Occlusion for fixed prosthodontics: A historical perspective of the gnathological influence

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This article addresses the historical perspective of the gnathological influence upon the concepts of occlusion for fixed prosthodontics. A critical assessment and subsequent scientific validation of occlusal theories require an understanding of their evolution in the formative years and the subsequent development of effective models for clinical practice. While gnathological concepts offer a structured methodology for prosthodontic procedures, further research is needed to corroborate current occlusal treatment approaches. This review focuses on the "classic" fixed prosthodontic literature and the currently available scientific literature involving fixed prosthodontic dentate occlusion and gnathology. A MEDLINE search was performed to identify English-language peer-reviewed publications spanning the last 56 years, along with an extensive hand search for years prior. Electronic searches of the literature were performed in MEDLINE using the key words: case series, clinical trials, cohort studies, fixed partial denture occlusion, dental occlusion, dental occlusion research, centric relation, incisal guidance, maximal intercuspation, occlusal vertical dimension, and occlusion, in various combinations to obtain potential references for review. A total of 10,382 English-language nonduplicate titles were obtained for 1950-2006 for the key words "dental occlusion." Other key word searches produced smaller numbers of articles, many of which were duplicates due to multiple searches and were subsequently eliminated. Manual hand searching of the MEDLINE reference list and other journals of interest was performed to identify any articles missed in the original search. Articles were included for review if they contained emerging occlusal theories, new technologies, or occlusal studies that included multiple subjects in contrast to case reports. (J Prosthet Dent 2008;99:299-313)

The recognition of gnathological concepts, which began in the 20th century, may have reached its greatest penetration in predoctoral education in the 1970s. Since then, there has been an apparent attenuation as a result of the reduction of predoctoral prosthodontic education and by its integration into other disciplines.

An understanding of occlusion must be based on knowledge of the physiology of the masticatory system and insight into its functional geometry and dysfunctional adaptations.[1-5] A critical assessment requires a review of the historical evolution surrounding the concepts and theories of occlusion in the formative years and its subsequent scientific validation, which is the aim of this paper. Select literature, both supporting and contrasting, is highlighted.

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Presented at the Academy of Prosthodontics annual meeting, Niagara Falls, Ontario, May, 2004.

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History of gnathology

Stallard first coined the term *gnathology* in 1924, defining it as the science that relates to the anatomy, histology, physiology, and pathology of the stomatognathic system and that includes treatment of this system on the basis of examination, diagnosis, and treatment planning. McCollum[6] formed the Gnathological Society in 1926 and, along with Harlan, is credited with the discovery of the first positive method of locating the transverse horizontal axis and transferring the recording to an articulator using components from a Snow Facebow. The Gnathological Society grew from a few to 15 and finally 24 dentists, converging as a "clinic club" attempting to explore and record their observations of occlusion and eccentric movements in a scientific manner over a 13-year period between 1924 and 1937.

Stuart[6] became associated with the Gnathological Society early and published the classic "Research Report" with McCollum in 1955. Their observations led to the development of the principles of mandibular movements, transverse horizontal axis, maxillomandibular relationships, and an arcon articulator that was designed to accept the transfer of these records. The goal was to truly capture maxillomandibular relationships that accurately reproduced border jaw movements and which would prescribe the best occlusal interface. The registration of the horizontal and sagittal displacements of patients was believed to allow the maximum cusp height-fossae depth with proper placement of ridges and grooves as described in the anatomical illustrations of McHorris[7] and Schillingburg.[8]

It is interesting to note that McCollum believed in the concept of bilateral balanced occlusion in the restoration of the natural dentition. However, Stuart[5] did not, as he observed failures due to the unequal wear of the buccal and lingual cusps causing deflective occlusal contacts or interferences with a loss of centric-related closure. Patients noted that their masticatory freedom was lost and it caused them to bite their cheeks and tongue.

Fundamentals of gnathology

The fundamentals of gnathology include the concepts of centric relation, anterior guidance, occlusal vertical dimension, the intercuspal design, and the relationship of the determinants of mandibular movements recorded using complex instrumentation to the occlusion in fixed prosthodontics. These fundamentals were reported in Principles of Occlusion by Pokorny DK, Blake FP, Anaheim, Denar Corp, 1980, and in The History of Gnathology by Stuart CE, Golden IB, Ventura, CE Stuart Instruments, 1984.

Centric relation

The early gnathologists studied the recorded tracings made during manipulated mandibular movements. When the mandible travels forward along the sagittal plane it is considered a protrusive excursion or protrusion. Therefore, retrusion is the movement toward the posterior, and it is the most retruded physiologic relation of the mandible to the maxilla to and from which the individual can make lateral movements that defines centric relation (CR) to the gnathologist. Further investigations led the gnathologists to believe that mandibular (condylar) movements are governed by the 3 axes of rotation. The concept of centric relation evolved as a 3-dimensional characterization, resulting in its description of centric relation as the rearmost, uppermost, and midmost (RUM) position of the condyle in the glenoid fossa.

The gnathologists believed in the concentricity of centric relation. The radiographic interpretation in Weinberg's[9-11] research supported this concept. Weinberg[12] showed the 2-dimensional space of the long axis of the condyle by using an anatomically aligned lateral transcranial temporomandibular joint (TMJ) radiographic technique so that interpretations could be made. When radiographs of the TMJs were made with the patients' mandible in the maximal intercuspal position, the investigators believed that deflective occlusal contacts would displace the position of the condyle within the glenoid fossae asymmetrically, either anteriorly, posteriorly, or superiorly.[13-16]

This observation may be measured quantitatively and used as a diagnostic aid along with the clinical evaluation and occlusal analysis of mounted diagnostic casts. A pre- and posttreatment axially corrected tomogram will produce a more accurate segmented image of condylar position, as compared to a transcranial radiograph. Diagnostic information related to the condyle disc articulation also can be acquired with a nuclear magnetic resonance (MRI) image.[17,18] A central gnathological theme was to have maximal tooth intercuspation coinciding with centric relation.[19] Often this situation or goal was historically referred to as centric relation occlusion (CRO). The Glossary of Prosthodontic Terms, eighth edition (GPT-8), describes CRO as centric occlusion, which may or may not coincide with maximal intercuspation.[20] After prosthetic intervention and/or occlusal equilibration to CRO, new radiographs of the TMJs can illustrate changes mimicking symmetry and concentricity of the condyles in the glenoid fossae.

It is important to note that there are no high-level research studies that relate mandibular concentricity to temporomandibular disorders (TMD) and orofacial pain.[21] This finding does not eliminate the obligation of documenting the pre- and posttreatment condylar position for clinical procedures that alter the occlusal vertical dimension and mandibular position with occlusal devices, occlusal equilibration, and complex restorations involving maximum intercuspation.[22]

In the GPT-8, centric relation is

defined as the maxillomandibular relationship in which the condyles articulate with the thinnest avascular portion of their respective disks with the complex in the anterior-superior position against the shapes of the articular eminencies. The inclusion of a nonclinically verifiable anatomical relationship added to the definition compelled Ash[23] to question whether centric relation was destined for obsolescence. A study of 7 dental schools, including both faculty and students, resulted in the conclusion that there is no consensus on the definition of centric relation, which contributes to the confusion students have regarding the definition and the recording of centric relation.[24] The clinical practice of prosthodontics would be difficult without the application of a repeatable reference point that CR encompasses in the development of fixed and removable prostheses. Dawson[25] believed that there is hardly an aspect of clinical dentistry that is not adversely affected by a disharmony between the articulation of the teeth and the centric relation position of the temporomandibular joints. In many gnathological circles the treatment of patients with severely disorganized occlusions would begin reconstruction with transitional restorations, including cast-metal occlusal surfaces. The occlusion would be subsequently adjusted to a centric relation-centric occlusion position with a mutually protected articulation until the physiological adaptation of the patient was achieved. The gnathological treatment concept typically required that both the maxillary and mandibular teeth be prepared so as to eliminate any deflective tooth contacts, deprogram the musculature, and stabilize the temporomandibular joints to a reproducible position. Following this adjustment or tooth preparation, a pantographic recording would be made prior to definitive rehabilitation to achieve an "organic occlusion." Cast-metal transitional crowns have limitations related to cost, inability to increase the occlusal vertical dimension, and changes in mandibular position that cannot be equilibrated easily to a new maximum intercuspal relationship. It is the authors' opinion that, out of convenience, clinicians attempt to accomplish these revisions with laboratory-processed acrylic resin provisional restorations.

Anterior guidance

Disocclusion refers to separation of opposing teeth during eccentric movements of the mandible, as reported by Christensen.[26] D'Amico,[27] after making anthropologic observations of skulls of Native American Indians and reviewing studies of Australian Aborigines that had edge-to-edge anterior occlusions, and noting the severe wear of the entire dentition, suggested the concept of canine guidance. Stuart and Stallard[4] also observed this phenomenon and therefore developed anterior guidance as part of their gnathological concept in mutually protected articulation. According to the philosophy of gnathology, the anterior teeth protect the posterior teeth in eccentric movements and conversely have the posterior teeth protect the anterior teeth in maximal intercuspation (mutually protected articulation) without any deflective occlusal contacts or interferences in speech.

Occlusal vertical dimension

Anterior guidance may be developed through multiple disciplines in oral and maxillofacial surgery, orthodontics, prosthodontics, occlusion, or a combination of these. The development of occlusal vertical dimension (OVD) is a function of maxillary and mandibular growth along with the eruption of the dentition and accompanying alveolar bone formation.[28] Growth variations and acquired processes can alter the OVD. This spatial relationship is often measured by the evaluation of phonetics, the interocclusal distance from rest position to mandibular incisal contact into the lingual cingulum area of the maxillary incisors, and facial-tooth esthetic profiling.[29,30] The mandibular-maxillary incisal relationship assists in establishing the anterior reference of occlusal vertical dimension (OVD). After studying children through adolescence and edentulous adults, Thompson and Brodie[31,32] reported that occlusal vertical dimension is constant and does not vary though life. Other investigators found that the vertical dimension of rest varies with speech, emotion, jaw relationship, resorption, body position, and after natural tooth contacts are lost.[33-43] As such, these variations may impact determinations of the OVD.

Desjardins[44] noted that the rest and occlusal vertical dimensions are considered some of the most difficult mandibular positions to evaluate and are evaluated in the most unscientific manner. He concluded that because all methods of determining rest position are somewhat unscientific, evaluation of OVD should not be confined to a single technique or consideration.

If the anterior teeth are to be restored, then from the articulated diagnostic casts, a diagnostic arrangement can be designed to optimize the mutually protected articulation, and this relationship can then be transferred to the provisional restorations. Additionally, this design may be used to fabricate a custom incisal guide table in autopolymerizing acrylic resin onto the articulator's incisal guide table.[45] In gnathology, this technique should be performed first so that the OVD and anterior guidance are established and then harmonized with the posterior determinants. The posterior tooth morphology is then designed so as to incorporate the maximum development of a mutually protected articulation, without infringement upon phonetics and/or esthetics.

Intercuspal position

Once a functional and reproducible centric relation is established that

is without TMJ pathology, and a functional mutually protected anterior guidance is developed, then the posterior occlusal morphology may be designed. The goal of gnathology is to establish an occlusion that is interference free and entails the concept of an organic occlusion. Organic (organized) occlusion encompasses disocclusion, cusp to fossae relationship, centric (relation) occlusion, uniform centric contact, forces directed in line with the long axes of the teeth, tripodism, twin centric contact for cross tooth stability, narrow occlusal table, maximum cusp height, and fossae depth with supplemental anatomy.[4]

Competing occlusal concepts

As gnathology was evolving, several competing occlusal concepts and permutations were theorized, ranging from modification of the gnathological schema to other treatment approaches based upon different reference perspectives. Beyron,[46] following his observations on Australian Aborigines, suggested that uniform tooth contact and resultant attrition on several teeth in lateral occlusion was a positive and inevitable outcome. As a modification of canine guidance, the Pankey-Mann-Schuyler (PMS)[47] philosophy in complete oral rehabilitation was to have simultaneous contacts of the canine and posterior teeth in the laterotrusive (working) excursion, and only anterior teeth contact in the protrusive excursive movement.[48-49]

Schuyler[50-52] further suggested that incisal guidance without freedom of movement from a centric relation occlusion to a more anterior tooth intercuspation will "lock-in" the posterior occlusion. The incisal guidance along with "long centric" is determined by the distance from transverse horizontal axis-centric relation and the normal freedom of movement in the envelope of function. This method requires that the incisal guidance be established and the mandibular posterior buccal cusps be placed to a height measured along the occlusal plane as dictated by the Curve of Monson. The maxillary posterior teeth are developed after the completion of the mandibular restorations as dictated by a wax functionally generated path record, as suggested by Meyer,[53] and placed on a vertical displacement articulator. The definitive restorations are equilibrated into a centric relation position with mandibular buccal cusps onto fossae-marginal ridge contact with "freedom in centric" anterior guidance and group function in laterotrusive (working) excursion. It must be noted that the PMS philosophy was developed and its use advocated on a nonarcon articulator, which may not accept interocclusal records made at increased OVD.[54]

Moller[55] reported on the electromyographic study of the actions of the muscles of mastication in 1966. In the process, other occlusal concepts evolved, including the myocentric (neuromuscular) occlusion philosophy that selects the rest position as the reference position. In 1969, Jankelson[56,57] introduced the use of transcutaneous electric neural stimulation (TENS), in the form of a Myomonitor unit (Myotronics-Noromed, Kent, Wash). After a time period of stimulation with the unit and when it is determined that the muscles are relaxed, an interocclusal record is made to establish "myocentric occlusion." Jankelson[57] defines myocentric occlusion as that terminal point of occlusion achieved by isotonic muscle contraction from the rest position along the myocentric (muscle-balanced) trajectory. He further observed that the position created may or may not coincide with the intercuspal position, but in no instance did it coincide with centric relation. In a study of 10 subjects, he concluded that, by means of inspection, palpation, and intensity-duration curves, the unit stimulated the fifth and seventh cranial nerves neurally.[56] A particular occlusal morphology was not described.

Remein and Ash[58] investigated the characteristics of "Myomonitor centric" as it relates to centric relation, centric occlusion (intercuspal position), reproducibility, and the effect of head posture on the recording. In a study of 10 individuals, the authors concluded that the "Myomonitor centric" is not reproducible because the reference point, rest position, varies on anterior-posterior head position, and its pulsed intercuspation position is anterior to centric relation and centric occlusion. Also, the axis of rotation is located anteriorly and inferiorly from the transverse horizontal (terminal hinge) axis. Clinically, it would appear to be difficult to integrate a verifiable and repeatable occlusal design (cusp-fossae, ridge and groove direction) with this concept. Kantor[59] and Strohaver,[60] in independent studies, concluded that Myomonitor registrations, in reality, recorded a protrusive relationship.

The selection of maximal intercuspation (MI), irrespective of centric relation, as a treatment position is often used for the placement of a single crown in the presence of an acceptable anterior guidance, OVD, TMJ, and neuromuscular-proprioceptive health.[61-62] The use of MI as a treatment position relies upon the presence of a predominating anterior guidance, noted by Schuyler,[52] and neuromuscular-proprioceptive feedback. However, the selection of a patient's existing MI as a treatment position is not always possible, as centric occlusion may not exist or may be eliminated by missing teeth or as tooth quadrants are prepared for fixed restorations. Quadrant casts, which lack cross-arch articulation, and a nonadjustable or average value articulator are typically used with this method. Additionally, this approach lacks appropriate bilateral condylar determinants and/or exact 3-dimensional spatial dynamics of jaw movements. As a result, any treatment or intervention that alters the occlusal interface without respect to a reference position and/or posterior guidance factors may potentially become contributory to occlusal discord, which may be visualized as oc-

clusal interface errors, in particular, in posterior molar regions, requiring significant chairside adjustments to achieve proprioceptive acceptance by the patient.

In a literature review of the historical concepts of anterior guidance, Thornton[63] divided articles into those that advocated group function and those that supported canine protected articulation. Thornton concluded that evidence-based science does not preclude superiority of one philosophy over another, but current observations appear to number more proponents of canine protected articulation.

In relation to incisal guidance, it is important to note the research of McNamara[64] on a rhesus monkey, followed by Gibbs and Mahan et al[65] on 11 human subjects with complete dentitions, that showed the independent EMG recordings of the superior (SLP) and inferior (ILP) bellies of the lateral pterygoid muscle. Stabilization of the disk occurs when the SLP muscle and the ILP muscle work interactively. The SLP contracts maximally upon clenching, such as during maximal intercuspation, and the ILP contracts during protrusive movements with incisal guidance. This observation of reciprocal muscle activity suggests the elimination of posterior and/or laterotrusive contacts in protrusive excursive movement because of the potential effect on the TMJ-disk relationship and a possible contributing factor in temporomandibular disorders.

Though 90% of natural dentitions have a deflective occlusal contact or an occlusal "prematurity" between centric relation and the intercuspal position, it is usually in the form of a slide that has both a vertical and horizontal component occurring in all 3 planes.[66-70] Pullinger et al[71] suggests that an intercuspal position anterior to the retruded contact position in association with bilateral occlusal stability may be protective. According to Ash and Ramfjord,[72] the horizontal "long centric," from centric relation to the intercuspal position, is illustrated as in an occlusal adjustment and as incorporated into a restoration. Dawson[73] illustrates the "freedom in centric" concept within the lingual concavity of the maxillary anterior teeth. He redefines long centric as "freedom to close the mandible either into centric relation or slightly anterior to it without varying the vertical dimension at the anterior teeth." Additionally, long centric accommodated changes in head position and postural closure. The measurable amount of long centric needed is the difference between centric-related closure and postural closure, which is rarely more than 0.5 mm.

The gnathologists believe that once the condyles are positioned in centric relation, any movement out of this position would disarticulate the TMJs and disocclude the posterior segment, thus, nullifying any horizontal cusp-fossae area contact. This belief, combined with the immediate anterior disocclusion, would question the validity of an adjusted and/or restored horizontal contact area in the posterior segment. The task of adjusting maximum intercuspation contacts in 2 different positions on an articulator may result in a lack of precision in both positions.

The evidence for gnathological concepts

Reviewing the literature and searching for a scientific basis for occlusion leads to the realization that the earliest reports were predicated upon years of successful clinical observations or subjective experiences and closely held anecdotal opinions that were sometimes associated with proprietary mechanical instrumentation. Occlusal concepts were initially formulated and developed for the edentulous patient requiring prosthetic rehabilitation. Following the exercise of these concepts in clinical practice, they were refined and applied to the fixed prosthodontic reconstruction of the natural dentition.[74-78] In the process, some of the approaches to removable prosthodontic treatment, such as geometric formulations for bilateral balanced occlusion to stabilize denture bases,[79,80] were eliminated or modified for fixed prosthodontics, while others were retained as clinical observations and supporting scientific research advances were made.

The exact number of patients examined and the manner in which patients were included or excluded is not readily apparent in the research report by Stuart.[6] The control of examiner biases and variables or the comparisons to control groups were nonexistent. During these seminal years, when evidence-based dentistry was not yet conceived, prosthetic dentistry had to rely upon the lowest level of scientific proof to make decisions about methods to replace missing teeth as well as the shapes of the occlusal surfaces. As a result, from many critical thinking dentists of that time, a variety of occlusal theories with permutations and accompanying terminology developed. Therefore, reaching even a consensus or finding treatment parameters in the presence of many different occlusal philosophies and mechanistic treatment proved difficult, if not contentious. Additionally, considerations for those patients with severe discordant skeletal malocclusions or craniofacial anomalies did not always fit the gnathological model.[81-85]

Centric relation and maximal intercuspation

Celenza[86] studied 32 subjects who had fixed complete-mouth restorations articulated and restored in the centric relation position (centric occlusion) over a 2- to 12-year period. The subjects were reexamined by manual guidance into centric relation, revealing that no occlusal deflections were observed either by the operator or the patient. However, with use of a deconditioning device (occlusal plane) for 5 minutes, there was a perceivable deflective occlusal contact for 30 of the 32 patients. Celenza interpreted

this observation as a strong adaptation on the part of the neuromusculature, where the centric relation location then becomes a neuromuscular position, not a ligamentous position, and because of the neuromusculature conditioning "the precision of the occlusion may be more important than the position." Celenza concluded that these observations do not dictate a change in methodology, but might help in explaining occlusal discrepancies between centric relation and the intercuspal position in the natural dentition.

While it has been demonstrated that bimanual manipulation with an anterior Lucia-type deprogrammer for recording centric relation offers the greatest repeatability in recording condylar position, the importance in the number of centric stops for proper masticatory function remains unreported.[87,88] Reproducibility of the transverse horizontal axis (THA) was investigated by Preston,[89] who suggested that in determining the THA, an apparent arc may result from the resolution of compound condylar movements. He suggested that the single transverse horizontal axis exists as a fact in articulating instruments and as a theory in the human craniomandibular complex. It is important to note that locating the THA arbitrarily and accompanied by interocclusal records made at an increased OVD has been shown to create different paths of closure and resultant deflective occlusal contacts of restorations.[90]

The masticatory system has the capacity to adapt to various influences.[91] The centric position may change over time because of joint remodeling, functional alterations in the condyle-disc articulation, and neuromuscular release.[92] Posterior displacement at both the occlusal surfaces and the condyles was small when deflective occlusal contacts on the retruded path of closure were removed.[93] McNamara[94] reported on the occlusal adjustment of natural teeth to achieve a physiologically accepted occlusion based upon a reduction of the muscle's silent period similar to a control group. Experimentally induced interferences in the retruded range of healthy individuals have been reported to elicit masticatory muscle tenderness. Experimentally induced occlusal interferences may cause tooth pain, loosening of the tooth, a change in muscle tension levels, masticatory patterns, and sometimes a clicking joint. However, this effect appears to be transient as the traumatized teeth tend to move away from the adverse occlusal forces.[95] Occlusal adjustment therapy has been advocated as a treatment modality for temporomandibular disorders. Dawson[96] questioned the 1996 National Institute of Health technology assessment conference[97] on TMD that indicated that there are no clinical trials that demonstrate that occlusal adjustment is superior to noninvasive therapies.

It is the authors' opinion that centric relation should not be dismissed as a treatment position of "prosthodontic convenience," as it allows for a reproducible reference point during the extended treatment phase and an occlusal scheme to be designed and developed.

Anterior guidance

Many treatment philosophies have indicated that the element of disocclusion should be brought forward to the anterior teeth and, thus, establish anterior guidance. Shupe et al,[98] through an electromyographic (EMG) study of the masseter and temporalis muscles of 9 subjects with a maxillary occlusal splint, suggested that there is less muscle activity generated in a canine protected articulation versus a group function guidance. Williamson and Lundquist,[99] through use of a maxillary occlusal splint for 4 TMD symptomatic and one asymptomatic subject, showed decreased EMG activity of the masseter and temporalis muscles when anterior guidance was developed on the splint, which then increased when anterior guidance was eliminated. These studies suggested to the investigators that there will be less wear on posterior teeth and less stress on the temporomandibular joint with anterior guidance. Jemt et al,[100] in a case series crossover study of 5 individuals treated with a maxillary implant-supported FPD and opposing mandibular dentition, observed that the masticatory pattern may be influenced by canine protected articulation versus group function type of occlusion. Carlsson et al[101] reported that occlusion type and tooth wear in childhood predicted increased anterior tooth wear 20 years later, whereas nonworking-side interference reduced the risk for such wear in 35-year-old subjects.

The evolution from analog stylus and graphic table pantographic recordings to the development, improved convenience, and verification of digital electronic jaw tracking devices (Denar Cadiax Compact; Whip Mix Corp, Louisville, Ky) has been studied.[102-104] Reproducibility of border movements was investigated by Clayton,[105-108] who made mandibular recordings on a patient with a dysfunctional temporomandibular joint(s) that illustrated irregular tracings using an electronic pantograph to determine a pantographic reproducibility index (PRI). After occlusal splint therapy and reduction of TMD symptoms, rerecordings on the pantograph would show reproducible tracings. At this time, definitive treatment would include occlusal equilibration or prosthodontic treatment to the reproducible centric relation position. While the PRI may serve as an indicator of a repeatable centric relation position, uniform border movement path, or a neuromuscular release, its use as a diagnostic modality for patients with TMD and orofacial pain has not been scientifically validated as a gold standard.[109]

Occlusal vertical dimension

Severely worn dentitions and/or patients with missing teeth may re-

quire restoration of a collapsed OVD to an appropriate level. Bernhardt et al[110] reported on the risk factors for high occlusal wear: bruxism, male gender, loss of molar contact, and edge-to-edge incisor relations. DiPietro[111] noted that individuals with a low Frankfort Mandibular Plane Angle (FMA) do not tolerate procedures that increase the occlusal vertical dimension. Turner and Missirlan[112] suggested evaluation of loss of posterior support, phonetics, interocclusal distance at rest, and face height, along with facial soft tissue contours, before altering the OVD. The authors observed heavy molar contact for patients with high FMAs along with a lack of incisal guidance. Patients with low FMAs may develop excessive vertical overlap/incisal guidance initially, but as a result of tooth attrition over time, they subsequently develop an edge-to-edge occlusion and its destructive results. Therefore, the patient with a low FMA may require greater intervention as a result of the discordant occlusion and tooth attrition. Either extreme will challenge the development of an occlusal scheme that will protect the TMJ, anterior guidance, and dentition at an acceptable OVD.

Rivera-Morales and Mohl[113] reviewed the research on occlusal vertical dimension as it relates to the health of the masticatory system on severely worn dentitions. The hypothesis that moderate changes in the OVD cause hyperactivity of the muscles of mastication, or involve TMD symptoms, was not supported by scientific research.

Additionally, there are many extrinsic and intrinsic factors that affect the rest position and its reproducibility as a fixed entity, and, therefore, OVD should be considered a range. Rivera-Morales and Mohl[113] conclude that the absence of compelling scientific evidence to prove or disprove the routinely used clinical techniques should not be regarded as a justification for careless or haphazard approaches in the establishment of OVD.

Clinical observations by others have shown that the use of an acrylic resin occlusal splint for posterior teeth with an increased OVD, without regard to anterior guidance or rest position, can result in the intrusion of the posterior teeth and extrusion of the anterior teeth.[114] In a closed OVD with a collapsed posterior or severely worn occlusion, it has been suggested to increase the support of the posterior teeth to allow the anterior teeth to couple to provide anterior tooth guidance.[115] The incisal edges of the mandibular incisors are directed into the cingulum fossae of the maxillary lingual area of the anterior teeth. The design should result in disocclusion of the posterior segment in excursive movements, and when maximum closure occurs, the anterior teeth should touch only by the slightest amount (0.0005 in).[116,117] All of these observations suggest that while OVD may be represented by a variable range, there are inviolate end points and other influencing factors.

Fixed prosthodontics

Beyron[118] surmised that the occlusal restorative requirements should attain the jaw and tooth relations essential for harmonious and self-perpetuating occlusal harmony. These requirements included bilateral contact with axial loading between most teeth in the intercuspal position and in the retruded contact position with a distance of less than 1 mm between them, group function-gliding contacts, and an acceptable interocclusal distance. Goodacre et al[119] reviewed the research on the clinical complications in fixed prosthodontics and did not link occlusion directly as a causative factor. Indirectly, those complications involving porcelain/prosthesis fracture, loss of retention, and tooth fracture may have been associated with occlusal or parafunctional factors. Pokorny,[120] in an article on FPD failures, indicates that deflective occlusal contacts can loosen an FPD, cause sensitivity, and be a contributing factor to an acute periodontal disturbance. However, Yi et al[121] reported that subjective function was not significantly influenced by FPD design, occlusal factors including various occlusal schemes, or the number of FPD units. DeBacker et al[122] found that caries and the loss of retention were the primary reasons for FPD failures over a 20-year period. The impact of occlusion upon loss of retention or crown retainer stability was not reported.

The authors note other factors that could possibly be directed to occlusal complications, but there were insufficient data and studies to substantiate this possibility, which would include TMD, pain and sensitivity, and mobility of the abutments. Anterior FPDs need to restore gliding tooth contacts to eliminate deflective posterior tooth contacts in eccentric jaw movements, while posterior FPDs need to maintain the OVD, and together they may provide mutual protection for each other. It is believed by the authors that single FPDs required to restore both functions may load abutment teeth in directions or vectors other than the long axis or create simultaneous compression and tension moments on the terminal abutments and may, as a result, lead to failure of the restoration, cement bond, or abutment tooth.

Placing these selected articles into a hierarchy of evidence, as recommended by Eckert et al[123] and by Jacob and Carr,[124] would rank them in the lowest level of confidence relative to any particular occlusal therapy. Table I lists examples of publications that were expert opinion (level V) or reports in which a case series of patients (level IV) were described and as such are rated at a greater confidence level than expert opinion. However, the lack of a proper study design/question/methodology, inclusion or exclusion criteria, control groups, and elimination of potential examiner bias weaken their scientific strength. There are currently no research publications identified on dentate occlusion that qualify at level I, II, or III, and this indi-

TABLE I. Level IV-V research strength. Chronological series of publications focusing on occlusal research studies and related key concepts as they first appeared in literature. Duplicate or replication studies are not listed unless study design was improved or if results were different. Key: N = number of subjects in study, OVD = occlusal vertical dimension, TMD = temporomandibular dysfunction, CR = centric relation, CO = centric occlusion, CRO = centric relation occlusion, FMA = Frankfort-mandibular angle, FPD = fixed partial denture, ICP = intercuspal position, RCP = retruded contact position, M = men, W = women, IFP = inferior belly of lateral pterygoid muscle, SFP = superior belly of lateral pterygoid muscle, RP = retruded position, IP = intercuspal position

Author	Year	Method/ Study	Study Parameters	Outcomes/ Results/ Conclusion	Hierarchy
McCollum, Stuart[6]	1955	Clinical observations of centric relation replicability, centric occlusion coincident and pantographic recordings transferred to mechanical articulator replicating recordings	Unknown	Condylar movement and anterior guidance/canine disclusion with maximal intercuspation coinciding with centric relation prescribe the occlusal interface.	Expert opinion
Schuyler[51]	1959	Clinical experience/observations of incisal guidance based upon esthetics, phonetics, lip support, and incisal contact	Unknown	Maximal intercuspation should be based upon functional closure that is anterior to centric relation (<1 mm), incisal guidance predominates occlusal interface.	Expert opinion
Pankey, Mann[47]	1960	Clinical approach to treatment developed using the Monson spherical theory, Meyer functional generated path, and Schuyler incisal guidance	Unknown	Group function, long centric occlusion prescribe the occlusal interface.	Expert opinion
D'Amico[27]	1961	Anthropological observations of American Indian skulls with advanced attrition and severe tooth destruction. Australian Aborigine comparisons by Hector Jones	Unknown	Canine guidance important to prevent destructive tooth attrition.	Expert opinion
Beyron[47]	1964	Observational study of living Aborigines by clinical exam, casts tooth attrition and resultant occlusion, cinematography of masticatory patterns	n=46 (35M/11W) 15-45 age range	Helocoidal wear form resulting in group function; recommended bilateral contact between most teeth in intercuspal position and between posterior teeth in retruded contact position with distance less than 1 mm between them, with axial loading, group function-gliding contacts, and acceptable interocclusal distance.	Case series
Jankelson[56]	1969	Myomonitor stimulation of V and VII cranial nerves to develop occlusion	n=10 (4M/6W) 20-60 years 9 dentate/1 edentulous	Neuromuscular occlusion approach to restoration. Occlusal interface was not described.	Case series
Weinberg[10]	1970	Radiographic imaging study of TMJ for duplicability and concentricity	n=14, radiographs made 1 week apart	Radiographic technique is repeatable, consistent, and TMJ is concentric.	Case series

Table I. *continued* (2 of 5) Level IV-V research strength. Chronological series of publications focusing on occlusal research studies and related key concepts as they first appeared in literature. Duplicate or replication studies are not listed unless study design was improved or if results were different. Key: N = number of subjects in study, OVD = occlusal vertical dimension, TMD = temporomandibular dysfunction, CR = centric relation, CO = centric occlusion, CRO = centric relation occlusion, FMA = Frankfort-mandibular angle, FPD = fixed partial denture, ICP = intercuspal position, RCP = retruded contact position, M = men, W = women, IFP = inferior belly of lateral pterygoid muscle, SFP = superior belly of lateral pterygoid muscle, RP = retruded position, IP = intercuspal position

Author	Year	Method/ Study	Study Parameters	Outcomes/ Results/ Conclusion	Hierarchy
Clayton, Kotowicz, Myers[105]	1971	Study of whether graphic tracings are affected by different OVD, bearing surface forms, and tooth contact	n=3	Mandibular movements can be affected by changes in all 3 variables tested.	Case series
Strohaver[60]	1972	Comparison study of 5 centric relation recording methods and myo-centric relation Part I: Retrospective study of fixed restorations where centric occlusion coincided with centric relation	n=1M with full dentition n=32	Myo-centric recordings were most variable compared to others.	Case report
Celenza[86]	1973	Part II: Prospective study of individuals with restored occlusions not necessarily restored to CRO position to assess recording methods	I. n=32 with 2- to 12-year treatment follow-up II. n=15 (7M/8W) 31-55 years	After using occlusal splint, 30 of 32 patients displayed deflective contacts wearing occlusal splint. Concluded that precision of occlusion may be more important than position.	Case series
Calagna[93]	1973	Centric relation registrations of completely dentate patients, with measurable CR and CO difference, normal health, and no TMD	n=15 (9M/6W) 22-49 years	Variety of deconditioning methods were used with extended occlusal device producing best results compared to other chair-side methods.	Case series
Kantor, Silverman, Garfinkel[59]	1973	Centric relation registrations by chin point guidance with/without or anterior deprogramming device	n=15 21-45 years	Centric relation can be located using many techniques, with bilateral manipulation producing the greatest consistency and Myomonitor techniques the least.	Case series
Hoiffman, Silverman, Garfinkel[22]	1973	Condylar position measured 3-dimensionally in articulator mountings recorded by chin point guidance in comparison to hand-articulated casts in ICP	n=52M 22-46 years	Centric relation found to be 0.28 mm posterior and inferior to centric occlusion with some medio-lateral differences.	Case series
McNamara [64]	1973	Rhesus monkey study on EMG lateral pterygoid muscle activity	n=1	Recorded independent activity of IFP and SLP, suggesting anterior guidance development for occlusal treatment.	Case report, animal study

TABLE I. *continued* (3 of 5) Level IV-V research strength. Chronological series of publications focusing on occlusal research studies and related key concepts as they first appeared in literature. Duplicate or replication studies are not listed unless study design was improved or if results were different. Key: N = number of subjects in study, OVD = occlusal vertical dimension, TMD = temporomandibular dysfunction, CR = centric relation, CO = centric occlusion, CRO = centric relation occlusion, FMA = Frankfort-mandibular angle, FPD = fixed partial denture, ICP = intercuspal position, RCP = retruded contact position, M = men, W = women, IFP = inferior belly of lateral pterygoid muscle, SFP = superior belly of lateral pterygoid muscle, RP = retruded position, IP = intercuspal position

Author	Year	Method/ Study	Study Parameters	Outcomes/ Results/ Conclusion	Hierarchy
Remein, Ash[58]	1974	EMG study of Myomonitor centric position using a fully adjustable articulator	n=10 (3M/7W) 21-50 years	Myomonitor centric position is anterior and inferior to transverse hinge axis, is variable with head position, and is not reproducible.	Case series
DiPietro, Moergheli[111]	1976	Significance of Frankfort-mandibular angle and OVD literature report supported by cephalometric data and studies collected by others	Not stated	Reported that low FMA patients have greater occlusal forces and do not tolerate increase in OVD.	Expert opinion, review of orthodontic literature
McNamara DC[94]	1977	Electromyographic (EMG) study of patients before and after elimination of deflective occlusal contacts in centric and eccentric positions compared to nondysfunctional group	n=27 (18 with functional disturbances and 9 without to serve as control group)	Duration of EMG silent periods and latency of jaw-opening reflex was reduced following treatment (occlusal adjustment) of functional disturbance group within range similar to EMG silent periods of control groups.	Case series with attempt to compare with "normal" control group.
Jankelson[57]	1979	Myomonitor-neuromuscular occlusion derived from stimulating temporalis and masseter muscles	n=400 Over 6-year period	Rest position is reference position for maximum intercuspation.	Case series
Weinberg[9]	1980	Radiographic imaging of TMJ concentricity, dysfunction, and occlusal factors	n=138 (10M/80W) 16-71years	Posterior condylar displacement associated with dysfunctional centric relation.	Case series
Jemt, Lundquist, Hedegard[100]	1982	Light-emitting diodes to track jaw movement for patients with maxillary fixed implant prosthesis opposing mandibular dentition, canine protected articulation, or group function occlusion	n=5	Individuals preferred group function occlusion prosthesis and had more horizontal mastication patterns; canine guidance group had more vertical mastication patterns.	Case series with crossover
Williamson, Lundquist[99]	1983	EMG study of effects of anterior guidance provided by occlusal splint	n=5W of which 4 had history of TMD	Elimination of posterior contacts by anterior discussion occlusal splint decreases activity of elevator muscles.	Case series
Gibbs, Mahan, Wilkinson, Mauderl[65]	1984	EMG study on inferior (ILP) and superior lateral pterygoid (SLP) muscle activity	n=11 (8M/3W) dental students, 2 had TMD symptoms	SLP and ILP demonstrated nearly reciprocal EMG activity. SLP activated during clenching in retruded contact.	Case series

Table 1. *continued* (4 of 5) Level IV-V research strength. Chronological series of publications focusing on occlusal research studies and related key concepts as they first appeared in literature. Duplicate or replication studies are not listed unless study design was improved or if results were different. Key: N = number of subjects in study, OVD = occlusal vertical dimension, TMD = temporomandibular dysfunction, CR = centric relation, CO = centric occlusion, CRO = centric relation occlusion, FMA = Frankfort-mandibular angle, FPD = fixed partial denture, ICP = intercuspal position, RCP = retruded contact position, M = men, W = women, IFP = inferior belly of lateral pterygoid muscle, SFP = superior belly of lateral pterygoid muscle, RP = retruded position, IP = intercuspal position

Author	Year	Method/ Study	Study Parameters	Outcomes/ Results/ Conclusion	Hierarchy
Turner, Missirlan[112]	1984	Clinical observations of severely worn dentition and methods used to determine decreased OVD	n=unknown	Multiple methods of assessing OVD used in individuals with severely worn dentition.	Expert opinion
Shupe, Mohamed, Christensen, Finger[98]	1984	EMG study comparing group function to anterior guidance on maxillary occlusal splints	n=9 (5M/4W) 23-41 years	Canine guidance should be required to reduce forces to posterior teeth and muscle activity.	Case series
Clayton, Beard[108]	1986	Electronic pantographic reproducibility study and indexing for diagnosing TMD	n=25	Electronic method of assisting in graphic detection of TMD and reproducibility of tracing border movements.	Case series
Brose, Tanquist[115]	1987	Literature review of anterior coupling influence on mandibular movement	N/A	Anterior teeth can be modified to achieve coupling to posterior controls by occlusal adjustment and anterior restorations.	Expert opinion
Pullinger[71]	1988	Study of occlusal variables associated with joint tenderness and dysfunction	n=224 (120M/102) 23.9 mean age group	ICP anterior to RCP in association with bilateral occlusal stability may be protective.	Case series
Agerberg, Sandstroselt[67]	1988	Study of occlusal interference frequency between centric relation and centric occlusion or nonworking contacts that prevented group function	n=140 15-22 age-range	Observed that majority of individuals had deflective contacts that did not appear to interfere with mastication.	Case series
Wilson, Nairn[68]	1989	Clinical assessment of centric relation and centric occlusion	n=15 dental students/ nurses	Determined 0.2-0.4 mm difference between RP to IP.	Case series
Rivera-Morales, Mohl[113]	1991	Extensive review of animal and human studies regarding restoration of OVD	N/A	Literature reviewed does not substantiate that a moderate increase in the OVD will result in hyperactivity of the masticatory muscles and symptoms of TMD.	Systematic review of literature

TABLE I. *continued* (5 of 5) Level IV-V research strength. Chronological series of publications focusing on occlusal research studies and related key concepts as they first appeared in literature. Duplicate or replication studies are not listed unless study design was improved or if results were different. Key: N = number of subjects in study, OVD = occlusal vertical dimension, TMD = temporomandibular dysfunction, CR = centric relation, CO = centric occlusion, CRO = centric relation occlusion, FMA = Frankfort-mandibular angle, FPD = fixed partial denture, ICP = intercuspal position, RCP = retruded contact position, M = men, W = women, IFP = inferior belly of lateral pterygoid muscle, SFP = superior belly of lateral pterygoid muscle, RP = retruded position, IP = intercuspal position

Author	Year	Method/ Study	Study Parameters	Outcomes/ Results/ Conclusion	Hierarchy
Yi, Carlsson, Ericsson, Wennstrom[121]	1996	Study of 34 patients with 43 FPDs worn for 10 years with variety of occlusal schemes	Of 200 patients, 34 (19W/15M) were willing to participate in retrospective study	All 3 types of occlusal contact patterns seemed to be compatible with long-term function of extensive FPDs.	Case series
Goodacre[119]	2003	MEDLINE search, 50-year literature review of survival and failure modalities of FPD	N/A	Fixed partial dentures failures: caries (18% of abutments and 8% of prostheses), endodontic treatment (11% of abutments and 8% of prostheses), loss of retention (7% of prostheses), esthetics (6% of prostheses), periodontal disease (4% of prostheses), tooth fracture (3% of prostheses), and prosthesis/porcelain fracture (2% of prostheses).	Meta analysis design with systematic review of literature.
Carlsson, Egermark, Magnusson[101]	2003	Randomly selected 7-, 11-, and 15-year-old subjects were examined clinically and using questionnaire for parafunction and tooth wear focusing on occlusal factors and function and dysfunction of masticatory system	n=100 (original 402) random selection, examined after 20 years	Oral parafunctions in childhood may be persistent trait in many subjects. Class II occlusion and tooth wear in childhood predicted increased anterior tooth wear 20 years later, whereas nonworking-side interference reduced risk for such wear in 35-year-old subjects.	Longitudinal case series
Nilner[92]	2003	Literature review of musculoskeletal disorders and occlusal interface	N/A	Extensive literature review supporting Beyron's original observations.	Systematic review of literature
Forsell, Kalso[125]	2004	Application of evidence-based medicine to occlusal treatment of TMD	N/A	Review methodology on occlusal splints and TMD.	Systematic review of literature
Bernhardt, Gesch, Splieth[110]	2004	Occlusal wear studied and related to risk factors such as bruxism, gender, and social situations	n=2529	Factors for high occlusal wear: bruxism, male gender, loss of molar contact, edge-to-edge incisor relations, unemployment.	Epidemiologic case series
De Backer, Van Maele, De Moor, Van den Berghe, De Boever[122]	2006	Study to investigate longevity of 332 FPDs over 20 years performed by students and faculty	n=193	66% FPD survival rate, caries and loss of retention were primary causes for failure. Impact of occlusion not reported.	Retrospective case series

cates a void in the current literature.

A recent systematic review of occlusal treatments revealed 16 randomized controlled clinical trials (RCT) of occlusal splints, and 4 on occlusal adjustments revealed equivocal results.[125] The etiologic significance of occlusal factors has been questioned based upon the weak or nonexistent epidemiological data and systematic studies.[126] To date, there have not been randomized controlled trials or comparative clinical evaluations of the different therapeutic principles in oral reconstructions with indicators to determine mandibular position, contact pattern of mandibular excursive movements, and occlusal designs.[127,128]

Ash[129] concluded that until evidence-based science finds one or more acceptable causal factors, the clinician is faced with the need to provide therapy that has some reasonable degree of objective and/or subjective impact on the effects of a disorder. Klineberg and Stohler[130] concluded that the clinical and biologic research evidence that supports the fundamental understanding of the occlusion and best prescription for occlusal management is not strong. However, the lack of evidence cannot be interpreted as evidence of the lack of effect. It was noted that variations in treatment philosophies proposed for optimal restoration of occlusion evolved from clinical treatment experience and have not been systematically studied to determine long-term outcomes. Even without a role in TMD etiology, occlusion retains an important role in dental practice. Occlusal factors may have different effects in different subjects, as no single factor is capable of causing a disease or a functional disturbance on its own.[131] Guidelines for fixed prosthodontic treatment continue to be developed based upon consensus, refined by clinical research and outcome studies.[132-136]

SUMMARY

As prosthodontists, the authors recognize the need for reliable evidence-based research to support specific treatment for a variety of occlusal situations. This research must encompass measurability, reproducibility, transferability, and ease in performance of treatment. Gnathological concepts offer a structured methodology for prosthodontic treatment in the presence of a disorganized or dysfunctional occlusion requiring fixed prosthodontics. Gnathology will historically be judged as a significant stimulus to relate the physiology of occlusion to biomedical concepts in complex restorative treatment. Further scientific research is needed to validate occlusal treatment theories and prescribed treatment of the occlusal interface. The lack of an evidence-based model does not diminish the goal of precision and excellence in the clinical management of fixed prosthodontics. Ultimately, the clinician must evaluate and assimilate the available literature and research evidence along with individual clinical experiences and accepted parameters of care.

REFERENCES

1. Guichet NF. Applied gnathology: why and how. Dent Clin North Am 1969;13:687-700.
2. Stuart CE, Stallard H, editors. Principles involved in restoring occlusion to natural teeth. A syllabus on oral rehabilitation and occlusion. Vol. 1. San Francisco: University of California; Ventura CE. Stuart Instruments; 1959. p. 1-11, 5, 1-9.
3. Stuart CE. Gnathologic tooth preparation. Chicago: Quintessence; 1985. p. 74, 150.
4. Stuart CE, Stallard H. Oral rehabilitation and occlusion. Vol. II. San Francisco, University of California; Ventura CE Stuart Instruments; 1969. p. 1-6.
5. Stuart CE. The contributions of gnathology to prosthodontics. J Prosthet Dent 1973;30:607-8.
6. McCollum BB, Stuart CE. A research report. South Pasadena: Scientific Press; 1955. p. 12-3, 34, 86-91.
7. McHorris WH. Occlusal waxing manual. Memphis Gnathological Academy of Research and Education; 1977. p. 1-89.
8. Schillingburg HT, Wilson EL, Morrison JT. Guide to occlusal waxing. 3rd ed. Chicago: Quintessence; 2000. p. 1-58.
9. Weinberg LA, Lager LA. Clinical report on the etiology and diagnosis of TMJ dysfunction-pain syndrome. J Prosthet Dent 1980;44:642-53.
10. Weinberg LA. An evaluation of duplicability of temporomandibular joint radiographs. J Prosthet Dent 1970;24:512-41.
11. Weinberg LA. An evaluation of asymmetry in TMJ radiographs. J Prosthet Dent 1978;40:315-23.
12. Updegrave WJ. Radiography of the temporomandibular joints individualized and simplified. Compend Contin Educ Dent 1983;4:23-9.
13. Weinberg LA. Anterior condylar displacement: its diagnosis and treatment. J Prosthet Dent 1975;34:195-207.
14. Weinberg LA. Posterior bilateral condylar displacement: its diagnosis and treatment. J Prosthet Dent 1976;36:426-40.
15. Weinberg LA. Posterior unilateral condylar displacement: its diagnosis and treatment. J Prosthet Dent 1977;37:559-69.
16. Weinberg LA. Superior condylar displacement. Its diagnosis and treatment. J Prosthet Dent 1975;34:59-76.
17. Katzberg RW, Schenck J, Roberts D, Tallents RH, Manzione JV, Hart HR, et al. Magnetic resonance imaging of the temporomandibular joint meniscus. Oral Surg Oral Med Oral Pathol 1985;59:332-5.
18. Carr AB, Gibilisco JA, Berquist TH. Magnetic resonance imaging of the temporomandibular joint: preliminary work. J Craniomandib Disord 1987;1:89-96.
19. Pokorny DK. Current procedures in fixed prosthodontics. Dent Clin North Am 1971;15:685-710.
20. The glossary of prosthodontic terms. J. Prosthet Dent 2005;94:21-2.
21. Racich MJ. Orofacial pain and occlusion: is there a link? An overview of current concepts and the clinical implications. J Prosthet Dent 2005;93:189-96.
22. Hoffman PJ, Silverman SI, Garfinkel L. Comparison of condylar position in centric relation and in centric occlusion in dentulous subjects. J Prosthet Dent 1973;30:582-8.
23. Ash MM Jr. Philosophy of occlusion: past and present. Dent Clin North Am 1995;2:233-55.
24. Jasinevicius TR, Yellowitz JA, Vaughan GG, Brooks ES, Baughan LW, Cline N, et al. Centric relation definitions taught in 7 dental schools: results of faculty and student surveys. J Prosthodont 2000;9:87-94.
25. Dawson PE. Centric relation. Its effect on occluso-muscle harmony. Dent Clin North Am 1979;23:169-80.
26. Christensen C. The problem of the bite. Dent Cosmos 1905; 47:1184-95.
27. D'Amico A. Functional occlusion of the natural teeth of man. J Prosthet Dent 1961;11:899-915.
28. Lux CJ, Conradt C, Burden D, Komposch G. Three dimensional analysis of maxillary and mandibular growth increments. Cleft Palate Craniofac J 2004;41:304-14.
29. Walther W. Determinants of a healthy aging dentition: maximum number of bilateral centric stops and optimum vertical dimension of occlusion. Int J Prosthodont 2003;16 Suppl:77-9.

30. Storey AT, Kenny DJ. Growth, development, and aging of orofacial tissues: neural aspects. Adv Dent Res 1989;3:14-29.
31. Thompson JR. The rest position of the mandible and its significance to dental science. J Am Dent Assoc 1946;33:151-80.
32. Thompson JR, Brodie AG. Factors in the position of the mandible. J Am Dent Assoc 1942;29:925-41.
33. Atwood DA. A cephalometric study of the clinical rest position of the mandible. Part 1: the variability of the clinical rest position following the removal of occlusal contacts. J Prosthet Dent 1956;6:504-9.
34. Swerdlow H. Roentgencephalometric study of vertical dimension changes in immediate denture patients. J Prosthet Dent 1964;14:635-50.
35. McGee GF. Use of facial measurements in determining vertical dimension. J Am Dent Assoc 1947;35:342-50.
36. Boos RH. Intermaxillary relation established by biting power. J Am Dent Assoc 1940;27:1192-9.
37. Lytle RV. Vertical relation of occlusion by the patient's neuromuscular perception. J Prosthet Dent 1964;14:12-21.
38. Silverman MM. Determination of vertical dimension by phonetics. J Prosthet Dent 1956;6:465-71.
39. Smith DE. The reliability of pre-extraction records for complete dentures. J Prosthet Dent 1971;25:592-608.
40. Tallgren A. The continuing reduction of the residual alveolar ridges in complete denture wearers: a mixed-longitudinal study covering 25 years. J Prosthet Dent 1972:27:120-32.
41. Sheppard IM, Sheppard SM. Vertical dimension measurements. J Prosthet Dent 1975;34:269-77.
42. Toolson LB, Smith DE. Clinical measurement and evaluation of vertical dimension. 1982. J Prosthet Dent 2006;95:335-9.
43. Pound E. Let /S/ be your guide. J Prosthet Dent 1977;38:482–9.
44. Desjardins RP. Clinical evaluation of the wax trial denture. J Am Dent Assoc 1982;104:184-90.
45. Chiche GJ, Pinault A. Esthetics of anterior fixed prosthodontics. Chicago: Quintessence; 1994. p. 118-9.
46. Beyron H. Occlusal relations and mastication in Australian Aborigines. Acta Odont Scand 1964;22:597-678.
47. Mann AW, Pankey LD. Oral rehabilitation: Part I. Use of the P-M Instrument in treatment planning and in restoring the lower posterior teeth. J Prosthet Dent 1960;10:135-50.
48. Pankey LD, Mann AW. Oral rehabilitation: Part II. Reconstruction of the upper teeth using a functionally generated path technique. J Prosthet Dent 1960;10:151-62.
49. Mann AW, Pankey LD. Concepts of occlusion; the P.M. philosophy of occlusal rehabilitation. Dent Clin North Am 1963;9:621-36.
50. Schuyler CH. Factors of occlusion applicable to restorative dentistry. J Prosthet Dent 1953;3:772-82.
51. Schuyler CH. An evaluation of incisal guidance and its influence on restorative dentistry. J Prosthet Dent 1959;9:374-8.
52. Schuyler CH. The function and importance of incisal guidance in oral rehabilitation. 1963. J Prosthet Dent 2001;86:219-32.
53. Meyer FS. The generated path technique in reconstructive dentistry: Part II. Fixed partial dentures. J Prosthet Dent 1959;9:432.
54. Schillingburg HT, Hobo S, Whitsett LD, Brackett S, Jacobi R. Fundamentals of fixed prosthodontics. 3rd ed. Chicago: Quintessence; 1997. p. 28.
55. Moller E. The chewing apparatus. An electromyographic study of the action of the muscles of mastication and its correlation to facial morphology. Acta Physiol Scand Suppl 1966;280:1-229.
56. Jankelson B, Sparks S, Crane PF, Radke JC. Neural conduction of the Myo-Monitor Stimulus: A quantitative analysis. J Prosthet Dent 1975;34:245-53.
57. Jankelson B. Neuromuscular aspects of occlusion. Effects of occlusal position on the physiology and dysfunction of the mandibular musculature**.** Dent Clin North Am 1979:157-68.
58. Remien JC 2nd, Ash M Jr. "Myo-Monitor centric": an evaluation. J Prosthet Dent 1974;31:137-45.
59. Kantor ME, Silverman SI, Garfinkel L. Centric relation recording techniques: a comparative investigation. J Prosthet Dent 1973;30:604-6.
60. Strohaver RA. A comparison of articulator mountings made with centric relation and myocentric position records. J Prosthet Dent 1972;28:379-90.
61. Beyron H. Occlusion: point of significance in planning restorative procedures. J Prosthet Dent 1973;30:641-52.
62. Becker CM, Kaiser DA, Schwalm C. Mandibular centricity: centric relation. J Prosthet Dent 2000;83:158-60.
63. Thornton LJ. Anterior guidance: group function/canine guidance. A literature review. J Prosthet Dent 1990;64:479-82.
64. McNamara JA Jr. The independent functions of the two heads of the lateral pterygoid muscle. Am J Anat 1973;138:197-205.
65. Gibbs CH, Mahan PE, Wilkinson TM, Mauderli A. EMG activity of the superior belly of the lateral pterygoid muscle in relation to other jaw muscles. J Prosthet Dent 1984;51:691-702.
66. Posselt U. Range of movement of the mandible. J Am Dent Assoc 1958;56:10-3.
67. Agerberg G, Sandstrom R. Frequency of occlusal interferences: a clinical study in teenagers and young adults. J Prosthet Dent 1988;59:212-7.
68. Wilson J, Nairn RI. Occlusal contacts in mandibular retrusion. Int J Prosthodont 1989;2:143-7.
69. Wilson J, Nairn RI. Condylar repositioning in mandibular retrusion. J Prosthet Dent 2000;84:612-6.
70. Grasso JE, Sharry J. The duplicability of arrow-point tracings in dentulous subjects. J Prosthet Dent 1968;20:106-15.
71. Pullinger AG, Seligman DA, Solberg WK. Temporomandibular disorders. Part II: Occlusal factors associated with temporomandibular joint tenderness and dysfunction. J Prosthet Dent 1988;59:363-7.
72. Ash MM, Ramfjord SP. Occlusion. 4th ed. Philadelphia: W.B. Saunders; 1995. p. 407-8.
73. Dawson PE, editor. Evaluation, diagnosis, and treatment of occlusal problems. 2nd ed. St. Louis: Mosby; 1989. p. 265.
74. Guichet NF. Biologic laws governing functions of muscles that move the mandible. Part I. Occlusal programming. J Prosthet Dent 1977;37:648-56.
75. Guichet NF. Biologic laws governing functions of muscles that move the mandible. Part II. Condylar position. J Prosthet Dent 1977;38:35-41.
76. Guichet NF. Biologic laws governing functions of muscles that move the mandible. Part III. Speed of closure--manipulation of the mandible. J Prosthet Dent 1977;38:174-9.
77. Guichet NF. Biologic laws governing functions of muscles that move the mandible. Part IV. Degree of jaw separation and potential for maximum jaw separation. J Prosthet Dent 1977;38:301-10.
78. Schwartz H. Occlusal variations for reconstructing the natural dentition. J Prosthet Dent 1986;55:101-5.
79. Bonwill WG. The scientific articulation of the human teeth as founded on geometrical, mathematical and mechanical laws. Items Int 1899;21:617-56, 873-80.
80. Hanau RL. Articulation defined, analyzed and formulated. J Am Dent Assoc 1926;13:1694-1709.
81. Bryant SR. The rationale for management of morphologic variations and nonphysiologic occlusion in young dentition. Int J Prosthodont 2003;16 Suppl:75-7.
82. Ross B. Satisfactory occlusal relations for the individual with craniofacial anomaly. Int J Prosthodont 2003;16 Suppl:74-5.
83. Capp NJ, Warren K. Restorative treatment for patients with excessive vertical overlap. Int J Prosthodont 1991;4:353-60.
84. Ambard A, Mueninghoff L. Planning restorative treatment for patients with severe Class II malocclusions. J Prosthet Dent 2002;88:200-7.
85. Keim RG, Collins B, Morgando C, Smart F, Zeigler R, Wasson J. Two phase treatment of a severe Class II, division I malocclusion. Am J Orthod Dentofacial Orthop 1996;109:461-5.
86. Celenza FV. The centric position: replacement and character. J Prosthet Dent 1973;30:591-8.
87. Keshvad A, Winstanley RB. Comparison of the replicability of routinely used centric relation registration techniques. J Prosthodont 2003;12:90-101.
88. Alstergren P. Determinants of a healthy aging dentition: freedom in the retrusive range of occlusal contacts and multidimensional freedom for functional tooth contact. Int J Prosthodont 2003;16 Suppl:79-80.
89. Preston JD. A reassessment of the mandibular transverse horizontal axis theory. 1979. J Prosthet Dent 2004;91:505-12.
90. Bowley JF, Morgano SM. Occlusal plane discrepancies generated by transverse horizontal axis deviations. J Prosthet Dent 2001;86:67-73.
91. Sessle BJ. Biological adaptation and normative values. Int J Prosthodont 2003;16 Suppl:72-3.
92. Nilner M. Musculoskeletal disorders and

the occlusal interface. II. Int J Prosthodont 2003;16 Suppl:85-7.
93. Calagna LJ, Silverman SI, Garfinkel L. Influence of neuromuscular conditioning on centric relation registrations. J Prosthet Dent 1973;30:598-604.
94. McNamara DC. Occlusal adjustment for a physiologically balanced occlusion. J Prosthet Dent 1977;38:284-93.
95. Clark GT, Tsukiyama Y, Baba K, Watanabe T. Sixty-eight years of experimental occlusal interference studies: what have we learned? J Prosthet Dent 1999;82:704-13.
96. Dawson PE. Position paper regarding diagnosis, management, and treatment of temporomandibular disorders. The American Equilibration Society. J Prosthet Dent 1999;81:174-8.
97. Dworkin SF. Behavioral and education modalities. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1997;83:128-33.
98. Shupe RJ, Mohamed SE, Christensen LV, Finger IM, Weinberg R. Effects of occlusal guidance on jaw muscle activity. J Prosthet Dent 1984;51:811-8.
99. Williamson EH, Lundquist DO. Anterior guidance: its effect on electromyographic activity of the temporal and masseter muscles. J Prosthet Dent 1983;49:816-23.
100. Jemt T, Lundquist S, Hedegard B. Group function or canine protection. 1982. J Prosthet Dent 2004;91:403-8.
101. Carlsson GE, Egermark I, Magnusson T. Predictors of bruxism, other oral parafunctions, and tooth wear over a 20-year follow-up period. J Orofac Pain 2003;17:50-7.
102. Chang WS, Romberg E, Driscoll CF, Tabacco MJ. An in vitro evaluation of the reliability and validity of an electronic pantograph by testing with five different articulators. J Prosthet Dent 2004;92:83-9.
103. Bernhardt O, Kuppers N, Rosin M, Meyer G. Comparative tests of arbitrary and kinematic transverse axis recordings of mandibular movements. J Prosthet Dent 2003;89:175-9.
104. Celar AG, Tamaki K. Accuracy of recording horizontal condylar inclination and Bennet angle with the Cadiax compact. J Oral Rehab 2002;29:1076-81.
105. Clayton JA, Kotowicz WE, Myers GE. Graphic recordings of mandibular movements: research criteria. J Prosthet Dent 1971;25:287-98.
106. Roura N, Clayton JA. Pantographic records on TMJ dysfunction subjects treated with occlusal splints: a progress report. J Prosthet Dent 1975;33:442-53.
107. Clayton JA. A pantographic reproducibility index for use in diagnosing temporomandibular joint dysfunction: a report on research. J Prosthet Dent 1985;54:827-31.
108. Clayton JA, Beard CC. An electronic, computerized pantographic reproducibility index for diagnosing temporomandibular joint dysfunction. J Prosthet Dent 1986;55:500-5.
109. Mohl ND, McCall WD Jr, Lund JP, Plesh O. Devices for the diagnosis and treatment of temporomandibular disorders. Part I: Introduction, scientific evidence, and jaw tracking. J Prosthet Dent 1990:63:198-201.
110. Bernhardt O, Gesch D, Splieth C, Schwahn C, Mack F, Kocher T, et al. Risk factors for high occlusal wear scores in a population-based sample: results of the Study of Health in Pomerania (SHIP). Int J Prosthodont 2004;17:333-9.
111. DiPietro GJ, Moergeli JR. Significance of the Frankfort-mandibular plane angle to prosthodontics. J Prosthet Dent 1976;36:624-35.
112. Turner KA, Missirlian DM. Restoration of the extremely worn dentition. J Prosthet Dent 1984;52:467-74.
113. Rivera-Morales WC, Mohl ND. Relationship of occlusal vertical dimension to the health of the masticatory system. J Prosthet Dent 1991;65:547-53.
114. Okeson JP. Management of temporomandibular disorders and occlusion, 6th ed. St. Louis: Elsevier; 2008. p. 488-9.
115. Brose MO, Tanquist RA. The influence of anterior coupling on mandibular movement. J Prosthet Dent 1987;57:345-53.
116. McHorris WH. Occlusion with particular emphasis on the functional and parafunctional role of anterior teeth. Part 1. J Clin Orthod 1979;13:606-20.
117. McHorris WH. Occlusion with particular emphasis on the functional and parafunctional role of anterior teeth. Part 2. J Clin Orthod 1979;13:684-701.
118. Beyron H. Optimal occlusion. Dent Clin North Am 1969;13:537-54.
119. Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JY. Clinical complications in fixed prosthodontics. J Prosthet Dent 2003;90:31-41.
120. Pokorny DK. Fixed bridge failures. J Mich State Dent Assoc 1961;43:203-7.
121. Yi SW, Carlsson GE, Ericsson I, Wennstrom JL. Long-term follow-up of cross-arch fixed partial dentures in patients with advanced periodontal destruction: evaluation of occlusion and subjective function. J Oral Rehabil 1996;23:186-96.
122. De Backer H, Van Maele G, De Moor N, Van den Berghe L, De Boever J. A 20-year retrospective survival study of fixed partial dentures. Int J Prosthodont 2006;19:143-53.
123. Eckert SE, Choi YG, Koka S. Methods for comparing the results of different studies. Int J Oral Maxillofac Implants 2003;18:697-705.
124. Jacob RF, Carr AB. Hierarchy of research design used to categorize the "strength of evidence" in answering clinical dental questions. J Prosthet Dent 2000;83:137-52.
125. Forssell H, Kalso E. Application of principles of evidence-based medicine to occlusal treatment for temporomandibular disorders: are there lessons to be learned? J Orofac Pain 2004:18:9-22.
126. Dao T. Musculoskeletal disorders and the occlusal interface: I. Int J Prosthodont 2003;16:83-4.
127. McNeill C, editor. Science and practice of occlusion. Chicago: Quintessence; 1997. p. 319-20.
128. Taylor TD, Wiens J, Carr A. Evidence-based considerations for removable prosthodontic and dental implant occlusion: a literature review. J Prosthet Dent 2005;94:555-60.
129. Ash MM. Occlusion: reflections on science and clinical reality. J Prosthet Dent 2003;90:373-84.
130. Klineberg I, Stohler CS. Interface 4: Occlusion. Int J Prosthodont 2003;16 (Suppl):71-94.
131. Palla S. The interface of occlusion as a reflection of conflicts within prosthodontics. Int J Prosthodont 2005;18:304-6.
132. Principles, concepts and practices in prosthodontics--1994. Academy of Prosthodontics. J Prosthet Dent 1995;73:73-94.
133. American College of Prosthodontists. Parameters of care for the specialty of prosthodontics. J Prosthodont 2005;14(4 Suppl 1):1-103.
134. McGarry TJ, Edge MJ, Gillis RE Jr, Hilsen KL, Jones RE, Shipman B, et al. Parameters of care for the American College of Prosthodontists. POC version 1, March 1996. J Prosthodont 1996;5:3-70.
135. Michalakis KX. Fixed rehabilitation of an ACP PDI class III patient. J Prosthodont 2006;15:359-66.
136. Potiket N. Fixed rehabilitation of an ACP PDI Class IV dentate patient. J Prosthodont 2006;15:367-73.

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