Sixty-eight years of experimental occlusal interference studies: What have we learned?

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Statement of problem. Understanding is needed regarding the effect that occlusal interferences have on the teeth, periodontium, and especially on jaw function.
Purpose. This article summarizes research in which experimental occlusal interferences have been placed on the teeth of animals and human volunteers.
Material and Methods. Data from 18 human and 10 animals studies were reviewed. Experimental occlusal interferences were grouped into those that alter intercuspal position and those contacting on lateral jaw movement only. The outcome of these interferences were analyzed according to their local pulpal-periodontal, jaw function, or bruxism effects.
Results. Experimental occlusal interferences in maximum intercuspation had a deleterious effect on periodontal and pulpal tissues of the affected tooth; sometimes this produces a disruption of smooth jaw function and occasionally jaw muscle pain and clicking. Experimental occlusal interferences that contact only in a lateral jaw movement are infrequently harmful to jaw function. Furthermore, no reliable evidence demonstrates that occlusal interferences can cause nocturnal bruxism, or stop it.
Conclusion. Transient local tooth pain, loosening of the tooth, a slight change in postural muscle tension levels, chewing stroke patterns, and sometimes a clicking joint can be induced by an experimental occlusal interference. Because such findings are present in relatively asymptomatic patients, these data do not prove that occlusal interferences are causally related to a chronic jaw muscle pain or temporomandibular joint dysfunction problems. (J Prosthet Dent 1999;82:704-13.)

CLINICAL IMPLICATIONS

Although occlusal therapy may be justified for reasons of esthetics, gross occlusal instability, or dental disease, the data do not exist showing that occlusal interferences are the cause of chronic jaw dysfunction problems. Conversely, this review suggests that when a patient's complaint is tooth pain or mobility, occlusal interferences are a potential and likely contributing factor.

Over the years, many researchers have claimed that occlusal interferences cause a variety of deleterious local dental and masticatory system effects.[1-5] However, proof of a causal relationship must be provided through rigorous experimentation. The accumulation of data on the broad question, "Are occlusal interferences deleterious?" has been gathering for over 68 years.

The purpose of this literature review is to focus on experiments where artificial occlusal interferences have been placed on the teeth of animals or human subjects. The review addresses 4 questions regarding: (1) the effect of experimental interferences (all kinds) on the periodontal and pulp tissues of individual teeth in experimental trauma; (2) the effect of high restoration on jaw function; (3) the effect of excursive occlusal interferences on jaw function; and (4) the effect of occlusal interferences (all types) on bruxism.

EXPERIMENTAL OCCLUSAL INTERFERENCES AND INDIVIDUAL TEETH

The quest for a better understanding of the effects of occlusal trauma began with a study by Gottlieb and Orban[6] in 1931. They experimentally placed high crowns on the teeth of young and old dogs (n = 33) and then killed the animals at various time points, rang-

Presented at the annual meeting of the Academy of Prosthodontics, Colorado Springs, Colo., May 1998.
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ing from 12 hours to 13 months. Harvested jaws were submitted to qualitative histologic analysis. The authors reported that local resorption of the alveolar bone around the teeth with the high crowns was induced within 24 hours. The rapidity of bone resorption appeared to be dependent on the age of the animal, being more rapid in the young than in the old. Unfortunately, no information was provided about any pulpal changes and the magnitude of the interference was never quantified. In those situations where longer periods (greater than 13 months) elapsed before the animal was killed, the traumatized teeth of the animals presumably moved into new positions to relieve the trauma because normal supporting bone was evident at examination. Overall, these data were a convincing demonstration of the local but transient, traumatic effects of a high crown on the investing alveolar tissues. These data did not assess whether irreversible pulpal damage occurred or the issue of whether occlusal trauma contributed to periodontal disease progression.

The role of occlusal trauma in periodontal disease was first evaluated by Box,[7] who placed a high crown on the lower incisor of a sheep and, after 104 days, killed the animal. By using a combination of qualitative clinical and histologic analysis methods, he reported an increased mobility and deepening of the gingival pocket on the experimental teeth and suggested that periodontal disease progression was enhanced by occlusal trauma. Although this data were extremely limited, Box's study precipitated the assumption that "occlusal trauma is an important co-factor of periodontal disease."[7] This assumption resulted in dentists frequently using occlusal adjustment as a critical part of their periodontal treatment program.

Twenty-three years after Box's study, Wentz et al[8] evaluated the effect of "jiggling" forces on periodontal tissues. They applied "jiggling" forces to the maxillary right second premolar in 6 monkeys by using a combination of a high crown and lingual arch wires for 2 days to 6 months. They described alveolar bone resorption and inflammation of the investing periodontal tissues. However, they also reported that the inflammatory changes disappeared and functional adaptation, such as widening of the periodontal ligament, was observed in the 3- to 6-month specimens. Unfortunately, they did not carefully control periodontal inflammation as a variable and therefore did not definitively answer the question about whether occlusal trauma accelerated periodontal disease (as determined by attachment loss) or simply made the teeth loose and sore for a period.

In 1974, Svanberg and Lindhe[9] evaluated the effect of long-term "jiggling" forces on experimentally induced periodontitis in beagle dogs. They placed a cap splint device in the upper jaw and a bar on the lower jaw that caused "jiggling"-type occlusal trauma. Of the 13 beagle dogs studied, 9 dogs had healthy periodontium and 4 had experimental periodontitis in the mandibular fourth premolar region. Dogs were killed after 7, 14, 30, and 180 days. They reported that the periodontal ligament in the periodontally healthy group was wider and the teeth more mobile. These changes suggested the teeth had more or less become adapted to the altered occlusion by the end of the experiment. In the experimental periodontitis group, there was increased vascular leakage, leukocyte migration, and osteoclastic activity. Despite these changes, they did not report or demonstrate acceleration of actual periodontal attachment loss with subsequent accelerated pocket deepening as a result of occlusal trauma. At the same time, Polson et al[10,11] were conducting studies on squirrel monkeys using experimental occlusal interferences (EOI) on teeth with and without periodontal inflammation. They found that plaque-induced tissue inflammation, not occlusal trauma, was the major factor in the progression of periodontal disease. Their data were in complete agreement with Svanberg and Lindhe,[9] and they concluded that plaque-induced tissue inflammation and not occlusal trauma was the major factor in the progression of periodontal disease.

Few studies have actually been conducted on traumatic occlusion on pulpal tissues. Animal studies reporting occlusal trauma as a cause of pulpal inflammation have not conducted actual pulp testing. However, a unique study was performed on human subjects by Ikeda,[12] who placed experimentally high inlays (75-280 μm) on teeth and measured pain and sensory thresholds with an electronic pulp tester. Ikeda reported that 10 of 14 teeth in 6 healthy human subjects with high inlays showed a strong and consistent decrease in pulpal pain threshold to electric stimulation immediately after the inlays were placed (within 2-29 days). He also demonstrated that the decreased pain threshold returned to normal in 6 of these 10 teeth when the high inlay was removed by adjustment. In another 4 of the 10 teeth, the tooth pain threshold was still slightly diminished at the end of the observation (even though the tooth was adjusted back into normal contact). He concluded that the majority of the teeth demonstrated a predictable decrease in pain threshold when a high inlay is placed on a tooth. Moreover, this threshold will return to normal in a majority of teeth, if occlusal adjustment is performed, or if enough time passes so that the tooth can be physiologically intruded by the occlusal forces.

Summary of local effects

Iatrogenically placed high crowns or restorations in maximum intercuspation can have a local deleterious effects (inflammation and sensory change) on the investing alveolar tissues and pulpal tissues of teeth. This effect appears to be transient, from several days to

Table I. Articles in which EOIs were used in human subjects: Description of study

Authors	Size of EOI	Type of EOI	Duration of study	No. of subjects	Outcome assessment method
Anderson and Picton[16]	500 µm	ICP	N/A	4	Occlusal forces measured
Graf and Zander[25]	N/A	Balancing	Same-day effect	5	Number of tooth contacts and clinical symptoms
Schaerer and Stallard[26]	N/A	Balancing	2 days	4	Occlusal contacts with chewing and clinical symptoms
Shaerer et al[27]	500 µm	Balancing	2 days	3	Occlusal contact
De Boever[28]	N/A	Balancing	8 days	4	EMG levels
Randow et al[17]	250 µm	ICP contact on first molar	14 days	8	Clinical symptoms and EMG balance
Funakoshi et al[18]	300 µm	ICP contact on first molar	7 days	6	Resting EMG in various head positions
Bakke and Møller[5]	50 to 200 µm	ICP contact on first molar	Same-day effect	4	EMG during clenching
Hannam et al[30]	N/A	Working side contact on first premolars	Same-day effect	5	EMG during clenching and jaw movement
Riise and Sheikholeslam[19]	~500 µm	ICP contact	7 days	11	Clinical symptoms and resting EMG
Rugh et al[38]	0.5-1 mm (lateral and forward)	ICP contact on first molars	10 to 21 days	10	EMG activity during sleep
Magnusson and Enbom[32]	N/A	Balancing contact	2 wk	12	Clinical symptoms
Ikeda[12]	75 to 280 µm	ICP contact on first and second premolar	29 days	6	Electric pain threshold
Karlsson et al[33]	N/A	Balancing contact	1 wk	12	Masticatory movement
Rossouli and Christensen[22]	240 µm	ICP contact on premolar and molar	Same day	12	Jaw tipping
Christensen and Rassouli[20]	240 µm	ICP contact on premolar and molar	Same day	12	EMG balance
Shiau and Syu[39]	1500 µm	Balancing	1 mo	27	EMG levels and jaw movement
Baba et al[24]	N/A	Working and balancing contact on molars	Same day	12	EMG levels with clenching

several weeks, because the traumatized teeth tend to move away from the adverse occlusal forces. These local adverse sensory and periodontal-osseous effects of occlusal trauma would appear to be well-accepted as indications for occlusal adjustment therapy.

EFFECT OF A HIGH CROWN ON JAW FUNCTION

The putative role of occlusal interferences and the masticatory motor system and temporomandibular joint (TMJ) has been addressed in several animal and human studies. Available animal studies in the literature begin with Ruben and Mafla,[13] who placed metal splints bilaterally in 6 monkeys, where the vertical dimension of occlusion (VDO) was increased by 4 mm at the first molar area. One experimental group (2 monkeys) had only a flat occlusal plane splint, whereas the other group (4 monkeys) had a premature contact at the first molar area on the splints. The metal splints were placed for 15 and 55 days before the monkeys were killed, and the TMJs were submitted to histologic analysis. Results showed that destructive bony tissue changes were evident in the condyles, glenoid fossa, and neck of the condyle in both the 15- and 55-day specimens. In 55-day specimens, the condyle was displaced mesioinferiorly and there was flattening of the articular eminence and the condylar head. Both flat and pivoted splints caused traumatic changes in the TMJs.

Another animal model–based study of the effect of occlusal interferences on TMJs was conducted by Kvinnsland et al,[14] who reported on the effect of experimental traumatic occlusion on blood flow in the TMJ

Table II. Articles in which EOIs were used in human subjects: Results of study

Anderson and Picton[16]	The load on the EOI was 2 times greater than on a same tooth without EOI.
Graf and Zander[25]	Reported increased number of contacts during chewing and no significant effect on jaw pain or function with balancing EOI.
Schaerer and Stallard[26]	Immediate adaptation in that the teeth touch more often initially, but no perceptible change in chewing pattern. They reported no clinical symptoms with balancing EOI.
Schaerer et al[27]	The number of occlusal contacts increased about 2 times above normal.
De Boever[28]	EMG patterns during mastication did not change within the 8 days after insertion of balancing-EOI.
Randow et al[17]	Asymmetric resting EMG persisted until EOIs were removed. Six subjects had TMJ and muscle tenderness, 3 had clicking, and in 1 subject, this problem persisted for 9 mo.
Funakoshi et al[18]	Asymmetrical resting EMG after EOI, but when interference was reduced, EMG levels returned to normal.
Bakke and Møller[5]	ICP-EOI (unilateral) caused EMG changes during clenching. Specifically, increased EMG on ipsilateral side and decreased on contralateral side.
Hannam et al[30]	Some subjects showed small differences, but no consistent effects of working EOI on EMG or jaw movement.
Riise and Sheikholeslam[19]	2 subjects showed increased EMG in temporalis, but no changes in masseter. 1 mo after the removal of EOI, the resting EMG had returned to original pattern in all subjects. 7 subjects had transient pain, tenderness, and fatigue in jaw muscles.
Rugh et al[38]	No relationship between ICP-EOI and EMG levels. Some subjects had mild jaw muscle and TM joint tenderness and mobility on the EOI teeth.
Magnusson and Enbom[32]	Balancing EOI group had 10/12 subjects report subjective jaw pain symptoms. In controls, 3/12 reported subjective jaw pain symptoms during 2-wk study.
Ikeda[12]	10 of the14 teeth had decreased pain threshold after an ICP-EOI. These thresholds return to baseline in only 6/10 teeth after OA.
Karlsson et al[33]	Opening magnitude and movement velocity were different after OA.
Rassouli and Christensen[22]	Assumed no bending of mandible and calculated 0.7 degree frontal plane rotation from a 240 μm EOI. The contralateral condyle to EOI would be elevated 0.5-1.0 mm.
Christensen and Rassouli[20]	EMG with EOI increased +21% more on same side and decreased –14% on opposite side (P = NS).
Shiau and Syu[39]	The velocity of jaw closing decreased immediately after the insertion of the overlay, and the closing pathway near the occlusal phase of chewing cycle was narrower.
Baba et al[24]	Balancing EOI increased temporal EMG on nonworking side and decreased on working side when compared with baseline EMG without EOI when clenching in a canine edge-to-edge position.

of the rat. They placed a 1-mm high EOI (using composite material) unilaterally on the first maxillary right molar in 30 rats. At 1, 5, 10, 15, and 20 days after placement of the interference, blood flow in the TMJ was assessed by injecting fluorescent microspheres just before killing the rats. Results revealed that there was an increase in blood flow at 15 to 20 days on the ipsilateral side, compared with the contralateral side. There was also an increase in blood flow in both ipsilateral and contralateral TMJs in the experimental animals compared with 10 control animals. They interpreted these results as demonstration of altered joint loading as a result of the interference.

In a similar experiment, Richardin et al[15] placed an EOI (occlusal splint) of 2 heights (low and high but of unknown height) bilaterally in 12 rats, and measured EMG activity of the anterior temporalis, superficial masseter, and anterior digastric muscles. Increased activity in the anterior temporalis and superficial masseter muscles was reported during the late phase of opening that was not observed in the control animals. Unfortunately, these EMG data were subjectively interpreted and the authors did not perform any quantitative statistical analysis.

These 3 animal studies hint that when substantial disruption in the occlusal scheme might be deleterious to the TMJ and alter jaw muscle function. What these studies cannot answer is whether these changes are normal accommodative responses or the beginning of a chronic dysfunction. Moreover, it is hard to know whether the effects described in these animals can be generalized to the human because the size of the interferences are quite large. Last, the fact that human orthognathic surgery patients can and do have substantial changes in their occlusion without consistently having jaw function problems argues that the above animal data reflects accommodative remodeling changes and not pathologic jaw dysfunction.

As there is always a question about the applicability of animal study data to the human situation, in recent years, human subjects have been the preferred experimental model for occlusal trauma research (Tables I and II). Anderson and Picton[16] began the process by placing either "normal height" or "500 μm high" onlays on the occlusal surface in 4 subjects. They positioned load-sensors in these onlays to record occlusal forces during bread mastication under the 2 conditions. They found that the load on the 500-μm high onlay was 2 times greater than on the same tooth with the normal height onlay. Randow et al[17] experimentally placed a "high" gold onlay on the occlusal surface of a mandibular molar in 8 healthy subjects. This interference was approximately 250 µm above the contacting plane, thus putting the tooth in supracontact. They used bilateral resting surface EMG recordings from the masseter, temporalis, and suprahyoid muscles. The EOI was in place for 14 days and the EMG recordings were performed immediately before and after the placement, and then again 7 days later. They described bilaterally increased EMG activity in 3 subjects, bilaterally decreased activity in 3 subjects, and higher EMG activity on the ipsilateral side with a reduced EMG activity on the contralateral side in the temporalis after the interference. This study also reported on, but did not measure, a disturbed mandibular coordination with function in 6 of the 8 subjects. Randow et al[17] reported that these 6 subjects complained of TMJ tenderness and muscle tenderness as a result of the occlusal interference. Finally, new spontaneous TMJ clicking was reported during mandibular opening bilaterally in 3 subjects during this experiment (these symptoms occurred at 7 to 14 days after insertion of the inlay). In 1 subject, there was still severe irregularities of the movement in both joints near maximal mandibular opening 1 week after the removal of the inlay. This symptom persisted for 9 months and abated after treatment with stabilization splint.

In the same year, Funakoshi et al[18] studied the surface EMG activity at rest taken from the masseter, temporalis, and digastric muscles of 3 subjects where a 300 µm experimental high restoration (metal overlay) was placed on a molar for 7 days in 3 subjects. EMG recordings were performed before placement, during (at 7 days), and up to 1 month after the interference was removed. Like Randow et al,[17] Funakoshi et al[18] reported that an asymmetric postural muscle activity resulted from the occlusal interferences, which were not present before the overlay's placement. When this interference was removed, the asymmetric activity levels were reported as diminished to a normal, balanced level. However, they did not comment on any clinical effect of the EOI on masticatory muscle or TMJ function, except for a note that one of the subjects complained of transient periodontal pain at the tooth where the overlay was placed. Moreover, they categorized EMG into balanced or unbalanced types but did not perform any statistical analyses on these data.

Bakke and Møller[5] reported that unilateral premature contact caused a significant asymmetry of activity in masseter and temporalis muscles during clenching. They incorporated the EOI by inserting 1 to 4 celluloid strips between the first molars unilaterally in 4 subjects. The heights of the interferences were 50, 100, 150, and 200 µm above the contacting plane. They used surface EMG during clenching, recording bilaterally from anterior and posterior temporalis and masseter muscles. They reported asymmetric muscle activity during clenching that was increased on the ipsilateral side and decreased on the contralateral side; however, they did not attempt to test the validity of their observations with a statistical analysis.

Riise and Sheikholeslam[19] experimentally placed a high amalgam restoration on the occlusal surface of a right maxillary first molar that was 500 µm above the occlusal surface in 11 subjects without symptoms of functional disorders in the stomatognathic system. EOI was in place for 7 days and EMG recordings were recorded before placement, during (at 1 hour, 48 hours, and 1 week) and up to 1 month after the EOI was removed. They used surface EMG of masseter and anterior temporalis at rest and reported that 1 hour after insertion of the interference 2 subjects showed increased activity in the resting anterior temporalis muscle of 1 side. At 48 hours and 1 week after insertion of the interference, there was still a significant increase in the resting EMG activity of the right and left anterior temporalis muscles. Like Funakoshi,[18] they found that 1 month after the removal of the interference, the postural activity had returned almost to its original pattern in all subjects. Regarding masseter muscle, there was no significant increase of postural activities throughout the experimental period. They also reported (3 hours after the placement of the interferences) that 7 subjects complained of pain, tenderness, and fatigue in the elevator muscles. Moreover, 8 subjects developed dysfunctional symptoms in the masticatory muscles or TMJ within 12 hours after the insertion of the EOI. Importantly, within a week, these symptoms gradually subsided in 4 subjects, whereas 4 subjects still reported moderate dysfunction symptoms until the interference was removed. This study used an improved quantitative analysis of the EMG levels and performed statistical testing. Unfortunately, the clinical observations of pain and tenderness were not quantified in any fashion.

In a 2-part study, Christensen and Rassouli[20,21] reported the effects that a unilateral EOI had on both the surface EMG activity at rest and on the tipping of the mandible. EMG recordings were taken from the masseter muscle of 12 subjects where a minimum height of 0.24 ± 0.21 mm rigid acrylic resin onlay splint was placed unilaterally in the second premolar and first molar region. EMG recordings from bilateral masseter muscles were performed with and without an acrylic resin onlay. They reported relative masseteric EMG activity (EMG with the splint / EMG without the splint) during clenching showed 121% ± 69% in the ipsilateral side to the onlay and 86% ± 19% in the contralateral side, respectively. These changes were not statistically significant. Christensen and Rassouli also described the tipping effect that the EOI had on the mandible.[22,23] Rotation of the mandible during clenching was measured with the jaw tracking device (electrognathograph) whose target (magnet) was attached to the labial surface of the mandibular incisor in the same 12 subjects of the previously mentioned study. The results revealed an upward rotation of the mandible (0.7 ± 0.3 degrees) contralateral to the interference side in the frontal plane. They also reported a significant linear association between upward rotation of the mandible in the frontal plane and relative masseteric EMG activity (EMG with or without the splint) during clenching on the ipsilateral side to the interference. Unfortunately, the system they used had some limitations. The rotation in the frontal plane could be affected by the rotation in the sagittal and horizontal planes. The calculation of the rotation was made under the assumption that the mandible is rigid and would not deform during clenching. They also speculated that the condyle contralateral to the interference could elevate 0.5 to 1.0 mm. Furthermore, it is still unknown if a 0.7-degree rotation could actually cause structural damage to the TMJs or if this degree of change is well within the capacity of the TMJ to adopt.

EFFECT OF LATERAL INTERFERENCES ON JAW FUNCTION

In addition to the effect of high restorations on jaw function, it has been claimed that posterior teeth, which contact in a lateral motion (namely, working and balancing interferences), have adverse effects on jaw function. Graf and Zander[25] used a telemetric system to study the number of times an experimentally placed balancing interference would touch during function. They reported that a balancing-EOI had an increased number of contacts during chewing, but no significant effect on jaw pain or function was observed. Schaerer and Stallard[26] placed an experimental lateral occlusal interference of unknown height in 4 subjects and noted that the only change was that these teeth touched more often. They reported no change in the number of chewing strokes or the overall pattern of the chewing cycle, nor did they describe any jaw dysfunction. By using the same method, Schaerer et al[27] performed an experiment to examine the effect of balancing interference on the EMG activity during mastication. They recorded tooth contact and EMG activities in the anterior and posterior temporalis and masseter muscles during chewing movements before and immediately after the insertion of the balancing interference in 3 subjects. The result showed that there was an increase in the number of tooth contacts at the balancing interference. Although 40% of these tooth contacts elicited the inhibition of EMG activity, they could not demonstrate a deleterious effect of the balancing interference on the jaw-closing muscles.

De Boever[28] investigated whether an experimental occlusal balancing interference would cause changes in the EMG during mastication. He placed an experimental occlusal balancing interference (gold inlay) on the first premolar in 4 dental students with normal occlusion for 8 days. Masticatory EMG recorded from anterior temporalis muscles 1 month and immediately before, immediately, 3, and 8 days after the insertion, then immediately and 10 days after the removal of the interference. He found that EMG patterns during mastication did not change either immediately or 8 days after the insertion of the experimental balancing interference. In addition, teeth on which the gold inlays were placed did not exhibit induced mobility during the experiment.

Kloprogge and Griethuysen[29] did not actually place "high crowns," but reported that abnormalities in the pattern of coordination of the masticatory muscles were related to dental restorations. They measured EMG from anterior temporalis and masseter muscles in 3 normal subjects without any dental restoration and 8 temporomandibular disorder (TMD) patients with restorations. Presence of a number of wear facets on the restoration revealed by detailed occlusal examination with articulating paper was linked with the abnormalities in the EMG (decreased activity, time difference between right and left side). They reported removing these wear facets caused instantaneous disappearance of symptoms of TMD in some patients and partial improvement in other patients. However, actual data were not provided. There are a number of flaws in this study. There was no description regarding the number of restorations and how well they occluded with the rest of the teeth. It was not clear what type of occlusal adjustment was performed and what type interferences were present (on natural teeth or on restored teeth) in these patients. Furthermore, the method by which the patients' symptoms were assessed was entirely unblinded and subjective.

Hannam et al[30] evaluated the effects of working side occlusal interferences on muscle activity and jaw movement. They introduced the EOI by putting a composite material on the buccal cusp of the working side maxillary right first premolar in 5 normal subjects. They recorded EMG from anterior and posterior temporalis and masseter muscles and jaw movement during gum-chewing, before and immediately after the insertion of the working side interference. The experiment was performed on the same day (< 2 hours from start to finish). No consistent effects were found for the experimental working side interference on EMG or jaw movement changes.

One theory of balancing interferences is that canine guidance is protective of the jaw. In other words, when subjects contact on a canine only in a lateral jaw position, the subject produces less force than if they were contacting on several teeth, including a posterior tooth. Rugh et al[31] performed actual testing of this concept by using splints that had molar guidance versus canine guidance built into the splint. They found that it did not matter which tooth was the guiding tooth, because the subject was not willing to clench as hard on one tooth versus multiple teeth, whether canine or molar, in a lateral jaw position. The whole concept of canine guidance and canine-protected occlusion is actually a concept that is illogical if protection from parafunction is the subject of debate. That canines do not inherently protect the jaw and teeth from bruxism is clear because in the strong bruxer, the clinical observation of canine attrition is common.

Magnusson and Enbom[32] studied the effects of experimentally placed balancing interferences in 2 healthy subject groups. In 1 of the groups, bilateral balancing side interferences were applied, whereas the application was simulated in the control group. In the experimental group, 10 of 12 subjects reported subjective symptoms and 7 developed clinical signs of TMD during the 2 weeks. In the control group, 3 of 12 subjects reported subjective symptoms and 3 developed clinical signs of TMD during the 2-week study period. It was concluded that there is no simple relationship between interferences and signs and symptoms of TMD, but they do induce accommodative behaviors in many subjects.

Another theory of how interferences induce TMD problems is "avoidance of the occlusal interferences." At best it can be demonstrated that mandibular movement patterns are influenced by occlusal changes but the significance of these movement pattern changes is not known. For example, Karlsson et al[33] examined changes in masticatory movement patterns by insertion of an experimental balancing side interference and reported that some of the movement variables (opening magnitude, movement velocity) were significantly changed immediate after insertion of balancing side interferences, but an adaptation of the neuromuscular system (to the interference) was evident within 1 week after the insertion.

In a recent study on this topic, Baba et al[24] studied the effect of the EOI on the masticatory muscle activity during clenching in various positions. They placed 3 types of EOI (metal onlay) with unknown height on 12 normal subjects. The interference types were (1) canine raiser on the upper right canine, which discluded all other teeth during a right eccentric jaw motion; (2) working side (right) interference on the second molar; and (3) nonworking (balancing, left) side interference on the second molar. EMG activity in the anterior and posterior temporalis and masseter muscles during maximum clenching for 2 seconds in intercuspal position (ICP) and in a right canine edge-to-edge position was recorded bilaterally before and immediately after the placement of the interference. They reported that EMG activity of the anterior and posterior temporalis muscles during maximum clenching with nonworking side EOI increased on the working side and decreased on the nonworking (balancing) side in a lateral jaw position. For masseter muscles, the activity remained unchanged.

Summary of jaw function effects

The data reviewed suggest the following relationship between iatrogenic occlusal interferences (both in ICP and on a lateral movement) and jaw function. First, it can be concluded that a high crown or restoration will likely induce accommodations in postural and functional jaw muscle patterns. The magnitude and variability of these alterations are less for lateral occlusal interferences than for ICP interferences. What is not clear is whether these varied (sometimes present, sometimes not) postural elevations and asymmetries of muscle function under experimental interference conditions are associated in any way with the initiation of a chronic muscle pain or TMJ dysfunction problems. While this is possible, data are not strong or consistent and the degree of accommodation is probably related to the degree to which the interference disrupts the occlusion. In other words, the bigger the interference in ICP, the more it alters jaw function. In addition, many of the interferences used in these experiments were moderately large (>300 μm). Actually, it is a logical and expected result that the jaw would alter its function in response to a high tooth contact, especially considering that the tooth would be somewhat painful to chew upon. The most direct evidence between EOIs (for interferences in ICP but not lateral motion) and TMDs is that sometimes they have induced long-lasting TM joint symptoms (clicking) in some subjects and sore jaw muscle in other subjects. These data are limited and largely based on unblinded observations collected without careful calibrated examination. Although sore jaw muscles and painless clicking are not desirable results, they alone do not constitute a substantial or serious TMD. Overall, these data suggest that, although occlusal interferences are harmful locally, the likelihood of a substantial TMJ or masticatory muscle pain disorder developing is moderately low, but not absent.

Moreover, if symptoms develop, they are most likely to be transient in nature. This conclusion is based on the fact that most studies, which kept the interference in place more than a few days, showed some resolution of the subjective tooth soreness and jaw muscle complaints. Unfortunately, no study kept the EOI in place longer than 4 weeks with most being 2 weeks or less. Additional work on the effect of long-term EOIs on jaw function is needed. Such studies need at a minimum: (1) controls "normal height" inlays or onlays;

(2) careful measurement of the size of interference over time (as was performed by Ikeda et al); (3) blinded and calibrated examiners; (4) a standardized protocol for the clinical examination of jaw function; and (5) outcome measures that are clearly understood as jaw dysfunction behaviors, such as medication use, pain diaries, chewing modifications, and loss-of-motion measures.

EFFECT OF OCCLUSAL INTERFERENCES ON BRUXISM

Although it is accepted that heavy bruxism can traumatically injure a tooth, a variation on this relationship is that an occlusal interference can induce bruxism or other forms of involuntary motor responses in the masticatory system, often described as "muscle hyperactivity." The basis of this latter theory can be described as the "occlusal contact avoidance theory." Some proponents of the avoidance theory state that the avoidance occurs during the day, and during sleep there is a loss of the avoidance response, so the patient subsequently attempts to grind away the offending interference. The hypothesis of occlusal interferences are an inducer of sleep-bruxism or other forms of muscle hyperactivity during sleep is disputed.

Budtz-Jorgensen[34] cemented occlusal overlays bilaterally on the posterior teeth of 8 *Macaca irus* monkeys for 4 weeks. These overlays raised the vertical dimension by 3 to 4 mm and an additional occlusal interference was added unilaterally for 4 weeks. He reported that the monkeys showed distinct signs of bruxism during this experimental period, but unfortunately, objective evidence of the bruxism events (EMG recordings during sleep) was not recorded.

In 1981, Budtz-Jørgensen[35] again cemented occlusal overlays on the posterior teeth of 6 *Macaca irus* monkeys. These splints also raised the vertical dimension by 3 to 4 mm and an occlusal interference was given unilaterally for 3 weeks. Cortisol levels of plasma, 24-hour urine samples, body weight, and mobility of the teeth were measured. Immediately after the insertion of the splints, approximately 2-fold rise of the mean 24-hour urinary cortisol excretion rate and a significant decrease of urinary volume and body weight occurred. Teeth on the interference side showed increasing mobility, and occlusal wear facets developed on the splint during the 3-week experimental period. Urinary cortisol levels reduced to that of baseline 4 weeks after the splints were removed. He concluded this result supported the hypothesis that a dysfunctional occlusal relationship may result in bruxism associated with emotional stress. It was not clear whether he was saying that the experiment itself was a stressor and the monkeys bruxed more or if the occlusal interference induced the bruxism. Without a control group, this question cannot be answered by the study.

In human subjects, Bailey and Rugh[36] conducted unilateral EMG recordings of the masseter muscle of 9 patients with bruxism. The recordings were taken before, during, and after occlusal adjustment and revealed no significant increase or reduction in bruxism in 8 of the 9 patients as a result of the treatment. Kardachi et al[37] measured nocturnal masseter EMG levels on 4 bruxism patients before, during, and 3 months after an occlusal adjustment. In another 2 subjects with bruxism, they performed the same recordings but the treatment was a mock equilibration. No significant differences in the EMG levels between the groups were found. Finally, Rugh et al[38] placed deflective molar occlusal interferences (0.5 to 1 mm forward and lateral deflection from centric relation) in 10 normal subjects. They monitored the level of nocturnal masseter muscle activity for at least 10 nights before, during, and after placement of the interference. The study showed no relationship between occlusal interferences and increased levels of bruxism. However, several subjects exhibited some mild unilateral muscle tenderness, TMJ tenderness, and mobility on the tooth with the interference.

Shiau and Syu[39] studied the effect of working side interferences on daytime mandibular movement patterns in bruxers. They placed a metal overlay (1.5 mm in thickness) on the buccal cusps of the adjacent upper premolar and molar in 13 bruxers and 14 nonbruxers. Chewing movements were measured at the mandibular incisor in 2 dimensions. They also recorded EMG of the anterior temporalis, masseter, and anterior digastric muscles. These measurements were performed before, immediately, 1 day, 1 week, and 1 month after the insertion of the overlay, and 9 bruxers and 13 nonbruxers completed the experiment. Results revealed that the velocity of jaw closing decreased immediately after insertion of the overlay, and the closing path near the occlusal phase was narrower. For clinical symptoms, 1 nonbruxer complained of pain in the masseter muscles 1 day after the insertion of the overlay. Four of 9 bruxers reported less frequent or no bruxism during the experimental period. The flaws of these studies are that the 2 experimental groups were not gender matched, and there was no description of their ages and the inclusion criteria for the bruxer group was not provided. No actual measurement of sleep bruxism was performed and there was no description of which statistical test was used to analyze the parameters of jaw movement.

Summary of bruxism effects

The relationship of occlusal interferences and nocturnal bruxism behaviors, no reliable evidence has demonstrated that occlusal interferences can cause nocturnal bruxism, or stop it, if the naturally occurring interferences are removed.

SUMMARY

The first item addressed in this review was whether EOIs have a deleterious effect on the periodontal and pulpal tissue of the effected tooth. On the basis of the current review, the answer to this question is, emphatically, YES. Several reports demonstrate alveolar bone remodeling and irritation of the local periodontal tissues with an EOI. However, these induced traumatic and inflammatory changes are transient, and best considered as a functional adaptation to the increased load. In most situations, the tooth appears to move over time within the alveolus to a new position such that the increased forces are minimized, or the tooth develops an increased mobility. With regard to the specific role occlusal trauma plays in the loss of periodontal attachment levels when bacterial-induced periodontal disease is controlled, these data suggest that plaque-induced tissue inflammation and not occlusal trauma is the major causative factor.

Regarding pulpal tissue damage from EOIs, the only carefully conducted study on this issue concluded that the majority of the teeth with a "high crown or filling" will demonstrate a predictable decrease in pain threshold on electrical pulp stimulation. However, when the high inlay is reduced by adjustment, this threshold will usually return to normal in a majority of teeth. If no adjustment is carried out, the data suggest that, as time passes, the tooth will be intruded by the occlusal forces and the pulp sensitivity will diminish (assuming the tooth does not break or crack). Of course, these local adverse pulpal sensory and periodontal-osseous effects from iatrogenic occlusal trauma would appear to be well accepted as indications for occlusal adjustment therapy.

The second question addressed was "are EOIs that disrupt intercuspal position (ICP) adversely affecting jaw function?" The answer is MAYBE. The limited data reviewed suggested that ICP-EOIs induce accommodations in postural and probably even functional jaw muscle use patterns. However, what is not clear is whether these ICP-EOI–induced changes (slight postural elevations and asymmetry of muscle activation) routinely lead to a true chronic muscle pain or TMJ dysfunction problems. To date, the preponderance of data presented on this topic do not prove this relationship. The most direct evidence between ICP-EOIs and TMD symptoms is that they have produced dysfunctional joint symptoms (such as clicking) in some subjects and transient sore jaw muscles in most subjects. Actual data on this are limited and are largely based on the observations without careful calibrated blind-to-status examinations being performed. Sore jaw muscles and painless clicking is not a desirable result, but it does not constitute a substantial or serious TMD. Overall, the picture painted by these data is that, although ICP-EOIs are harmful locally, the likelihood of a substantial TMJ or masticatory muscle pain disorder developing is moderately low but not absent and, if symptoms develop, they are most likely to be transient in nature.

The third question addressed was "are eccentric contact EOIs (eg, high crowns that interfere with normal anterior tooth guidance patterns only on a lateral movement) harmful?" This answer is RARELY, IF EVER. The research reviewed mostly focused on balancing EOIs and the data suggested a much less substantial effect on jaw function than ICP-EOIs and no evidence of pain and dysfunction was identified for the eccentric-only interferences.

Finally, with regard to the last question "do EOIs of any kind induce nocturnal bruxism behaviors?" The answer is NO. No reliable evidence has been put forth demonstrating that EOIs can cause nocturnal bruxism, or stop it, if the naturally occurring interferences are removed.

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0022-3913/99/$8.00 + 0. **10/1/102522**