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# Occlusion and Temporomandibular Disorders: Is There a Causal Relationship? A Critique of the Existing Scientific Literature

**Samuel J Higdon***

*Private Practice, Non-Surgical Management of Temporomandibular Disorders and Occlusal Dysfunction, USA*

***Corresponding Author:** Samuel J Higdon, Private Practice, Non-Surgical Management of Temporomandibular Disorders and Occlusal Dysfunction, USA.

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## Abstract

The hypothesis, "dental occlusion plays a significant causal role in temporomandibular disorders", has been a central point of contention for many decades in the attempt to understand these disorders. Recently, certain authors have asserted that the scientific literature does not support this hypothesis. Yet many clinicians working in the TMD arena continue to believe that various dental occlusal factors do play a role, perhaps a significant role, in the development of some types of TMDs.

This paper considers the quality of the scientific data on both sides of the issue, taking into account the epidemiologic requirements to demonstrate causation, as well as certain scientific principles that are considered central to the proof or refutation of a hypothesis.

What emerges from this investigation is that, in spite of there being a considerable volume of literature, particularly in the past 30 years, the quality of a substantial portion of that literature does not meet the stringent requirements of Science to establish causation. Although a limited number of studies of a specific design appear to be supportive of the hypothesis, this evidence is, thus far, insufficient as "proof". With regard to the original hypothesis, the only conclusion that can be drawn is that this hypothesis has neither been refuted nor proven and, thus, remains a viable hypothesis that may and should be further challenged in the future by a higher level of scientific inquiry.

Recent research suggests that the role of dental occlusion in temporomandibular disorders, quite apart from the issue of causation, may be more related to its potential as a perpetuating factor.

***Keywords:*** *Dental Occlusion; Temporomandibular Disorders; TMD; Criteria for Causation; Perpetuating Factor*

## Introduction

Historically, there has been a belief among certain members of the dental profession that dental occlusal factors have a strong, perhaps dominant, causal relationship to temporomandibular disorders (TMDs). The belief in this association was originally based primarily on direct clinical observation, with little scientific evidence to support it. Recently several investigators have asserted that the existing scientific literature does not support a causative association between dental occlusion and temporomandibular disorders [1-4]. However, Storey [5,6] and others have noted that because of flaws in investigatory design, the causative association between dental occlusion and temporomandibular disorders has not been invalidated and remains an open question. The purpose of this paper is to consider the qualitative value of the science that addresses this hypothesis.

Kirveskari and Alanen [7] have stated, "Much, if not most, of the confusion about the role of occlusion is deeply rooted in a lack of appreciation of the problems in causal inference." In addition to looking at the science that exists on both sides of the question of the role of occlusion in TMD, this paper will also consider concepts related to causation in a larger context, as defined by recognized scientific theorists and logicians, in an attempt to clarify what is meant in Science by the term, "cause."

## The Role of Hypotheses in Determining Causation

The statement that "dental occlusal factors have a causative role in the etiology of temporomandibular disorders" is a hypothesis. According to Karl Popper [8-10], the highly regarded philosopher of science, evidence "for" a hypothesis is necessary, but never sufficient, to validate it and thus a hypothesis is inherently insufficient to become an accepted scientific "truth". Rather, the hypothesis must be tested in an attempt to prove it wrong (to refute it). Only when it has been thoroughly tested by several means and has not been refuted, referred to as "survivability", is it accepted as scientific probability. This concept is known as Popper's principle of "refutation." It may also be referred to as "falsification."

One reason that evidence "for" a hypothesis is never sufficient to validate a hypothesis is that the observable evidence may, theoretically, fit two or possibly more hypotheses. Thus, to determine which of the hypotheses is "more scientific," it is necessary to test each to see which of them is the more "survivable." It can be said that what we currently believe to be scientifically "true" is not because it has been proven, but rather because it has not been refuted.

Although Popper's concepts of refutation and survivability are broadly accepted among epidemiologists, there are those who also espouse an alternative view of hypothesis evaluation. As opposed to the Popperian "refutationist" view, these might be referred to as advocates for "verification" [9]. Albert Einstein advocated for the Popperian view when he stated, "No amount of experimentation can prove me right; a single experiment can prove me wrong". It is broadly accepted in science, based on Popper's thinking, that what distinguishes a scientific hypothesis from a nonscientific or pseudoscientific hypothesis is whether it can be tested.

Applying Popper's "refutation" principle, if a hypothesis has not been proven incorrect, it remains a viable hypothesis. In theory, a hypothesis should be tested by those proposing it. However, in reality, this seldom happens. In practice, the testing of a hypothesis is typically done by those who may question its validity.

Regarding TMD and occlusion, the first question that must be answered is, "Is the science that challenges the hypothesis that dental occlusion has a causative role in TMD sufficient to invalidate the hypothesis?" This question is the focus of this paper.

## What Kinds of Scientific Studies?

Epidemiology is the field of science that studies questions regarding causation. Two broad types of studies are used in Epidemiology to test hypotheses. These are "experimental" studies and "observational" studies. Experimental studies are done in a laboratory or other controlled environment, where single factors can be tested and other variables can be controlled. Although this kind of study is considered to produce the highest level of scientific evidence for testing many hypotheses, experimental studies are often either too difficult or impossible to conduct. When experimental studies cannot be done, one of several types of observational studies may be the only option.

Observational studies can be rated on a hierarchical scale as to their scientific strengths. Each level on this scale has scientific limitations, as well as practical, logistical strengths and drawbacks. These include 1) Cross-sectional studies, 2) Retrospective (case-control) studies, and 3) Prospective (longitudinal or cohort) studies.

## Properties of a "Cause"

The epidemiologist and logical theorist, Mervyn Susser [10], has stated that, "epidemiologists have skirted the topic of the inherent properties of a cause." He has further asserted that it is taken as sine qua non that to establish causality, three attributes must be present: 1) association, 2) time-order, and 3) direction. Association means that a causal factor (X) must occur together with the effect (Y). Demon-

strating association is the first requirement of causal proof. If association is present, then time-order requires that a suspect causal factor (X) has preceded the effect (Y). If association and time-order can be shown, then to establish direction it must be demonstrated that a change in an effect (Y) is a consequence of change in the suspected causal factor (X).

Cross-sectional studies, by definition, assess the prevalence of a condition in a population at a fixed point in time. Based on this fact, they can determine association. But because they do not look either backward (retrospective) or forward (prospective), they are incapable of determining time-order and direction. Their scientific limitation is the fact that they cannot assess relationships of factors over time. Their practical benefits are primarily that they are relatively easy and inexpensive studies to conduct. This undoubtedly largely explains why they are so commonly used.

Retrospective studies, often referred to as case-control studies, can have some advantages over cross-sectional studies as they may allow establishing time-order. They begin by looking at effects and then attempt to establish time-order by looking backwards. The challenges of reconstruction of historical exposures can be difficult, thus making the establishment of reliable time-order difficult. The scientific strength of retrospective case-control studies is their ability to examine several different risk factors at once, although only one disease outcome at a time can be studied. Their scientific, as well as practical, limitation is that selection of controls can be difficult and time consuming, contributing to the cost of doing the study.

Prospective studies offer the greatest potential for establishing time-order and direction. Very few prospective studies on the causal relationship between occlusion and TMD have been done. The particulars of prospective studies will be discussed later, when the outcomes of such studies are considered.

Given the need to establish association, time-order, and direction to determine causation, and given that the existing scientific literature is deficient in providing this kind of evidence regarding the relationship between dental occlusion and TMDs, these facts alone beg the question as to whether the hypothesis of causation of TMD and occlusion has been adequately tested.

## What is a Cause?

The idea that dental occlusion could be the sole or predominant cause of TMD was a fairly common assumption in the 1960s and 1970s. Beginning in the 1980s, a "new" theory of causation, "multi-factorial" etiology, emerged within the dental profession. Few in the dental profession, then or now, have had any training in the fundamental principles of causation as understood by epidemiologists. As mentioned previously, Kirveskari and Alanen [7] have stated, "Much, if not most, of the confusion about the role of occlusion is deeply rooted in a lack of appreciation of the problems in causal inference." They further state that this is by no means limited to the dental profession. It is also a wide spread problem in medical literature. Interestingly, among epidemiologists there is not a consensus regarding certain issues associated with establishing causal relationships. However, there is now wide agreement that causal relationships having to do with human health issues are more often than not multi-factorial, and that single-factor causal relationships are quite unusual.

If dental occlusion can, in fact, be the sole or predominant cause of TMD, it would not only be unusual, it would have been quite easy to establish that relationship by testing the hypothesis. Obviously, that has not occurred. Therefore, the debate that has been framed within Dentistry, "Occlusal" vs. "Multi-Factorial" causation is a fabrication that does not accurately reflect real-world epidemiology in the wider health care environment. Of course causation of TMDs is a multi-factorial issue. The real questions are, "What are the multi-factors that are involved in the causation of TMD?" and "To what degree is dental occlusion a part of that multi-factorial picture?"

A number of occlusal factors have been examined in an attempt to assess their individual effect on TMD. These have included, skeletal anterior open bite, overbite, overjet, crossbite, incisor inclination, missing teeth, posterior occlusal support, balancing-side interferences, working-side interferences, intercuspal interferences, symmetry of contacts in the retruded contact position, and slide between the retruded contact position and the intercuspal position. Although some associations have been recognized, in most studies these have been

assessed individually, not in combinations of two or more. An experienced clinician will recognize that many TMD patients have more than one of the theoretically-deleterious occlusal factors present.

This raises the question of whether the presence of two or more potentially-causal occlusal factors increases the likelihood of contributing to a TMD, or alternatively, whether two or more occlusal factors may decrease the patient's ability to adapt to an adverse occlusal environment. Can two or more occlusal factors act as "causal complexes," as will be discussed later?

As just one example, clinicians have observed a relatively high prevalence of a deep, tightly occluding relationship of the anterior teeth in some TMD patients. This suspected causal relationship may involve not just the individual influence of the amount of overbite or of the amount of overjet, but the relative relationship of the two combined, the ratio or composite effect. While this type of relationship has also been recognized by a number authors [11,12] as a possible contributor to TMD, as Storey [5] has pointed out, few studies have been done to evaluate this relationship. When overbite and overjet have been considered as possible causal factors, in several studies they have been considered individually [13-15]. In one study, only the effect of overbite on selected muscles was evaluated [15] and in another, the effect of overbite and overjet (considered separately) were evaluated relative to three self-report measures [16]. Although retruded condylar position has been correlated with symptomatic TM joints [17], to date no study has been done that evaluates the relationship of overbite/overjet (their composite effect or ratio) to radiographically-determined condylar position in the fossae at maximum Intercuspation.

Theoretically, the effect on the TM joints of a deep and tightly-locked anterior relationship may be even further compounded. Heavy contact of the anterior teeth, with a deep, tightly overlapping relationship, combined with inadequate posterior occlusal support, could direct heavy occlusal forces in a distal direction. This combination could potentially contribute to stretching of ligaments that determine TM joint stability and possibly contribute to the loss of optimum TM joint structural integrity. This effect could, theoretically, result in not just disc displacement but also to disc interference problems, such as catching and locking of the joint(s), and intracapsular inflammation and pain.

The above theoretical example is only one of several possible multiple-factor occlusal relationships that could have a more profound effect than single factors acting alone. There is clearly a need to study combinations of occlusal factors as potential "causal complexes" in TMD.

### Necessary and Sufficient Cause

Understanding of causal relationships becomes more complex when "Necessary" cause and "Sufficient" cause are considered. These terms were first conceived and defined by Galileo Galilei in about 1600. "Necessary" cause means that the factor being considered must be present for the disease or disorder to occur. "Sufficient" cause means that the factor being considered, acting alone, is adequate to cause the disease or disorder but the factor's presence may not always result in an occurrence of the disease or disorder. When specific causal agents are studied, four types of causality need to be considered: 1) Necessary and sufficient cause; 2) Necessary but not sufficient cause; 3) Sufficient but not necessary cause; and 4) Neither necessary nor sufficient cause.

**Necessary and sufficient:** This means that the agent being considered is always present (necessary) in a disease or disorder and that exposure to the agent always causes the disease or disorder. True "necessary and sufficient" causes are very rare for any disease or disorder. Possible examples might include highly infectious diseases or exposure to highly toxic substances. But even in some of the most deadly epidemics of history, such as Bubonic Plague, there were some individuals who, even with exposure, did not contract the disease. Therefore, this scenario is seldom, if ever, true for TMD.

**Necessary but not sufficient:** This means that the agent is always present (necessary) in the disease or disorder but that exposure to the agent does not always cause the disease or disorder. This is the causal relationship most common in infectious (even highly infectious) diseases. It is the "model" upon which our most common concepts of causation are based. Its historical reference is Koch's postulates.

Although it is valid for infectious diseases in particular, it may be an erroneous and simplistic concept in many other situations. Necessary but not sufficient causation would be true for TMD if an occlusal factor (or stress, or bruxism, or trauma, or any other single factor) of some kind is always necessary for TMD to occur. However, there is no evidence that this is true.

**Sufficient but not necessary:** This means that any of several agents, individually, may have the potential (may be sufficient) to cause the disease or disorder. However, no single agent is always present (necessary) in causing the disease or disorder. An example where this would be true is with oral cancer, which can be caused by tobacco, radiation, or chronic irritation. "Sufficient but not necessary" would appear to be true in TMD when trauma is involved in the onset. However, where trauma is involved, there can also be predisposing factors that may play a role in the onset of the TMD. Thus in some circumstances, even the trauma acting alone might not be sufficient were it not for other predisposing factors. "Sufficient but not necessary" is probably true for some TMDs. However, it is less likely than in the following type.

**Neither necessary nor sufficient:** This means that several agents may be known to be involved in the disease or disorder, but not all in all cases. No single agent is always present (necessary) in the disease or disorder. No single agent, alone, may cause the disease or disorder (is sufficient) and a combination of two or more agents may be required to cause the disease or disorder. A different combination of agents may be causative in different individuals or at different times. Epidemiologists consider this to be the most common model of causation in diseases and disorders, generally, and it is almost certainly the most common with regard to TMDs. This relationship is the most complex and, for that reason, is by far the most difficult to scientifically demonstrate causation with either experimental or observational studies.

It is worth noting that, as one progresses down this list, the occurrence of the causal relationships becomes more common, the causal relationships become more complex, and the prospect of achieving scientific evidence of causation becomes increasingly daunting.

## History of Causal Thinking

Susser [10], in tracing the history of the development of causal thinking, states that prior to the 1950's there was a tendency for epidemiologists to think of causation in the context established by Koch's postulates; i.e. as "necessary but not sufficient." Recognizing that the "necessary but not sufficient" concept remains appropriate for infectious diseases and other conditions where a single causal factor could clearly be associated with causation, Susser points out that the intense investigation that began in the 1950s into the relationships between smoking and lung cancer, began to cause the pendulum to swing and has resulted in a nearly universal acceptance of "neither necessary nor sufficient" causation in a wide variety of chronic diseases and disorders. In this context, Rothman [18,19] and other epidemiologists now talk of "sufficient component complexes." Rothman states, "most causes that are of interest in the health field are components of sufficient causes, but are not sufficient in themselves."

## Is "Cause" the Right Word?

Susser [10], in providing a description of the characteristics of a cause, states, "In a pragmatic perspective, a cause is something that makes a difference." However, again looking at the historical development of causal thinking in an attempt to further clarify meaning, Susser has considered the terminology that has been used in describing causation. Although others continue to use the designation, "cause," Susser says that he has now abandoned the use of that term for "a broad, nonspecific category of 'determinants'". And he has further divided that term into "active determinants" and "static determinants." This choice of terminology has also been adopted by Rothman [11] and other epidemiologists.

According to Susser [10], these two designations are as follows: 1) An active determinant produces change; 2) It may be an intended or unintended intervention. 3) It may be a natural force or an accident. 4) It may be the removal or absence of something needed (such as vitamins).

A static determinant is usually an unchanging antecedent in a set of circumstances. This may result in outcomes that differ as the nature or quality of the condition differs. These are usually fixed attributes or circumstances, such as gender, heritage, or geography. They may be changeable attributes such as lowered immune system, poverty or rural isolation.

But returning to Susser's pragmatic description of "cause" as something that makes a difference, his description, although not very specific, is consistent with the definition of a cause provided by Lilienfeld and Stolley [20]:

"In practice, a relationship is considered causal whenever evidence indicates that the factors form **part of the complex of circumstances** which **increases the probability** [Emphasis added] of the occurrence of disease and that a diminution of one or more of these factors decreases the frequency of the disease".

## Correlations and Differentiation

Determining the cause(s) of TMDs is far from a straightforward and simple process. There is general agreement that TMD is a broad, generic term that encompasses a wide variation of conditions involving the masticatory musculoskeletal structures. There is also wide agreement that causation related to TMDs is of multi-factorial origin. The likelihood of identifying any single "cause" as having a predominant role is clearly remote.

The previous statements are very general in nature, providing almost no enlightenment related to causation, particularly regarding diagnostic variants under the broad rubric of "TMD". The current state of the scientific literature is seriously lacking, as most studies that have attempted to examine the possible causal relationship between dental occlusal factors and TMD have failed to provide adequate differentiation on at least one of three possible levels: 1) Differentiation by diagnosis; 2) Differentiation of possible causal factors; 3) Differentiation by specific type of occlusal factor.

To make this lack of specificity more clear, compare the following two statements:

"Occlusal disharmonies (general causative factor) are a significant etiologic factor in temporomandibular disorders (general diagnosis)."versus "Deep, tightly locked relationships of the maxillary and mandibular anterior teeth (specific co-factors) are significant etiologic factors in articular disc displacement of the temporomandibular joint (specific diagnosis)".

Each of the above statements is a hypotheses and could be tested. The second statement, however, significantly narrows the number of variables that would need to be tested, thus providing a more limited testing environment.

## Differentiation by Diagnosis

For either experimental research or observational studies to be done using specific diagnostic categories, a broadly accepted scheme of diagnostic categories would need to exist. There are several important reasons for such a diagnostic scheme to be available to both researchers and clinicians. Several such schemes have been proposed [21-24] but none have thus far been universally adopted. Those that have been proposed have demonstrated limitations [25]. There are very real challenges in arriving at such a diagnostic scheme that meets the needs of both researchers and clinicians. Okeson has elaborated on these difficulties [26]. However, until such a scheme can be devised and a consensus reached, further research will be hampered in important ways.

The need for as great a degree of specificity as possible in diagnostic differentiation is recognized. The current diagnostic schemes are lacking in this respect. For example, in the AAOP diagnostic classification [24], internal (disc) derangements are divided into only two categories, disc displacement with reduction and disc displacement without reduction. An experienced clinician will readily recognize that disc derangements with reduction actually represents a spectrum of conditions, from joints demonstrating only mild, uncomplicated clicking, through several levels of disc interference, often referred to as catching, to an advanced condition of disc interference approaching locking (near non-reduction.) These wide variations appear along a continuum, without clear delineation, and are significant to the

clinician because appropriate treatment could vary a great deal from no treatment at all (mild, uncomplicated clicking), through use of a stabilization appliance, to management possibly involving some kind of mechanical intervention to prevent further progression and locking. Furthermore, there is some evidence, primarily via imaging [27], to indicate that the articular disc can displace in several different directions. If each type of displacement has a different complex of causation, then being able to make these diagnostic distinctions would be critical to determining a related causal complex. To be able to compare the results of two or more studies that theoretically used the same variables, the diagnostic criteria used for selection of subjects must be the same. When the diagnostic criteria remain ill-defined, comparison between studies will remain suspect.

In summary, the less specific the diagnosis, the less valid will be the conclusions regarding causation. Much of the existing literature related to causation of TMDs uses no more specific a diagnosis than simply "TMD".

### Differentiation by Broad Areas of Causation

Several broad areas of possible causation are appreciated. For instance, recent trauma followed in close temporal sequence with onset of masticatory pain is considered an obvious etiologic factor in certain types of TMD. Because a history of trauma may represent a causative, or possibly a predisposing factor, patients who have a history of trauma to the face or head, including whiplash, either recently or in the past, should logically be identified and excluded from any study that is looking at some other potential causative factor. Likewise, patients who are known to brux their teeth should be excluded from a study that is looking at etiologic factors other than bruxism.

Selection of subjects for an observational epidemiological study, based on this kind of specific criteria, is equivalent to assignment of subjects in an experimental investigation. Exclusion of subjects based on confounding criteria of this kind have not been done in most studies.

### Differentiation by Specific Type of Occlusal Factor

Several specific types of occlusal factors, as previously described, have been considered in studies as possibly affecting masticatory function and as possible contributors to masticatory dysfunction. To the degree that occlusal factors might affect masticatory function, it would seem likely that not all occlusal factors would affect masticatory function in the same way or to the same degree. Unfortunately, comparisons of very specific occlusal factors to very specific conditions of the temporomandibular joints are seldom found in the current literature. Literature relating dental occlusion to TMD commonly tests a specific type of dental occlusal variable as a causative factor against the broad, general category of TMD, not against a specific diagnostic category. Therefore, for studies looking at occlusal factors as possible causative factors in TMD, the more specific the differentiation of the type of occlusal factor, the more specific will be the conclusions drawn from the study.

Previously, an example was suggested comparing deep, tightly locked relationships of the maxillary and mandibular anterior teeth as a possible etiologic factor in articular disc displacement of the temporomandibular joint. In summary, if a study were to be undertaken regarding the specific relationship described above, for that study to have the highest level of validity, it would not only need to compare the specific occlusal factors (deep, tightly-locked overbite and overjet) with the specific diagnosis (displacement of the articular disc), subject selection would need to exclude any other possible factors, such as a history of trauma, evidence of bruxism, or the presence of other occlusal factors that might potentially have contributed to the effect of disc displacement.

It is apparent that at the present time the dental literature related to dental occlusal factors, as they may relate to causation of TMDs, is seriously lacking in several ways regarding differentiation. The need for differentiation, in this manner, has been pointed out by several authors [6,28-30]. This error in design should be considered in future studies.

## Study Design in Epidemiology

When epidemiologic methods are used in attempting to demonstrate a causal association between dental occlusion and TMD, it is necessary that appropriate study design be used if the study is to be valid.

Epidemiologic studies can be one of two general types, 1) particularistic studies, and 2) association studies. When a causal association is being studied, only association study design is appropriate.

## Particularistic Study

In a *particularistic study*, the purpose is to determine the amount and distribution of a disease or disorder in a population. Such a study must use samples representing the base (general) population, acquired by methods such as randomized selection. This type of study is useful for various practical and administrative purposes. It is inadequate and inappropriate for etiologic analysis.

## Association Study

In an *association study*, the purpose is to consider the relationship between a disease or disorder and its possible cause. Such a study must use samples selected to represent the extremes of variation, not samples representing the general population. Example: In a study examining whether big rocks fall faster than small rocks, it is necessary to use only big rocks and small rocks to be able to distinguish differences in these two extremes. In an experimental study, attempting to demonstrate extremes of variation for purpose of making comparisons would require exposing people to possible causative factors that could increase the disease or disorder being studied. For ethical reasons, this is not possible. Therefore, in an observational study attempting to demonstrate these extremes, it is necessary to create these extremes for comparison by selection of subjects.

Miettinen [28] emphasizes this need in *Theoretical Epidemiology*. Unfortunately, a number of studies in the dental literature have attempted to examine the association of dental occlusion and TMD using particularistic study design [31-33]. Rothman [19] has indicated that this type of study design error is commonplace in medical epidemiology and has stated, "confusion over this point is deeply rooted".

Meeting the requirements of association-study methodology when assessing a causative relationship between dental occlusion and TMD is especially daunting because of the high prevalence of occlusal factors in the general population. Achieving a sufficient variation in the study base may be difficult, if not impossible. This may explain, in part, why studies using appropriate study design have been extremely scarce in the dental literature related to dental occlusion and TMD. This difficulty does not, however, justify using particularistic study design as a substitute.

## Critical Effect Size

Other examples of this dilemma have previously been encountered in dental research. For instance, in years past it was difficult to find subjects without any caries or totally free of gingivitis. The problem of acquiring sufficient numbers of subjects to demonstrate a significant difference between test and control samples has also been pointed out by Storey [5,6]. He has said, "the likelihood that occlusal interferences are significantly associated with TMD (the power of association,) will be determined by the significance level desired, by the number of subjects, and [by] the Critical Effect Size." Here he references Kraemer and Thiemann [34] "The Critical Effect Size is the difference in the parameter being measured between the test and control samples". Storey goes on to say, "Because the prevalence of occlusal interferences has been reported to be approximately the same in the symptomatic population as in the treatment populations, the Critical Effect Size is very small and therefore the number of subjects needed to establish an association is extremely high. It is not surprising that epidemiologic studies, most with inadequate numbers of subjects, have found only weak or no associations between occlusal interferences and TMD". Therefore, assuming all other factors are equal (which is not likely to be the case), the larger the number of subjects in a study, the more valid will be the results.

As a means of demonstrating this effect, consider a group of 57 studies cited by Okeson [35] that looked at the effect of a variety of occlusal factors as they related to TMD. In these 57 studies, the number of subjects in the studies ranged from 12 to 3428. Okeson indicates which of these studies demonstrated a causal relationship (based on the author's conclusions) and which did not.

Counting the number of positive correlations ("Yes"-35) and the number of negative correlations ("No"-22), this is a ratio of 1.8545/1 in favor of a positive correlation between occlusal factors and TMD. If all studies having less than 200 subjects [number arbitrarily chosen] are eliminated (28 studies) and the same calculation is done again, out of the 29 remaining studies, 21 found a correlation ("Yes") and 8 found no correlation ("No"). This is a ratio of 2.625/1 in favor of a positive correlation between occlusal factors and TMD.

Thus, it must be concluded that in doing epidemiologic studies, not only is it critical to use the appropriate study design, an associative study, to evaluate causal relationships, but because the occurrence of occlusal discrepancies is very high in the general population, it is also critical, when looking at the causal relationship between dental occlusion and TMD, that the study include very large numbers of test subjects and controls to demonstrate a valid association or lack thereof. Few studies that have looked at this issue have adequately met these criteria.

## Provocation Studies

Storey [5] has pointed out that, "epidemiologic data that addresses the question of an occlusal cause for TMD come from 1) clinical studies in which TMD patients seeking treatment are examined for occlusal factors thought to put patients at risk; 2) clinical studies of patients who are examined for signs and symptoms of TMD after receiving some from of occlusal treatment; and 3) surveys of non-treated individuals in whom correlations are sought between occlusal factors and symptomatology." In addition to explaining why a large number of these studies are flawed, as discussed above, Storey goes on to state, "Another approach to establishing cause-effect relationships is to provoke TMD in asymptomatic subjects. Provocation studies rule out many of the confounding variables in epidemiologic studies by introducing occlusal interferences into normal healthy subjects and observing the development of signs and symptoms of TMD." The value of provocation studies in assessing possible causation of TMD has also been pointed out by others [5,6,36-38,63,64].

The primary benefit of provocation studies is that they are prospective in nature and therefore have the potential to meet all of the requirements to demonstrate causation, as described by Susser; i.e. association, time-order, and direction. It is primarily because of this potential that several authors have stated that provocation studies are more powerful in design than other types of epidemiological studies in assessing a causative relationship between dental occlusion and TMD [5,6,36-38].

As with other types of studies, provocation studies have limitations. They have been done on both animals and on humans, and while animal studies have produced some interesting results [39], the most meaningful results come from those done on humans. For ethical reasons, the design of studies using human subjects is limited because of the potential for causing irreversible harm. As a result, most of these studies have been of 2 weeks duration or less. One study, in which 6 adults were evaluated following placement of "an occlusal prematurity causing lateral deflection of the mandible (balancing-side interference)," however, lasted up to 6 months [40].

Provocation studies done on humans are relatively few, compared to other types of epidemiologic studies and have generally involved fairly small numbers of subjects. Provocation studies have examined several variables. These have included introducing a "high" contact in the intercuspal or CR closure position [41-50]. They have included the introduction of an interference to working-side (laterotrusive) excursive movement [51-54]. Introduction of an interference to balancing-side (mediotrusive) excursive movements has also been studied [55-62]. In all but one study, these interferences were introduced into healthy subjects with no prior history of TMD. Most of these studies have measured changes in EMG recordings, primarily of the masseter and temporalis muscles. In addition, changes in subjective symptoms have been reported and changes of clinical indicators of dysfunction have also been assessed. Interestingly, in each of these three categories of provocation studies, the results of studies that appear to be assessing the same variables have been inconsistent. Several studies, however, have produced significant findings [37,40-47,51-58,60-62,64-67].

Storey [6] has stated, "Asymptomatic subjects in all these studies developed signs and symptoms of TMD (some very severe) over a short period of time." De Boever., *et al*. [63] stated, "These studies have shown that artificially introduced occlusal interferences can provoke immediate responses in the contraction pattern of jaw muscles and they may induce jaw muscle hyperactivity and pain in some subjects".

Certain authors have been critical of these studies for small study size and for not controlling for suggestion. Other design faults include short duration and the fact that the effect of the sudden introduction of an interference is not equivalent to the effect of a similar interference that has been present for a long time in the native occlusion [5,7,39,63]. Furthermore, as Christensen and Rassouli have pointed out, these studies have not "unequivocally established that the observed EMG and ENG changes have specific long-term detrimental effects, possibly because the exact nature and natural course of diseases and dysfunctions of the mandibular locomotor system are not fully understood."[65] Further quoting Christensen and Rassouli, "On the other hand, it is apparent that experimental occlusal interferences are associated with short-term clinical signs and symptoms, such as jaw muscle fatigue and pains, headaches, pains and clicking in the temporomandibular joints".

In spite of some apparent limitations and shortcomings, the potential of provocational studies to unquestionably stimulate symptoms and functional disturbances in otherwise healthy subjects, and the inherent strength of such prospective studies to fulfill the three criteria of scientific causation [10] cannot be dismissed.

### Unique Provocational Study

Of particular interest is a fairly recent study that was published in three parts [65-67]. The authors point out that, prior to this study, all previous studies involving the introduction of an experimental interference have been done on healthy subjects with no prior history of TMD. It is their contention that this may constitute a confounding factor. In prior studies, the ability for healthy subjects to adapt to an interference has been demonstrated to some degree over a period of several days after the interference had been introduced. They propose that subjects that have no history of TMD may have a greater capacity for adaptation than do subjects who, although not currently symptomatic, have a prior history of TMD.

To test this hypothesis, their study involved selecting two groups of subjects, all women, some with no prior history of TMD (n = 31) and a matched group that did have a history of TMD (n = 21). The original symptoms in the group with a TMD history were entirely of myogenous origin. Subjects were excluded if arthrogenous problems had previously been diagnosed clinically (clicking, crepitation, locking) or radiographically. All in this group had been successfully treated for these myogenous symptoms at the University by several methods. Members of each of these two groups were then randomly assigned to either a placebo or a true interference group. In one group a true balancing interference was introduced. In the placebo group, the introduction of an interference was simulated. The result was four groups, two with no TMD history and two with a TMD history. The study lasted 14 days.

Part one of this study [65] reported the clinical signs observed in each group. All subjects with a previous TMD history, including the placebo group, demonstrated a larger number of clinical signs than either of the groups without a previous TMD history. The group with a previous TMD history and who had a true interference demonstrated a significantly higher number of clinical signs than did any of the other three groups.

Part two of this study [66] reported the subjective reactions to the study over a period of 14 days. Those results are demonstrated in figure 1.

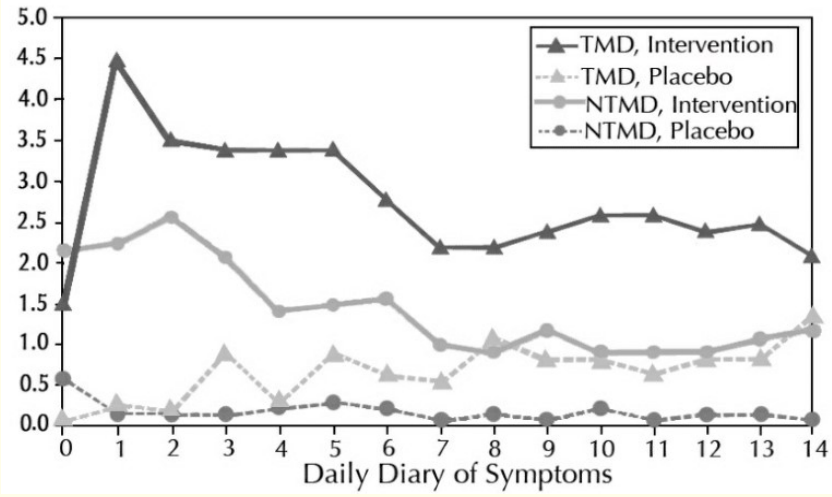


***Figure 1:*** *Mean level of response intensity of occlusal discomfort.*

The dramatic representation of the difference between those who had a history of TMD and who also had a true interference, as compared to all of the three other groups, makes a statement about the role of occlusal interferences as is frequently seen in the clinical environment. If that statement has less to do with the issue of causation and more to do with the role of occlusion as a perpetuating factor, it is none the less highly illuminating and suggests the need for more studies based on this model.

Part three of this study [67] reported the psychological factors and responses of the same subjects, which also varied significantly.

In the simplest terms, this study seems to demonstrate that several factors can be at play when an occlusal interference is introduced. These would include not only the effect of the interference itself on muscles and joints, but also the inherent adaptive capacity, or lack thereof, of the subject, the influence of suggestion (placebo effect), and the effect of certain psychological factors.

The results of this 3-part study would seem to beg the question that, after achieving a stabilization of the mandible on an occlusal appliance, including a reduction of symptoms and dysfunction, and a relative return of normal masticatory function, do pre-existing occlusal factors that may be present in the native dental occlusion, **whether or not they had a causative role in the onset of the TMD**, represent a risk for the return of the original symptoms and dysfunction if those occlusal factors are not eliminated?

## Discussion

Like many clinicians, this author has been influenced by early training and by many years of personal experience regarding the role of dental occlusion as it affects temporomandibular disorders. While acknowledging a resulting bias, this paper was an attempt to set aside that bias to look at the quality of the existing science on both sides of this topic in as objective a manner as possible, with a desire for increased understanding of the existing science.

It is immediately clear that the question of a causative relationship between dental occlusion and TMD is complex. If a discussion of this kind is to have credibility, the evidence on both sides of the question must be based on sound scientific reasoning. Such reasoning must derive from rules of logic described by individuals recognized as philosophers of science and by logicians in the field of epidemiology.

Although perhaps not universally accepted, Popper's principles of "refutation" and "survivability" are broadly seen as the foundation for contemporary assessment of hypotheses in the scientific setting. Applying these principles, those who question the hypothesis of an occlusal role in causation of TMDs will, therefore, need to find a more effective means of challenging it than simply stating that the "evidence does not support it". Here there is validity in the expression, "absence of evidence is not evidence of absence".

Based on Susser's criteria [10] to demonstrate causation; association, time-order, and direction, the majority of research that has purported to address the issue of a causative relationship between dental occlusion and temporomandibular disorders has been flawed in a number of ways and seldom meets these criteria. The limited number of studies that have risen to the level of meeting Susser's criteria, principally prospective provocational studies, although also flawed in certain ways, give us perhaps a glimmer of the potential to demonstrate a causative relationship that may meet the requirements of Science.

Discussion of issues of causation of TMDs is, unquestionably, of great academic interest. However, aside from those cases where trauma is clearly involved, the issue of causation in the majority of TMD patients is, for this author, of considerably less clinical interest. It is noted that this opinion is also shared by one of the most published challengers of the dental occlusal hypothesis, Charles Greene. Responding to a guest editorial by Penti Alanen [68] by way of a letter to the editor in the *Journal of Dental Research* in 2002, Dr. Greene stated the following, "*the question of whether occlusion still belongs on the large menu of possible TMD etiologic factors has become truly of academic interest only*. [Emphasis added] Such menus are often described as multi-factorial; but as I pointed out in a recent article [70], this term often is a cover-up for the word 'idiopathic.' While treating etiologic factors directly is generally superior to symptomatic treatment, many morphologic, functional, and behavioral variables cannot be manipulated therapeutically. . . **I am willing to leave occlusal imperfections on the menu of possible etiologic factors . . .**" [Emphasis added].

In that context, the interest of this clinician in the role of occlusion, as it relates to the long-term management of patient's TMD problems, is far more informed by the provocation study that involved a comparison between the response of patients who had a history of TMD compared to those who had no such history [65-67]; i.e. regarding the role of occlusion as a potential perpetuating factor. In the protracted attempts to assess the possible causal relationship between dental occlusion and TMD, the previously mentioned study is one of the most significant yet done and may represent a watershed in the search for understanding on this subject. Further studies based on this model may offer further insights.

Rather than continue to dwell on the arguments, pro and con, regarding the causative role of occlusion in TMDs, which, due to ethical constraints and the complexity of doing appropriate studies, may not be satisfactorily resolved in the foreseeable future, what should be of greater clinical interest is what treatments can consistently and effectively be utilized to address the symptoms and functional disorders of patients. And equally as important is what can be done to minimize the risks that patients will have their TMD problem chronically return. The importance of the role of dental occlusion is far more likely to be demonstrated in the arena of treatment and particularly regarding it's potential role as a perpetuating factor.

## Conclusion

For several decades the hypothesis, "Dental occlusion plays a significant causal role in temporomandibular disorders", has been debated and a substantial body of literature that examines this issue has emerged from scientific studies. Recently a number of "experts" have made claims that the existing scientific literature, "does not support" this hypothesis. This paper examines both the scientific principles that are applicable to the question of causation, in general, as well as the qualitative value of the scientific literature that specifically has considered the previously mentioned hypothesis. The conclusion is that most of this literature is qualitatively flawed in one or more ways and, therefore, does not refute the hypothesis. Applying Popper's "refutation" principle, it must be concluded that, far from having been refuted, the hypothesis of an occlusal causation for TMD remains viable and should be further challenged in the future by a higher level of scientific inquiry.

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