side of the stretch reflex arc, the primary ending neuron also sends a collateral to synapse on cells in Clarke's column. This secondary neuron projects to the vermis of the cerebellum via the ipsilateral dorsal spinocerebellar tract. This input to the cerebellum provides feedback from the muscles, which makes smooth coordination of movement and regulation of muscle tone by the cerebellum possible.

The spindle secondary ending neurons make polysynaptic connections that are excitatory to flexor motor neurons and inhibitory to extensor motor neurons, regardless of the muscle of origin of the secondary ending (Fig 33-7). They also send collaterals to neurons of Clarke's column, whose as-

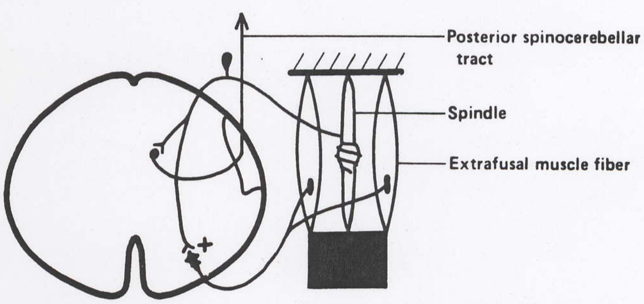


Fig 33-6. Central connections of the spindle primary ending neuron with the motor neuron to its own muscle (monosynaptic reflex arc) and with the cerebellum. The cell body of the secondary neuron that ascends in the posterior spinocerebellar tract is located in Clarke's column and projects to the ipsilateral cerebellar vermal cortex. Note that the synapse with the anterior horn cell is excitatory.

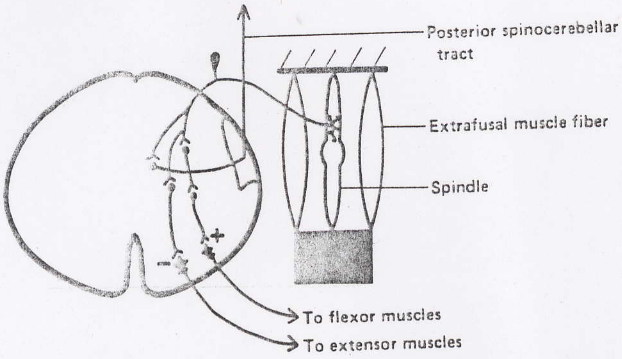


Fig 33-7. Central connections of the spindle secondary ending with flexor and extensor muscles (polysynaptic reflex arcs) and with the cerebellum. The cell body of the secondary neuron that ascends in the posterior spinocerebellar tract is located in Clarke's column and projects to the ipsilateral cerebellar vermal cortex.

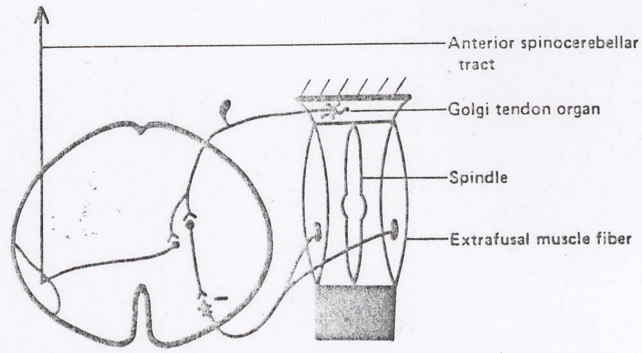


Fig 33-8. Central connections of Golgi tendon organ with motor neuron to its own muscle and with the cerebellum. The cell body of the secondary neuron that ascends in the anterior spinocerebellar tract is located in the base of the anterior gray and projects mainly to the contralateral anterior lobe of the cerebellum. Note that the polysynaptic pathway from the tendon organ is inhibitory to its muscle of origin.

cending processes project to the ipsilateral cerebellum via the dorsal spinocerebellar tract.

The Golgi tendon organ neurons make polysynaptic inhibitory connections with the motor neurons that innervate the muscle in which the organ is located (Fig 33-8). They also send collaterals to synapse on neurons in the anterior gray matter. These secondary neurons cross the cord and ascend in the ventral spinocerebellar tract to the contralateral cerebellum. The Golgi tendon organ functions to inhibit the contraction of its muscle when the tension in the muscle becomes excessive; it also probably plays a role in regulating the moment-to-moment tension in the muscle.

The interneurons of the spinal cord may be controlled by higher centers. They may be facilitated or inhibited so strongly that they become inexcitable by normal reflexive inputs. The central connections of the spindle secondary endings and Golgi tendon organs are polysynaptic, so it is possible that higher center activity could significantly alter input from these receptors. Phenomena such as emotional tension or depression may affect these higher centers so that polysynaptic local reflexes are grossly modified via their input at the local synapses.[70]

JOINT PROPRIOCEPTION

There are three types of receptors in and around joints that subserve proprioception. These include Golgi end organs, Ruffini endings, and Vater-Pacini corpuscles. The Golgi end organs are located in the ligaments of the joints. They adapt slowly and are relatively insensitive to movement. They fire in response to movements that tense the ligaments.[71]

The Ruffini (spray) endings are located in the joint capsules. These are also slowly adapting receptors, and their discharge rate varies with the angle of the joint (Fig 33-9). They serve as absolute detectors of angle and are directionally oriented around the joints so that different receptors are sensitive to joint rotation over ranges of 15° to 20° of arc. Many show their maximal steady adapted rates at full flexion or full extension. Others respond to angles in between, and their ranges overlap. By this type of activity the central nervous system is constantly afforded signals coded to indicate joint position. The Ruffini endings are more sensitive to movement than the Golgi end organs.

Vater-Pacini corpuscles are found in the pericapsular connective tissue. They are not numerous, and in one study of the innervation of a joint, only 7 of 121 units examined were Vater-Pacini corpuscles. These endings adapt rapidly and are very sensitive to quick movements and to vibration. They seem to serve as acceleration detectors.

Afferents from joint receptors synapse in the cord, and second order fibers ascend to the thalamus in the posterior column. Their tertiary neurons project to the contralateral sensory cortical areas I and II and to the ipsilateral sensory area II. These three receptors are believed to subserve conscious proprioception and do project to the sensory cortex.

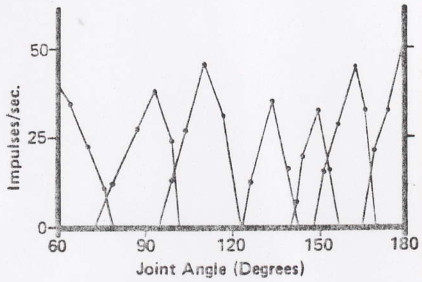


Fig 33-9. Response of seven Ruffini endings in a joint to movement of the joint through an angle of 120°. Note that response of any one ending is specific to a small range of joint angle, and it is silent outside this range. (Redrawn from Skoglund S: Acta Physiol Scand 36 (suppl 124):1, 1956.)

PROPRIOCEPTION IN THE STOMATOGNATHIC SYSTEM

The proprioceptive innervation of the stomatognathic system has a number of unique features. The human masseter muscle contains approximately 160 spindles, the temporalis muscle contains 217, and the medial pterygoid muscle contains 155.[72] The lateral pterygoid muscle contains only 2 to 18 spindles, and the anterior digastric muscle contains very few or no spindles.[73] Thus, there is a relative deficiency of spindles in the mandibular depressor muscles, while the elevators are richly supplied with proprioceptors. In spite of this imbalance, it has been shown that reciprocal activity of antagonistic mandibular muscles occurs in response to muscle stretching.[74] Mandibular elevators and depressors in the cat were freed from their insertions, and unit discharges were recorded in the trigeminal motor nucleus. It was found that unit discharges occurring when a mandibular elevator was stretched were inhibited when a depressor was stretched.

Stretching of the contralateral symmetric muscle also inhibits the recorded discharges from the ipsilateral muscle. This is seen in the limb innervation when the arms and legs move in opposite directions in walking and running. Even though the two sides of the mandible are firmly joined at the symphysis, its muscles show interactions that would allow independent unilateral function.

Cell bodies of the spindle afferents in the mandibular elevator muscles are found within the central nervous system in the mesencephalic nucleus of the trigeminal nerve (Fig 33-10).[53, 75, 76] One would expect these cell bodies to lie in the trigeminal ganglion, since all other primary proprioceptive cell bodies are located outside the central nervous system in the dorsal root ganglions. The functional significance of this aberrant location of the cell bodies is not known.

The capsule of the TMJ is richly innervated with proprioceptive nerve endings.[77–80] Golgi end organs, Ruffini endings, and Vater-Pacini corpuscles have all been identified in human TMJs, and studies in animals have shown that there are receptors in these joints that discharge continuously and others that discharge only during movement of the joints.[81] Subjects cannot position their mandible in a predetermined position with normal accuracy when one or both TMJs are locally anesthetized.[77] Studies in animals in which all muscles have been detached from the mandible have shown that mechanical stimulation of the joints or movement of the joints results in activation and inhibition of the mandibular muscles.[82, 83] Local anesthesia of the joints abolished the muscle responses. There is considerable evidence, therefore, that the TMJ receptors provide perceptual awareness of jaw position and movement.

Even though the mandibular depressor muscles are deficient in muscle spindles, the attachment of the lateral pterygoid to the TMJ meniscus is richly innervated with Golgi tendon organs.[84] Stretching of these receptors or mechanical stimulation of them could occur as the result of meniscus-condyle dyscoordination with or without joint sounds. Such stimulation would result in abnormal inhibition of the lateral pterygoid muscle and, therefore, mandibular muscle dysfunction; such muscle dysfunction is often observed in patients with deviations of the meniscus during jaw function.

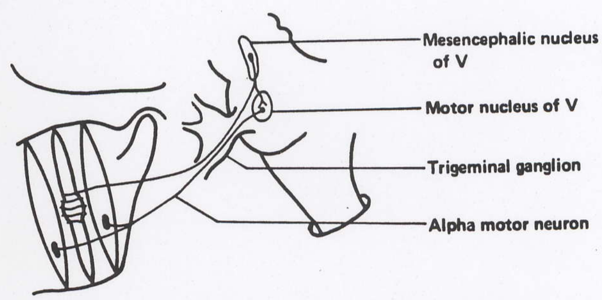


Fig 33-10. The central connection of spindle primary ending neuron with the alpha motor neuron in the masseter muscle. Note that the cell body of primary spindle neuron is not located in the trigeminal ganglion but is in the mesencephalic nucleus of cranial nerve V. The two neurons form the arc for the monosynaptic jaw jerk reflex.

A number of studies have demonstrated that the periodontal ligaments contain proprioceptors.[51–54] The proprioception neurons may innervate single periodontal ligaments or two or more adjacent ligaments.[85] The receptors are directionally oriented in the ligaments so that each one responds only to pressure applied to the tooth from one direction. When more than one ligament is innervated by a single nerve, all of its receptors respond only to pressure from the same general direction.

Tapping the teeth results in inhibition of the mandibular elevator muscles.[55, 86–89] A number of studies that did not demonstrate this effect conclusively created a controversy in the literature.[90, 91] However, when an electronically controlled mechanical stimulator was used to apply a nontraumatic tap to the upper central incisor, the masseter muscles were indeed inhibited.[55] This EMG silent period was abolished when the incisor was locally anesthetized and tapping of the canine on the opposite side continued to inhibit the masseters. It seems that in the studies that did not demonstrate the lack of inhibition with anesthesia of the tapped tooth, the uncontrolled tapping of the teeth had stimulated adjacent periodontal receptors or produced vibrations that activated muscle spindles or joint receptors. The teeth, which need protection from jaw closing forces, are provided with receptors designed to trigger this protection. Their sensory input reflexly inhibits jaw-closing muscles and activates jaw-opening muscles.

EFFECTS OF DENTAL THERAPY ON STOMATOGNATHIC PROPRIOCEPTION

A number of studies have demonstrated that mandibular arch width decreases when the lower jaw is protracted, depressed, or moved laterally.[92–95] An average convergence of 0.07 to 0.40 mm at the first or second molar region on wide opening of the jaws was reported. The decrease in arch width was greater at maximum protrusion, averaging 0.09 to 0.50 mm, and was least in lateral movement, averaging 0.1 mm.

When long-span fixed bridges are seated on the lower arch, stimulation of the periodontal ligament receptors resulting from jaw function is abnormal. When the lingual wall of the lower first molar alveolus moves lingually as a patient opens his mouth, the receptors in the periodontal ligament would be stimulated as though a lateral force from lingual to buccal had been applied to the molar. This decrease in arch width would not only act to abnormally stimulate periodontal ligament receptors but would also act to apply torque to bridge abutment teeth and break the cement seal of the teeth in their retainers. Splinting of any teeth, upper or lower, would serve to impose an unnatural condition on the receptors in the periodontal ligaments;[96] it would allow forces applied to distant teeth to affect the sensory input from abutment teeth.

Since extraction of the teeth eliminates the sensory input from the periodontal ligaments, it seems important to retain as many teeth as possible for removable prostheses or for overlay dentures when they are indicated. The placement of removable partial dentures also serves to apply abnormal forces from occlusion to the clasped teeth.

Experiments in animals have indicated that horizontal mandibular reflexes exist in mammals. Labiolingual forces applied to the central incisors of decerebrated rabbits result in a lateral movement of the mandible to the contralateral side.[97] If the forces are applied slowly, the lateral movement does not occur, so the reflex is probably initiated by a rapidly adapting periodontal receptor. Balancing occlusal interferences in human subjects can also initiate a lateral jaw movement. Schaerer, Stallard, and Zander placed fixed bridges in 3 subjects with balancing occlusal interferences.[98] Switches were positioned on the balancing interference and in the intercuspal position. Electromyographic records were also taken of the anterior temporalis, posterior temporalis, and masseter muscles bilaterally. Contact on the balancing interference demonstrated a prompt cessation of muscle activity in 40% of closures, followed by decreased activity in the ipsilateral temporalis and increased activity in the contralateral temporalis. Lateral movement of the mandible to avoid the balancing interference may be inferred from this study. Working side contacts elicited a reflex response in only 5% of closures. Goldberg has shown that the stretch reflex is significantly facilitated on the balancing side during lateral jaw deviation.[99] It seems that whenever a dentist alters the occlusal surface of a functioning tooth, he is modifying the proprioceptive input in the patient. Mandibular muscle spasms may rapidly disappear when occlusal interferences are removed.[49] Patients vary in their acceptance of dental restorations and prostheses even when the therapy appears to be properly done on close examination. Alteration or loss of proprioceptive input may serve to incapacitate patients differently. Patients may use the sensory input from the periodontal ligaments, the TMJ, or the muscle spindles in different ways so one is disadvantaged more than another when a dental prosthesis becomes necessary.

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