The physiology of splint therapy: a literature review

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Interocclusal orthopedic appliances or splints are routinely used in the treatment of disorders of the temporomandibular joint (TMJ) and masticatory system. Hard or soft removable acrylic appliances covering the teeth have been used to eliminate occlusal disharmonies,[1,2] prevent wear and mobility of the teeth,[3,4] reduce bruxism and parafunction,[5,6] treat masticatory muscle dysfunction,[7-10] and correct derangements of the TMJ.[11-13] Mandibular orthopedic repositioning appliances (MORA's) have been recommended for increased strength and athletic performance.[14-16]

A reduction of pain with splint therapy is well documented. Many studies[13,17-20] have reported resolution of symptoms after insertion of a splint. Clark, in an excellent pair of articles published in 1984, reviewed the design, theory and effectiveness for specific symptoms of orthopedic interocclusal appliances. He reviewed studies in the literature through 1980 and pointed out that in general there is 70-90 percent rate of clinical success in treatment of temporomandibular dysfunction with splints. While the treatment effect is predictable, the explanation of the physiologic basis of the treatment response is less understood. It is the purpose of this paper to review the types of splints and examine their effect on muscle behavior, tooth changes and TMJ function.

Splint types

This author has selected the stabilization splint, the repositioning splint, the pivot splint and the soft splint for review. A list of additional splint types, descriptions of their designs, alternate names and common usages are included in Table I. The four basic types covered here represent those used in most studies evaluating the clinical success of splint therapy. Pertinent pap-

Abstract

The clinician must frequently make treatment decisions with limited knowledge of the appropriateness and consequences of the different options. Patients have specific expectations: that the treatment they receive is the usual one, that they have been informed of the alternatives and the consequences, and most importantly that the treatment has a reasonable chance of success. In TMJ therapy, as with most treatments, the patient's improvement is closely connected to a proper diagnosis based on sound physiologic principles. This investigation will review four basic splint types and discuss their success in the resolution of various temporomandibular disorders. Since the position of the condyle-disc-fossa, the occlusal contact pattern and the masticatory muscle dynamics are interrelated, this study will focus on the physiologic changes splints may cause with modification of this tooth, joint and muscle relationship. Hopefully, selection of a specific splint design appropriate to the patient's disorder will be facilitated by better understanding of its physiologic and therapeutic effects.

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Key Words

Bruxism • Repositioning • Vertical dimension • Occlusal pattern • Masticatory muscle function

ers examining the results of clinical use of each type splint will be discussed.

Stabilization splints

Stabilization splints are commonly used for treatment of masticatory dysfunction signs and symptoms such as muscular pain, TMJ pain, clicking, crepitus, limitation of motion and incoordination of movement. This type of splint is constructed with even posterior occlusal contact in centric relation with the condyles "seated", separation of posterior teeth in protrusive or lateral movements (anterior disclusion) and canine rise in lateral excursions. It can cover the maxillary or mandibular dentition.

In a typical study Carraro and Caffesse[21] described the response of 170 TMJ patients treated only with a full coverage stabilization splint. The splints were worn full time, except for eating, and covered the maxillary or mandibular dental arches. Eighty-two percent of subjects responded favorably to the splint therapy. Symptoms of TMJ pain, muscle pain or dysfunction all improved. Thirty-seven percent of the patients were cured and 45 percent improved. Pain symptoms were significantly more likely to be cured than dysfunction symptoms. Clicking was the most difficult dysfunctional symptom to eliminate.

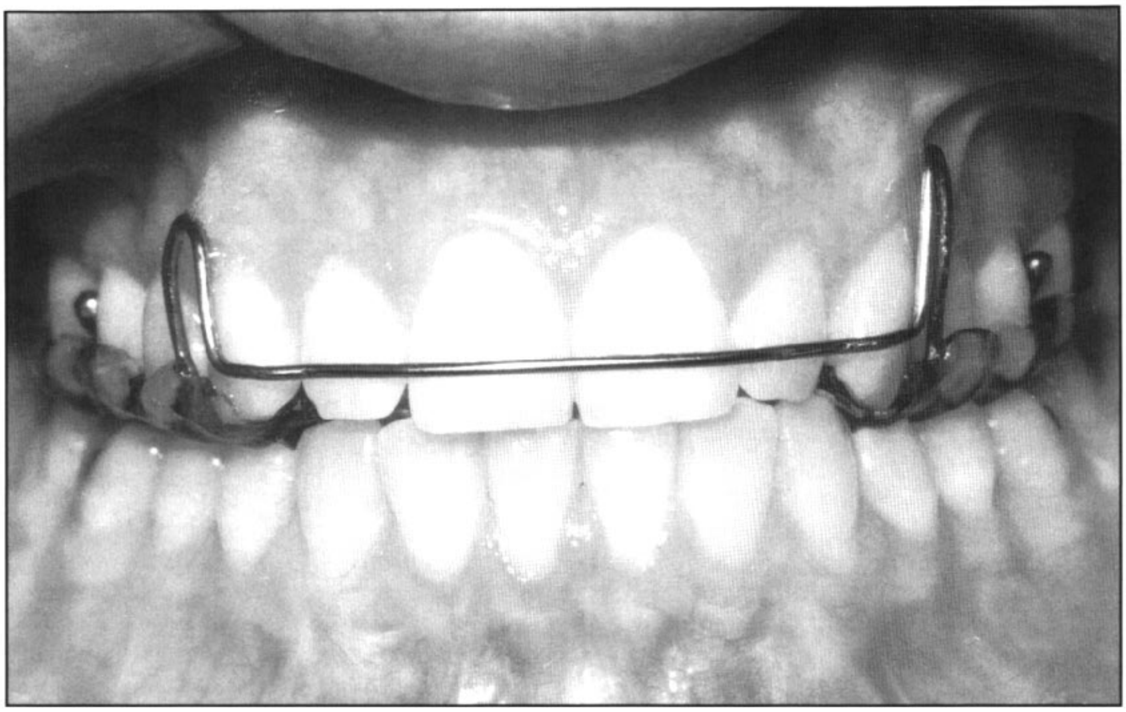
Thirty-three patients selected from a TMJ clinic population seeking treatment for pain, where the muscle or joint pain could be elicited by palpation, were evaluated by Okeson, et al.[22] They were treated for one month with a maxillary stabilization splint. Pain responses of individual muscles and the TMJ were scored. Interincisal opening was measured. Twenty-eight of 33 (85 percent) showed a decrease in observable pain scores. Maximum comfortable interincisal opening significantly improved while maximum interincisal opening did not change. Patients with chronic pain (six months or more) had the same improvement as the acute patients. There was no significant difference in symptoms between acute and chronic subjects.

Repositioning splints

Along with change in tooth contact and muscle function, splints can influence the temporomandibular joint. The proper position of the condyle to the meniscus and fossa is generally thought to be necessary for normal function. While there is some variation in condylar position in an asymptomatic population,[23,24] derangement of the disc with displacement of the condyle is implicated in disturbances of motion and degenerative joint changes. Splints may affect the joint in two ways: alter the stress or loading of the joint, and recapture or change condyle-disc-fossa position.

Most clicking is caused by a rapid change in position of the condyle or disc sometime during condylar translation.[25] Since the direction of pull of the external pterygoid is anterior and medial, in derangements the meniscus is usually dislocated forward and inward. Conceptually, keeping the mandible forward with a splint would "recapture" the normal disc-condyle orientation and eliminate the clicking. The initial enthusiasm for repositioning was supported by studies show-

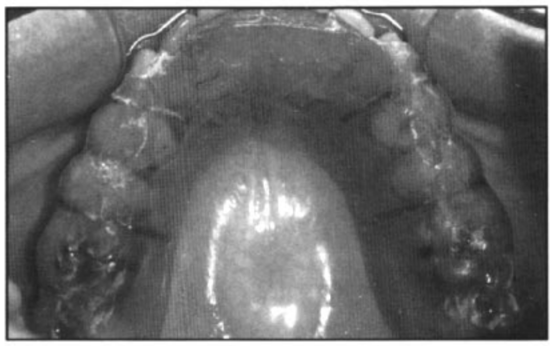
Repositioning splint



ing good clinical success.[9,25] Clicking was eliminated in 66-86 percent of the patients treated. Comparisons with flat plane splint treatment showed the superiority of repositioning appliances.[26,27] Longer term studies have now been published.

Lundh and Westesson[28] set up a prospective study to test the effects of an anterior repositioning splint on patients (n=24) with reciprocal clicking. The results were compared with those of a flat occlusal splint (n=23) and with no treatment (n=23). Clicking, palpatory tenderness and pain were rated. These ratings were made before treatment and at six, 17, and 52 weeks. The repositioning splints were worn full time for six weeks, then phased out. Pain was reduced and the clicking was eliminated initially with the repositioning. Tenderness improved but the clicking was unaffected in the flat plane group. However, at 17 weeks clicking returned in 18 of 24 repositioned subjects (74 percent). These questions remain: were the discs really recaptured and if so, is six weeks sufficient time for permanent stabilization and repair? It is also possible that the occlusal position was not stable enough to maintain disc position after the splints were discontinued.

Increasing the length of the splint therapy does not improve the treatment result. Following six months or more of active repositioning splint therapy control of noise and pain was achieved in 70 percent of 241 patients.[29] Fifty-three percent were successful after two years, and by the end of three years only 36 percent



were successfully treated. The later the click occurred in opening, the poorer the long term prognosis. Fourteen of the successfully treated cases were occlusally reconstructed and 34 had orthodontic treatment to maintain the altered jaw position. Forty-three percent of the restored patients and 50 percent of the orthodontic patients had return of clicking.

Lundh and Westesson[28] followed 15 patients for three years who had occlusal changes to maintain the disc in the recaptured position. Eleven were prosthodontically restored and four had orthodontic treatment. Radiographic examination of 11 patients post-repositioning showed that the condyle was frequently anterior and inferior in the fossa. Arthrograms revealed the disc in the correct relation to the condyle in nine of the 11 patients (82 percent). In a previous study by Lundh et al.,[27] cemented onlays were much superior to flat plane splint therapy, but the symptoms returned when the onlays were removed six months later. The authors suggest that permanent change in the occlusion may be key to effective treatment and account for the high incidence of success compared to Moloney and Howard.[29]

In a sample of patients with painful clicking on opening, closing or both, Tallents, et al.[30] described the results of examination with arthrograms and arthrotomograms in 141 joints. Fifteen percent of the clicking joints had meniscus displacement without reduction. In this subgroup, condylar translation was normal and mandibular movement patterns were not unusual. One would normally expect no noise with a non-reducing disc. Surgical exploration on four patients revealed adhesions, condylar grooves, soft tissue abnormalities and/or osteophytes. The same investigative group[31] reported that of 72 joints with clicking, only 53 had arthrographic evidence of a reducing meniscus. Of the 53, 41 would be candidates for repositioning (57 percent of the clicking joints). These reports suggest that not all clicking patients are candidates for repositioning therapy and that clicking is not always caused by a displaced disc.

Ronquillo and the group at Eastman Dental Center[32] studied the relationship between the pretreatment position of the condyle in the fossa to unsuccessful protrusive splint therapy. Of 142 patients with internal derangements, 72 were arthrographically confirmed to be suitable for repositioning therapy. The initial condylar position was measured on CO tomograms. The patients were followed from six months to five years. Seventy-one percent of the patients in the sample were successfully treated while 29 percent had return of clicking, locking and/or return of pain. Whether the condyle was anteriorly, centrally or posteriorly positioned before splint therapy had no bearing on the success of treatment.

Okeson[33] took a retrospective look at 40 patients treated for eight weeks with anterior repositioning splints. All patients had a primary diagnosis of a disc-interference disorder: disc displacement associated with distinct single joint sounds (n=25), a history of locking with recapture (n=8), and permanent dislocation (locking without recapture, n=8). After eight weeks of therapy 80 percent of the patients were free of pain, clicking and locking. The splints were phased out with a step-back procedure. No occlusal changes were attempted. Two and one-half years later 66 percent of the successfully treated patients had a return of joint sounds. Twenty-three percent reported joint pain. The average maximal interincisal opening improved from 37 millimeters to 43 millimeters. Eighteen percent had decreased opening. This study would conclude that repositioning therapy permanently resolves joint sounds only one-third of the time but reduces long term pain three-quarters of the time.

The author used the same data to evaluate success under differing criteria. The success rate was 25 percent if the patients were free of pain, clicking and locking. Accepting painless joint sounds, the success rate was 55 percent. Seventy-five percent were successful if only pain resolution was considered and 80 percent were better according to the patient. Therefore, if resolution of pain is the primary objective, repositioning has a good long term prognosis. If elimination of all signs of dysfunction is the goal, repositioning splint therapy is of limited value.

The group at UCLA's TMJ clinic[19] did a prospective study of treatment results related to the initial diagnosis. Patients were divided into three diagnostic subcategories: predominantly clicking with full condylar translation, restriction from osteoarthritis or locking, and myalgia without clicking or joint pain. Treatment method was based on the diagnosis. All patients received physical therapy. Clicking patients were repositioned; restricted and myalgia patients got stabilization splints while some nonbruxing myalgia patients and restricted patients received physical therapy only. Fifty-seven patients elected treatment and 15 did not. All received the same pretreatment instructions. The outcome 19 months after treatment was evaluated based on the patients' self-assessment of symptom improvement. Overall, 77 percent of the treated individuals reported improvement, while 33 percent of the untreated group reported improvement. The repositioning group reported less success than the other groups. As a result of the frequent failure to eliminate clicking long term, the authors have altered their treatment protocol. They are not requiring full time repositioning splint wear, and patients are informed that clicking will probably continue.

The enthusiasm and the high success rate reported initially for anterior repositioning is not supported by carefully controlled long term studies. Successful recapture of a displaced disc depends on readaption of stretched or torn ligamentous attachments and repair of the retrodiscal tissue. The disc displacement may also be of a type that is impossible to recapture.[34] Return of clicking after successful treatment means that the joints are not repairing themselves or that the original clicking was not caused by disc displacement.

Soft splint

Pivot splints

Treating an injured or painful articulation with traction is common in physical medicine. The pivot splint is a hard splint with single posterior contact on each side. The contact is usually on the most posterior tooth. If the mandible rotates forward around the fulcrum of the pivots, the condyle is distracted from the fossa and the joint is unloaded. Theoretically, unloading should be desirable in patients with internal derangements and intracapsular inflammations. In the craniofacial configuration of most patients the elevator muscles lie on or posterior to the most distal tooth. Therefore, contraction of the closing muscles does not result in joint unloading. The closing vector must be anterior to the pivot.

Lous[35] published the results in a study of 60 clicking patients treated with pivots. Previous traditional treatment methods had been unsuccessful. In these cases splint wear was supplemented with vertical pull headgear attached to a chin strap. The average treatment lasted three to four weeks with a three month follow-up. Seventy-two percent of the patients had elimination of symptoms. Seventeen percent had improvement but reoccurring symptom episodes.

Additional controlled studies of the pivot appliance are lacking. Because of the limited occlusal contact with this splint there is a possibility of change in tooth position. The clinician has better control of the occlusion with a full coverage splint. For treatment of internal derangements the anterior repositioning splint would give the therapist more control over condylar position. If joint unloading is the object of therapy, auxiliaries must be considered.

Soft splints

Soft, resilient splints are easily constructed. They may even be prefabricated. Their value for protection from trauma in athletics is well substantiated; their use to reduce parafunctional clenching and grinding is not. Harkins and Marteney[36] tested prefabricated soft splints (a modified Doubleguard appliance) in one-half of a sample of 84 dysfunction patients who had clicking and pain. The other half served as controls. The splints were worn full time for 10-20 days. Ten percent of the patients stopped clicking, 64 percent had less clicking, seven percent increased and 19 percent had no change. Myalgia did not change or worsened in 26 percent of patients. Minor occlusal changes were noted in 67 percent. There was no change in the controls. Okeson[37] tested the response of a soft splint and a hard splint on the same bruxing patient. (See section on Bruxism for complete discussion.) Soft splints might be useful on a temporary basis for relief of symptoms but because of the resilient material, adjustment of the occlusal contacts is difficult. Also, uncontrolled changes in tooth position may occur.

Conclusions

1. Stabilization splints are very successful for relief of symptoms, especially myofascial pain.
2. Pivot splints have limited application, but if

Splint Types

Outlined are the various types of splints, their design characteristics, additional names and common usages.

Bite plane splint:

Design: A maxillary or mandibular hard splint allowing contact of only one or more anterior teeth. The posterior teeth do not contact.

Other names Anterior jig, Luca jig, Hawley with biteplane or anterior deprogrammer.

Usage: Interrupt mandibular position sense, eliminate proprioceptive feedback from the posterior teeth and/or reduce muscle activity.

Hydrostatic splint:

Design: Fluid filled reservoir covering the teeth.

Usage: Equalize biting pressure.

MORA: (mandibular orthopedic repositioning appliance)

Design: Hard, mandibular posterior coverage splint usually with a lingual bar connecting the posterior segments.

Other names: Gelb splint.

Usage: Increase strength and athletic performance, change posterior occlusal contact, eliminate anterior tooth contact or restore vertical dimension.

Pivot splint:

Design: Mandibular splint with occlusal contact only on the most posterior tooth. May be unilateral or bilateral.

Usage: Unload the TMJ or stretch the joint. May be used in conjunction with vertical pull chin cup.

Soft splint:

Design: Resilient material. Full coverage.

Other names: Positioner, mouthguard, nightguard.

Usage: Treatment of myofascial pain dysfunction and bruxing. Emergency appliance.

Stabilization splint:

Design: Maxillary or mandibular full coverage incorporating even posterior contact at closure, anterior disclusion and canine guidance or group function in lateral excursions with no balancing side contacts. Usually constructed to centric relation position.

Other names: Flat plane, Shore (maxillary), Tanner (mandibular), superior repositioning, muscle deprogramming, or centric relation splint.

Usage: Multiple. Treatment of muscle and joint pain especially from occlusal contact discrepancies or parafunctional habits. Mandibular position deprogramming. Vertical dimension alteration.

Repositioning splint:

Design: Maxillary or mandibular hard splint with cuspal indentations or inclines to guide the mandible to a predetermined position.

Other names: Anterior repositioning, LARS (ligated anterior repositioning), orthopedic positioner.

Usage: Alter condylar position at occlusal contact, meniscus dislocation recapture.

used with the appropriate auxiliaries, can unload the TMJ.
3. Soft splints have no advantage over hard splints and are difficult to adjust. They can cause tooth position changes and increase parafunctional muscle activity (see Bruxism).
4. Clicking may be due to a derangement that cannot be rehabilitated with condylar repositioning.
5. TMJ clicking that has been initially eliminated with splint therapy has a good chance of reoccurring.
6. Reported success with splint therapy must be evaluated by the criteria used to define successful treatment.
7. Permanent change in the occlusion to maintain the altered disc-to-condyle relationship may improve success in repositioning therapy.

Occlusal changes

The nature of the occlusal scheme and specific tooth contact influences behavior of the muscles. Various tooth contact patterns and their effects on EMG amplitude and firing sequence have been studied.[38-45] The splint therapist has control over which teeth contact in the various mandibular functions. It is important to understand the changes in muscle behavior that accompany alterations in occlusal patterns so that better decisions can be made in the design of a splint.

Voluntary maximum clenching in humans was investigated by Wood.[45] With cemented maxillary splints adjusted for different tooth contact patterns, he monitored the activity of the masseter, the anterior temporal and posterior temporal muscles. Clenching with full contact of all teeth on the splint increased EMG activity 17 percent, predominately in the masseter. When the splint was reduced so that there were no contacts from the central incisor to the first molar on one side, he found no change in muscle activity. If the second molar occlusal contact on the same side was removed, electrical activity dropped 20 percent. Some subjects reported discomfort during the clench in the joint on the side with no contact. EMG activity decreased 13 percent with only canine to canine contact.

Miralles[46] showed similar results with a three-piece maxillary splint, sectioned between the lateral and the canine. One section covered the centrals and laterals, the others covered from the canine to the second molar. The elevators on one side were monitored with bipolar surface electrodes during clenches of four second duration. Elimination of bilateral or contralateral posterior sections of the splint decreased activity of the masseter and anterior temporal muscles, while ipsilateral removal had no effect. Removing the anterior section only had no effect. It is apparent that in centric relation with maximal clenching, the location of teeth in contact has more influence than the number of teeth.

The symmetry of muscle activity was tested at 10 percent and 50 percent of maximal clench by McCarroll.[47] When EMG clenching in intercuspal position on a retruded contact stabilization splint was compared with the same clench on a one-millimeter laterally repositioned splint, there was significant asymmetry of anterior temporal function in the lateral position. The masseter remained symmetrically active if there were bilateral, stable occlusal contacts even though the jaw was positioned laterally. In another study of 36 patients with muscle pain, delivery of a stabilization splint immediately improved masseter symmetry.[48] The changes in masseter symmetry were especially evident at clenching levels of reduced intensity.

Different occlusal protrusive functions also influence elevator muscle activity. Miralles[46] adjusted a flat plane maxillary splint to protrusive group function with no posterior contact and canine guidance in laterotrusive. He cut the splint into three sections between the laterals and canines. By removing different sections he could test protrusive group function against canine contact only, and against incisor contact only. If maximum voluntary CO clench represented 100 percent EMG activity, a protrusive clench with group function had 57 percent of maximal EMG for the masseter and 36 percent of the anterior temporal. The percentages when only the canines contacted was slightly less. If protrusive contact was limited to the four incisors, activity reduced further. If only the mesioincisal of the centrals functioned, maximal protrusive clench activity was reduced to 31 percent for the masseter and 18 percent for the anterior temporal.

Protrusion reduces elevator muscle activity but the number of teeth contacting appears to be the most significent factor in this reduction. Whether muscular inhibition emanates from the TMJ, the muscles or the periodontal membrane is unclear. In cats, stimulation of the pressure sensors in the periodontal membrane leads to a jaw opening reflex.[39] Bruxing may override normal neuromuscular feedback so muscle activity may not be reduced.

The clinical benefits of anterior guidance were demonstrated by Williamson and Lundquist.[49] A splint limiting excursive contacts to the anterior teeth shut down the masseter and anterior temporal activity that normally occurred with posterior tooth contact. They concluded that anterior guidance was necessary to reduce muscle activity. However, in their experiment the variable of change in vertical dimension with the splint was not controlled.

Shupe, et al.[50] compared flat canine guidance, steep canine guidance and group function. They tested the EMG activity of maximum voluntary clench, maximum voluntary grind and chewing. Surface electrodes were placed on the masseter and anterior temporal muscles in nine subjects. The occlusal schemes were developed in random order on a thin maxillary acrylic splint. During lateral clenching and grinding the EMG activity was lowest when the splint had steep canine guidance, nine percent less than flat canine guidance and 38 percent less than group function. The anterior temporal was more active in excursions than the masseter which is consistent with its normal function. Subjects chewing gum also produced the least EMG activity with steep canine guidance and the most with group function. As with Williamson, the investigators suggest that canine protected guidance would be the choice to reduce forces to the teeth.

Belser and Hannam[38] introduced a canine onlay in a group of subjects with naturally occurring group function. There was a general reduction in elevator activity with maximal isometric clenching in lateral position. In contrast to Shupe the muscle activity with gum chewing was unaffected.

Canines seem to have some special proprioceptive function that reduces muscle activity. To test the uniqueness of canine function, Graham and Rugh[51] compared canine guidance with molar guidance. They constructed maxillary splints identical in vertical dimension and centric occlusal contact. One splint had contact only on the canine in lateral excursion while the other had only molar contact. The EMG activity of the masseter and temporal was monitored while clenching in CO, during lateral excursion and clenching in lateral position. Both guidances reduced activity during lateral movement by an average of 81 percent. Maximum lateral clenching was reduced 43 percent. There was no statistical difference in EMG activity between canine and molar guidance. The large reduction during lateral movement versus less reduction during stationary lateral clenching may be due to central neural commands relaxing muscles allowing the jaw to open and move.

Unfortunately most splint studies have been limited to surface electromyography. By use of intramuscular electrodes the activity is known for all of the masticatory muscles during normal function. Prediction of the response of other than surface muscles to the occlusal alterations with splints should be fairly reliable.

The following principles based on the above studies would apply to the use of different occlusal schemes in splint therapy:

1. Bilateral, even contact allows maximal muscle effort, balances right and left muscle contraction and reduces pain of muscle origin.
2. Reducing the number of teeth in contact does not reduce clenching effort if bilateral balance is maintained.
3. In protrusive and lateral function, reducing the number of contacting teeth reduces muscle activity.
4. The anterior-posterior location of the working side tooth contact in lateral excursions is not the critical factor in reducing muscle activity.

Vertical dimension

Most splints alter the vertical dimension of occlusion and increase the functional length of muscles. The muscular length that develops maximum tension is defined by physiologists as the resting length. A fiber's isometric tension is enhanced by elongation and loading.[52] Different mammals show peak tension at the same sarcomere length (two to three micrometers between Z bands).

Manns[53] measured the masseter EMG at constant force and the force produced at constant EMG with changing vertical dimension measured at the anterior teeth. An interocclusal distance of 15-20 millimeters required the least EMG activity to produce a given force or generated the greatest force at a constant EMG level. Muscle activity increased at vertical dimensions above and below this functional length. The dome-shaped curve generated in the length/tension measurements is typical of mammalian skeletal muscle.[52] Each individual, therefore, had a vertical dimension of maximum muscle efficiency greater than that of occlusal contact.

It has been assumed that clinical rest position (postural position) would be the vertical dimension of minimal muscle effort. In other words the elevator muscles would be the most relaxed at clinical rest. Rugh and Drago,[54] using surface electrodes and a kinesiograph, determined that the mean vertical of minimal masseteric activity was 8.6 millimeters between the anterior teeth. The average postural position was 2.1 millimeters. Testing the masseter, posterior temporal and anterior temporal over the full range of mandibular opening, Manns[55] showed the minimal EMG activity of the temporals at 12 millimeters and the masseter at 10 millimeters. So as the vertical dimension increases from occlusal contact, muscular effort decreases. Presumably at the opening of minimal EMG, passive tissue stretch maintains mandibular position. With greater opening, stretch receptors become activated and muscle contraction increases.

When a splint is inserted there is an adaptation to a new resting postural position. In an interesting experiment with ten mandibular dysfunction patients Hellsing[56] measured the instantaneous changes in resting vertical dimension with a sequence of splint manipulations. He determined the vertical dimension before the insertion of a six millimeter thick splint, after one closure, after adjustment and repeated closures; then after removal with no closure, one closure, and multiple closures. The mean postural interocclusal distance of 2.8 millimeters before placement of the thick splint was reestablished at 1.3 millimeters after only one closure on the splint. Even though the occlusal contact vertical was increased six millimeters the freeway space was reestablished. The increased postural position was maintained with splint removal until the teeth were allowed to touch. After one contact the interocclusal distance returned to three millimeters. In Carlsson[57] the freeway space was immediately reestablished with cementation of a four millimeter bite raising mandibular splint and the postural activity of the anterior temporal muscle was reduced. Because muscle function changes instantaneously with tooth contact, periodontal afferent feedback must be responsible for this immediate adaptation. It is also noteworthy that not only the level of muscle activity during occlusal contact changes with vertical dimension but the postural muscle activity is also affected.

Introduction of a splint usually increases the vertical dimension. The instantaneous changes that occur in muscle behavior can be summarized as follows:

1. The elevator muscles are more efficient at a functioning length greater than the vertical dimension of occlusion.
2. The postural position of minimal muscle activity is at a larger vertical than clinical rest position.
3. Interocclusal splints that increase the occlusal vertical dimension beyond the freeway space cause an immediate adaptation to a new freeway space at an increased vertical dimension.
4. The EMG activity of the postural muscles (anterior temporals) is reduced with an increased vertical dimension of occlusion.

Therefore, the increase in vertical with a splint allows a muscle to function more efficiently during contact and be less active during postural functions. Furthermore, if TMD symptom relief is related to muscle activity reduction, then a thicker splint should have greater therapeutic effect. Manns[58] treated a sample of 75 TMJ pain patients with flat plane splints of one millimeter, four millimeters, and eight millimeters in thickness. While splint thickness had no relationship to clicking reduction, the thinner splints took longer to reduce the pain symptoms.

Splint-induced changes in the resting posture and reduction in muscle activity occur quickly (one week or less). Adaptive changes may occur with long term increases in vertical. Increase in a muscle's length, for example, with growth, stimulates addition of sarcomeres to the myofibril. In the cat and the rat, sarcomeres are added within three to four weeks.[59] Splint therapy may have a similar effect. Long term increase in vertical dimension may change a muscle's anatomical configuration.

It is also possible that when the vertical facial dimension is increased teeth are intruded in an attempt to reestablish the original facial dimension. Orthodontic extrusion of teeth to increase vertical dimension in some facial types, especially in nongrowing patients, is not always stable. There are some undocumented case reports[60] of iatrogenic intrusion of posterior teeth with Gelb-type splints. In an experiment with five adult Rhesus monkeys Ramfjord[61] used metallic implants in the teeth and alveolus to document long term changes with maxillary posterior flat plane splints (MORAs) that opened the bite seven millimeters (four millimeters at the molars). Cephalograms were taken before and after splint insertion and at autopsy. The animals were sacrificed from three to 36 months after insertion of the splint. In all animals the open bites closed within seven months. The maxillary incisors erupted 0.5-1 millimeter, the mandibular incisors 1-2 millimeters. Simultaneously the mandibular premolars intruded 2-2.5 millimeters, the mandibular molars 1.5 millimeters and the maxillary molars 0.5 millimeters. Most of the anterior open-bite closure occurred by intrusion of posterior teeth. The skeletal vertical returned toward the original dimension. The return to the original anterior skeletal dimension ranged from 40-90 percent of the splint increase. Changes after seven months continued but were slower. It is probable that long term splint wear in humans would show similar adaptations. Dental changes with full coverage splints have not been reported.

Bruxism

Bruxism may be defined as clenching or grinding of the teeth when the individual is not chewing or swallowing.[6] Parafunctional clenching and grinding is considered one of the common etiologic factors in temporomandibular dysfunction. The forces that can be generated with clenching can be incredible. In normal subjects the maximum biting force averages 162 pounds. During the tooth contact phase of mastication the mean force across teeth is 60 pounds.[62] The highest measured force in one bruxing individual was 975 pounds.[63] Therapists have long advocated the use of splints in treating myofacial and TMJ symptoms in patients who brux.[64] Wearing a splint will reduce tooth wear, but what is the effect of a splint on parafunctional activity? Do splints reduce or eliminate bruxing episodes, and do they alter muscle activity? Development of new technology to monitor muscle activity over long periods of time[6,65] has enabled investigators to study the effects of different therapies on bruxing activity. Below is a review of some recent studies of splints and bruxism.

How frequent are the bruxing episodes at night, and how long do they last? Fuchs[65] demonstrated that the masticatory muscles are more active than other muscles during sleep and as the depth of sleep increases muscle activity decreases. Clarke, et al.[13] with a small sample of 10 normal subjects and a good experimental technique, provided data on clenching during sleep. Any activity of the temporal or masseter muscles longer than two seconds was recorded with surface electrodes for seven nights. The experimental method excluded ordinary jaw movements and possibly grinding. The intensity of the EMG signal was compared with the maximum voluntary clench before sleep and upon awakening. Bruxing frequency ranged from 0-17 episodes per night with an average of five. The average duration of the muscle activity was 7.8 seconds with a range of 3-17 seconds. In intensity the average brux was 28 percent of maximum P.M. clench and 51 percent of the A.M. clench. In two subjects the force of bruxing exceeded the maximum voluntary clench. Four subjects had nights of no muscle activity.

Typically in bruxers there are short three to six second bursts of EMG activity followed by longer bursts of 80-90 seconds.[52] The contractions are bilateral and symmetrical.[66] To completely understand the change in bruxing activity with splint therapy one must evaluate the frequency and dispersion of bruxing episodes per night, the magnitude of the muscle contraction during each episode and the duration of that contraction. In some individuals the forces generated and the duration of a bruxing episode can produce considerable loads within the masticatory system.

The exact etiology of pain in myofacial dysfunction is unclear. Pain that occurs within a muscle that is the result of that muscle's contraction results from two different physiologic processes. Pain may appear with exhaustion or be delayed. Muscle contractions are classified in three ways: isometric, concentric or eccentric.[52] Concentric and eccentric contractions are dynamic; that is muscle length changes. With concentric contraction there may be shortening of muscle fibers and the production of positive work. Fibers lengthen while contracting and negative work results during eccentric contraction. Christensen, Mohamed and Rugh[67] studied isometric contractions of the masticatory muscles by having subjects execute a series of maximum voluntary clenches until exhaustion. The isometric endurance decreased with each episode. All tests elicited intolerable pain. The cause of pain at exhaustion was not identified but was ascribed to unknown chemical substances in the interstitial fluid. Other studies[52] show limited ischemia occurs during contraction but flow resumes as tension drops with fatigue. The pain is not the result of the buildup of lactic acid. Rapid recovery ensues with the cessation of contraction. The exhausted muscle may be stiff and tremble during recovery but the pain disappears quickly. Chronic lesions are not induced and the muscle quickly returns to normal.

Injury occurs in the contractile and non-contractile parts of the muscle with eccentric contractions. The resulting pain is typical after unaccustomed physical activity. This myofibrocytis is clinically characterized by diffuse pasty swelling or localized hard nodules (trigger points). On biopsy there is no evidence of ischemia but sub-microscopic morphological changes in the myofibril.[68] Pain appears 8-72 hours later (delayed muscle soreness). There is no spontaneous EMG activity in the resting, painful muscle and no so-called localized muscle spasms. The painful connective tissue shows typical histologic inflammation and edema.[52] Muscle repair occurs in three to four days.

Eccentric contraction in the masseter and lateral pterygoid can be experimentally induced. Christensen[69] determined the EMG activity of the masseters during voluntary grinding. The masseter showed negative work during laterotrusion and positive work during mediotrusion. The amount of negative work was determined by the amount of opening which is effected by cusp angulation. Steep cuspal inclines or a deep overbite might change the dynamic grind to a static clench. Both bellies of the lateral pterygoid are active during voluntary grinding. EMG with needle electrodes show that the inferior head of the lateral pterygoid on the contralateral side undergoes eccentric contraction during mediotrusion.

What happens with a splint? Initially Solberg, Clark and Rugh[70] showed dramatic reduction in total EMG activity per hour per night in eight bruxing patients during short term splint therapy. The masseteric EMG was recorded for twelve-plus nights before, 12-16 consecutive nights during, and 6-10 nights after splint wear. All patients showed an immediate reduction in EMG activity. The mean nightly reduction ranged from 14-60 percent of pretreatment levels. Activity returned to pretreatment levels for most subjects immediately after the splints were discontinued.

Kydd and Daly[71] compared 10 bruxing patients from the TMJ clinic with 10 control patients. The bruxing was evident by soreness in the morning and confirmed by a sleeping partner. The patients were monitored at home for masseteric EMG, EKG and body movement. Clenching or grinding could be identified with bilateral EMG electrodes. A full maxillary occlusal splint, two to four millimeters thick, was constructed for each bruxer. Activity during sleep was recorded for three nights before splint insertion and again for three nights after two weeks of splint wear. The controls had a mean total duration of rhythmic clenching of three minutes while the bruxers clenched 11.3 minutes (range 3-16 minutes). There was a significant increase in heart rate with each bruxing episode, but no association with body movement. The combined duration of bruxing with a splint was no different than the duration without a splint. Because the patients were not tested with the splints in place, it is unclear what happened to the EMG activity during splint wear. It is possible that bruxing was reduced with the splints and returned to pretreatment levels immediately with splint removal. If so, these results would be consistent with Solberg's[70] pre- and post-splint data. Interestingly, all subjects reported more comfort while using the splint.

Sheikholeslam, Holmgren and Riise[72] followed thirty-one patients with functional disorders and nocturnal bruxism for three to six months of maxillary flat-plane splint therapy. They found, as expected from most evaluations of splint therapy, significent improvement in the signs and symptoms of dysfunction (87 percent). EMG postural activity in the anterior temporal and masseter muscles were made in daytime recording sessions before splint insertion and after splint removal. There was a significant reduction of postural activity of the muscles at rest and the activity in the right and left anterior temporals was more balanced after the therapy. Since the splints were worn only while asleep, the change in daytime function must have been due to something happening differently at night. Whether the change occurred because of altered occlusion or altered nocturnal muscle activity was not determined. It is possible that a patient in pain would need more postural activity to maintain a comfortable position. The signs and symptoms returned to pretreatment levels within one to four weeks after cessation of splint therapy.

Okeson[37] tested the nocturnal bruxing response of the same person with a hard versus a soft splint. Ten bruxing subjects without symptoms were monitored nightly with single surface electrodes to the masseter muscle: five nights before, seven nights with one splint, five more without a splint, seven with the other splint and finally five more nights without a splint. Single clenching episodes were not identified. The hard maxillary stabilization splint and the soft vacuum-formed splint were carefully constructed to the same vertical dimension. Compared with the control periods, eight of 10 subjects had significant decrease in muscle activity wearing the hard appliance. When the soft splint was worn, five of 10 showed an increase in activity. Only one decreased. While the results with the hard splint were consistent with other studies, use of a soft splint may not be indicated for reducing parafunctional activity in patients with symptoms. Currently there is no adequate explanation why a soft splint would produce a different response than a hard splint. The occlusal contact pattern and proprioceptive feedback during tooth contact with the soft material is probably different.

Hamada et al.[73] used EMG recordings of the masseter and temporal to determine the effectiveness of splint therapy by plotting EMG activity versus the muscular tension produced. They selected 15 bruxers from a sample of bruxing patients with masticatory muscle tenderness. On three separate occasions during the day investigators plotted the forces generated for different EMG levels. The dysfunction patients were retested the same way after wearing maxillary stabilization splints and all symptoms had improved. They were compared with 20 normal subjects. Pretreatment, the bruxers required more EMG activity to produce the same level of tension that could be generated by the controls. After successful therapy the voltage/tension plots were the same for both samples. The painful muscles were less efficient.

The occlusal pattern may make no difference in reducing a bruxer's EMG activity. Measuring the amount of bruxing before and after treatment by wear facets on thin multilaminate splints, Mejias and Mehta[74] determined there were no differences between a full coverage stabilization splint and a Hawley with a biteplane. Kardachi, Baily and Ash[75] found no difference in EMG response between complete occlusal adjustment and mock occlusal adjustment in five bruxers. Any conclusion must be guarded because of the small samples.

A very interesting report on one subject was published by Cassisi, McGlynn and Mahan.[76] Using new technology that recorded, then analyzed the number of nocturnal suprathreshold (bruxing) episodes, the duration of each episode and the average masseteric EMG amplitude during each episode, they were able to determine the patient's response to a splint treatment sequence. Data was collected seven consecutive nights for each step in an intrasubject replication sequence of ABCACBA, where A was no splint; B was a non-occlusal splint, and C was a full coverage maxillary stabilization splint. The two splints were identical in shape. The non-splint did not contact teeth in the opposing arch. Both splints produced dramatic reductions in the frequency of bruxing per hour compared with the three baseline periods (mean of 10 or more bruxes per hour compared to less than three bruxes per hour). There were no visual differences in data of the amplitude and duration for the splint versus the non-splint phases.

Conclusions

1. There is good normative data for total EMG activity and total duration of bruxing episodes per night.
2. The total duration of clenching per night is higher in bruxers than control subjects.
3. Grinding is associated with eccentric contractions that can cause delayed muscle soreness.
4. Splints usually reduce the total amount of nocturnal activity in bruxers.
5. Splints may reduce the number of bruxing episodes per night.
6. Nocturnal splint wear changes daytime postural muscle activity.

Joint loading

Ultimately, to understand how the TMJ might be injured or deranged we must know how the joint is loaded and under what functional conditions. Behavior of the condyle as it revolves and translates during function is clearly described in the multitude of studies over many years of tracking mandibular motion. So far, it can only be inferred that the human joint is loaded during tooth contact. Two dimensional mechanical models estimating masticatory muscle vectors and the force across the teeth conclude that during clenching the joint must be loaded to maintain equilibrium.[77] Similar analysis when the occlusal contact is on only one side such as in chewing or lateral clenching show that the joint is always loaded on the contacting side.[78] Hatcher, et al.[79] compared three-dimensional mechanical and mathematical models of the human skull altering masticatory load, muscle attachment direction and muscle force. In the mechanical model the fossa was sectioned from the surrounding bone and the forces acting through the condyle were measured with a force transducer. Muscle force was related to standard EMG data and directions were calculated from skull measurements. The amount and direction of the ipsilateral and contralateral TMJ loads were estimated for unilateral occlusion on the first, second or third molars. In every experimental simulation the TMJ's were loaded.

J. dos Santos, Suziki and Ash[80] calculated the force reactions at the TMJ and the dentition on a two-dimensional mathematical model with two different splint designs. The stabilization splint increased the load across teeth and reduced the load at the TMJ. The anterior repositioning splint with a guiding ramp had the opposite effect.

In vivo measurment in two monkeys of the force on the condyle was made by Boyd, et al.[81] They cemented thin force transducers on the superior aspect of the condyles and transmitted data to remote recorders. The forces on the condyle ranged to 34 pounds during chewing, were greater on the working side and were greater for hard food than for soft food. Introduction of a two millimeter interference reduced TMJ forces, especially on the non-working side. In humans, adding an occlusal interference will reduce muscle activity on that side. While determination of the forces across many human joints has been accomplished, TMJ forces have not been measured directly.

Some idea of the role that splints may play in loads of the TMJ on patients may be inferred from the investigation of Ito, et al.[82] Using the Replicator system they measured small condylar movements during clenching, under different occlusal conditions. The Replicator can track condylar movement to within 0.125 millimeters. Five types of maxillary splints were made for each of five normal adults: a stabilization splint, a splint with anterior contact only, an anterior repositioning splint, a bilateral second molar pivot splint and a unilateral pivot splint. They reported that there were nonsignificant condylar movements clenching on stabilization, repositioning and bilateral pivot splints. Condylar movement averaged 0.44 millimeters superiorly and 0.19 millimeters anteriorly clenching on the anterior splint. Even though biting force is reduced when only the anterior teeth contact, the significant change in condylar position as evidenced by the condylar movement would indicate TMJ loading increased. Bite registration techniques using anterior jigs or leaf gauges therefore would increase TMJ loading. It remains to be determined whether this superior condylar position is clinically desirable. Bilateral posterior premature tooth contact does not increase joint loading as much as loss of posterior support. Even posterior tooth contact protects the joint from displacement.

When Ito, et al.[82] tested clenching on a unilateral posterior pivot splint, the pivot side condyle went down and posterior (0.21 millimeter and 0.15 millimeter), and the nonpivot side went up and anterior (0.19 millimeter and 0.16 millimeter) on average. If the resultant vector of the muscle forces on the mandible acts inside the triangle formed by the unilateral pivot contact and the right and left condyles, both condyles would be loaded and no distraction would occur. For the pivot side condyle to be distracted the total muscle vector would have to be outside the triangle and the non-pivot side muscle forces would have to be greater than the pivot side forces. A similar conclusion was reached by Hylander.[83] Because most studies show working-side muscles are more active during chewing than nonworking-side muscles[84] it is probable that the working-side condyle is not distracted during unilateral chewing. A wide range with different directions of condylar loading could occur with unilateral contact. Particularly with parafunctional activity, muscle contractions may be unrelated to mandibular position and normal proprioceptive control. The clinical consequences of joint loading and TMJ injury or dysfunction are not yet understood.

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