A rationale for a simplified occlusal design in restorative dentistry: Historical review and clinical guidelines

H. W. Anselm Wiskott, DMD, MS, MSD,[a] and Urs C. Belser, Prof. Dr Med Dent[b]

School of Dentistry, University of Geneva, Geneva, Switzerland

An occlusal contact pattern in which the number of occlusal contacts has been substantially reduced as compared with traditional schemes is described. Concepts that may have had a justification in balanced occlusions have been needlessly transferred to anterior disclusion mechanics. No natural dentition presents occlusal contacts as described in many texts and yet stability is established. The temporomandibular joint does present structural changes that should be accounted for when an occlusal anatomy is designed. The force vectors that are active on teeth are not directed along the longitudinal axes of the roots only, and thus occlusal contact locations will not determine the direction of functional forces. The stability of the teeth on the arch depends primarily on the forces of eruption from the periodontium and the balance between the resting pressures of the muscles of the cheeks and the tongue. The mechanics of the stomatognathic system are not as accurate as their counterpart on an articulator. The variability of the guiding surfaces inherent to the temporomandibular joints should be incorporated into an occlusal design. Occlusal contacts that do not fulfill a justifiable purpose may be eliminated, and the number of contacts may be reduced to one per tooth. (J Prosthet Dent 1995;73:169-83.)

Much has been written about the location of occlusal contacts (OCs) in maximum intercuspation (MI). Many authors have described OC patterns that they believed would promote optimal integration of the teeth into the stomatognathic system.

Two types of contact patterns have found acceptance for natural dentitions and fixed prostheses: the "gnathologic" and the "freedom-in-centric" types of occlusion. In gnathologic (or organic) schemes, MI coincides with the retruded contact position (RCP) (equivalent to centric relation contact position).[1] The relationship between both dental arches and the temporomandibular joints is set by the occlusal anatomy, which is designed to determine a unique position where MI can occur (Fig. 1, *a*).[2,3] Classically, this mechanical keying between the mandibular and maxillary arches is obtained by tripodized occlusal contacts. Conversely freedom-in-centric occlusion calls for a contact range between RCP and a position 0.5 to 1 mm anterior to it.[4] By necessity it relies on cusp-to-surface mechanics (Fig. 1, *b*).

HISTORICAL DEVELOPMENT

In the 1950s, accepted philosophies of interarch dynamics evolved from "fully balanced"[5,6] to "mutually protected"[7,8] occlusions.[9] During this transition, however, a number of features of the fully equilibrated contact pattern were needlessly transferred into the newer concept of anterior disclusion mechanics. There is still confusion today over attributes that may be suitable for complete dentures but are of questionable importance when applied to natural dentition or fixed prosthodontics. The main historical vestiges pertain to the overall arrangement and the individual anatomy of the occlusal surfaces. They will be briefly reviewed.

Occlusal curves

The earliest and most profound observation was by von Spee,[10] who believed a continuum had to be established between the angle of the eminentia and the arrangement of the occlusal surfaces of the teeth (Fig. 2). In his approach a steep condylar path required a profound "curve of Spee" and conversely a fairly horizontal path was best combined with a flatter arrangement of the occlusal surfaces. This relationship was later established in a more elaborate form in "Hanau's Quint"[11] and "Thielemann's formula."[12]

Another important author was Monson,[13] who described a tooth arrangement in which the occlusal surfaces were aligned along the outer surface of a sphere, which itself centered on the crista galli. Besides still being an important component of one philosophy of occlusal rehabilitation,[14] this concept derived the curves of Wilson[15] and Monson[13]

[a]Head of Scientific Clinic, Division of Fixed Prosthodontics.
[b]Professor and Chairman, Division of Fixed Prosthodontics.

0022-3913/95/$3.00 + 0. **10/1/59534**

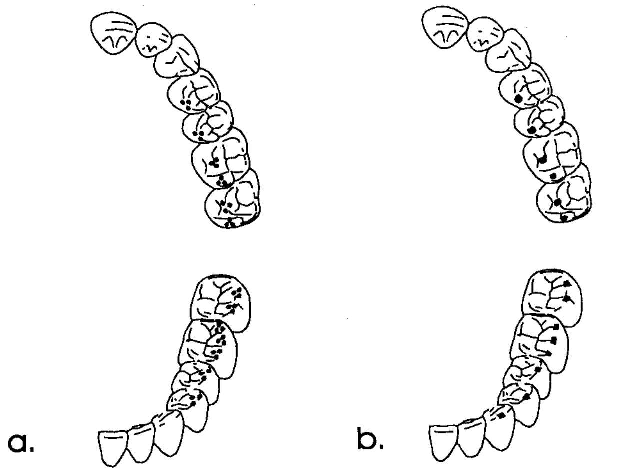

Fig. 1. a, Gnathologic contacts scheme; **b,** Freedom-in-centric contact scheme.

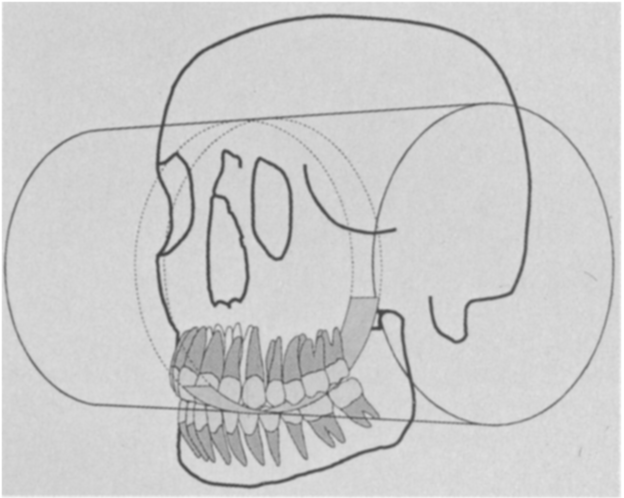

Fig. 2. Spee's concept of relation between angle of eminence and overall arrangement of occlusal surfaces. Condylar path and curve of Spee were located on outer surface of cylinder.

(Fig. 3). It appears that Monson's sphere was a refinement of Spee's cylinder if fully balanced occlusal schemes had to be established. In contemporary complete denture prosthodontics, one may refer to analogous concepts as "compensating curves" in the sagittal and frontal planes. The curvilinear arrangement of the teeth compensates for the inclination of the condylar path.

The Spee, Wilson, and Monson curves were designed to promote OCs on the entire arch during excursive mandibular movements. However, none of these curves has ever been reported to be present in natural dentitions.[16] Orthodontists actually treat toward an occlusal plane.[17] A residual or relapsing curve of Spee is often considered a failure.

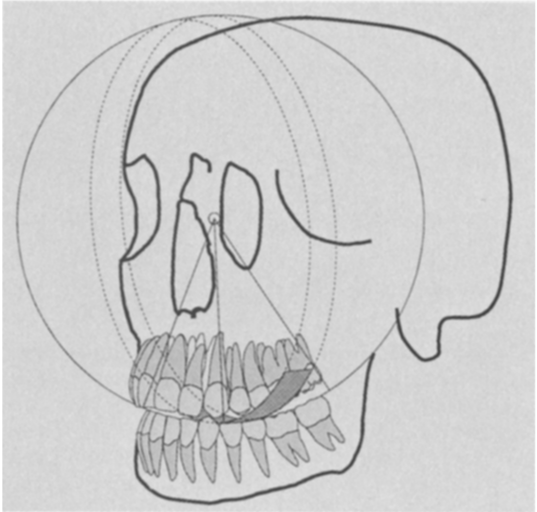

Fig. 3. Occlusal concept of Monson.[13] Axes of teeth converge toward common point and occlusal surfaces lie on surface of sphere. Lower lateral segments are concave in sagittal plane. As viewed from front, arrangement determines curve of Wilson in molar area and convexity on lower front teeth (sometimes referred to as Monson curve).

Occlusal anatomy

The other remnant of the fully balanced concept lies in the emphasis still placed, by some clinicians, on occlusal morphology as it relates to eccentric movements of the mandible.[18] In full balance the anatomy of cusps, inclines, and fossae combined to refined registrations of the condylar pathways have been considered an important determinant of denture stability. However, in contemporary anterior disclusion mechanics, elaborate designs of ridge and groove direction make little sense because by definition the teeth should disclude posteriorly during excursive movements. The establishment of a "near miss" chewing pattern is inappropriate as well because it does not provide for possible alterations of the functional envelope of mandibular movements beyond what is shown on the articulator.

Restorative procedures are taxing on both dentists and laboratory technicians. Whenever an essential phase, such as the design of the occlusal surfaces, can be simplified ("work smarter, not harder") this should be done. It is our contention that a sizable number of the OCs illustrated in Fig 1, *a* and *b*, are superfluous and do not actually fulfill the purpose ascribed to them. Therefore this work reviews some of the attributes of accepted occlusal schemes and presents the case for a substantially reduced number of OCs in MI. This is not to imply that the presence of a larger number of tooth contacts is necessarily harmful, but that they should not be striven for, neither during occlusal adjustment nor during restorative procedures.

INTERARCH TOOTH CONTACTS

Maximum intercuspation

Maximum intercuspation is the jaw relationship that establishes the greatest number of tooth contacts between opposing arches.[19] During function MI is the starting and end point of the chewing cycle. This was first shown by Hildebrand,[20] who demonstrated the presence of tooth contacts at the end of the masticatory cycle. MI is also the favored and longest-lasting position during swallowing.[21] Although a border position, RCP is a functional position as well. Clayton et al.[22] demonstrated that patients will function to the border tracings made by a pantograph if interferences are removed and do not restrict mandibular movements toward RCP.

Thus functional OCs occur preferentially in a manner that best stabilizes the mandible. During chewing and swallowing OCs cover a zone in the vicinity of RCP if function to RCP is unimpeded.

Location of occlusal contacts

Present-day concepts of occlusal stability and function are based on optimal intercuspation between maxillary and mandibular teeth. The mandibular buccal cusp should fit into the central fossae and embrasures of the maxillary teeth and the maxillary palatal cusps into the central fossae and embrasures of the mandibular teeth. This arrangement of occlusal contacts (OCs) was first described by Friel[23] in 1927 and has been carried to the present in slightly modified versions.[3, 24, 25]

Reality, however, is different from those idealized schemes. Black[26] estimated the occlusal surfaces to cover an area of 210 to 300 mm^2 of which an average of 48 mm^2 were OCs.[27] A one-to-five variation between subjects in the ratio of the total occlusal surface relative to the OC area was noted. Most OCs are located on a combination of flat and inclined surfaces or on two or more inclined planes.[28] In most situations, the lingual cusps of the maxillary molars were found to fit into a central fossa or on a marginal ridge of the opposing arch. This proportion decreased for second and first premolars, which presented contacts on inclined planes in 36% and 67% of the cases, respectively.[29]

Plasmans et al.[30] counted the number of OCs in three different clinical situations. Averages of three OCs for natural teeth, 2.3 for crowns, and 1.6 for amalgam fillings were found.[30] In a sample of 45 young adults, 80% exhibited some degree of dissymmetry in the number of OCs.[31]

Intensity of OCs

Teeth are not rigidly set in the maxillary bone but are merely suspended by the periodontal ligament to the effect that a tooth can actually be shown to "pulsate" inside its alveolus at each heartbeat.[32] As discovered by Riise and Ericsson,[33] the number of tooth contacts increases roughly twofold on light versus hard pressure. Variations in masticatory muscle activity also alter the intensity of OCs. Studies of diurnal variations indicate a random fluctuation of contact intensities[34] over a 24-hour period whereby the number of contacts and the total contacting surface decrease toward the end of the day.[35] Thus natural teeth have fewer and less ideally placed contacts than those described in theoretic schemes, and the intensity of tooth contacts is not constant.

TEMPOROMANDIBULAR JOINT

Traditional stomatognathologic views are based on the premise that simultaneous contact of all posterior teeth should occur in RCP only. Centric relation is the most important determinant of mandibular stability[36]; therefore some restorative techniques rely heavily on a definitely reproducible hinge axis location. For this to be true, the internal structures of the temporomandibular joints (TMJs) as primary determinants of hinge axis location should be absolutely stable themselves.

Structural changes

On a 24-hour basis, some researchers report variations in CR registrations.[37] The fluid content of the tissues surrounding the bony condyle fluctuates as it does in other soft tissues of the body,[38] thereby creating shifts in hinge axis recordings. Over a longer time span, evidence exists as to remodeling phenomena in the glenoid fossa either naturally or after artificial repositioning of the mandible. In a histologic study by Moffet et al.,[39] bone remodeling (progressive or regressive) has been demonstrated to varying degrees in the condyle and the glenoid fossa of each of 30 anatomic cadavers. Experimental data indicate that in younger animals the TMJ can structurally adapt to artificial repositioning of the mandible,[40] and the evidence of adaptation is ultimately removed by normally occurring remodeling processes.[41]

Clinically, a majority of patients have a 0.5 to 1.5 mm anteroposterior discrepancy between MI and RCP.[42] Celenza[43] described the recurrence of an inconsistency between MI and RCP after an MI-RCP coincidence was established: 30 out of 32 patients who were initially "gnathologically treated" to centric relation had a "deflective" contact 2 to 12 years after completion of therapy. Whether the TMJ is capable of major adaptive changes in response to mandibular repositioning[44, 45] or occlusal alterations[46] in adult subjects is still controversial.

Occlusal plane therapy

Occlusal planes have been recommended as conditioning devices to relax the neuromuscular apparatus and ensure optimal jaw relation recordings. Compared with other techniques, a Hawley-type appliance worn for 24 hours led to the most "consistent" and the most "retrusive" recordings.[47, 48]

Investigations over longer periods demonstrated a shift of the terminal hinge position over time, but no consistent pattern emerged. Kovaleski and De Boever[49] treated patients who had a functional disturbance of the TMJ and

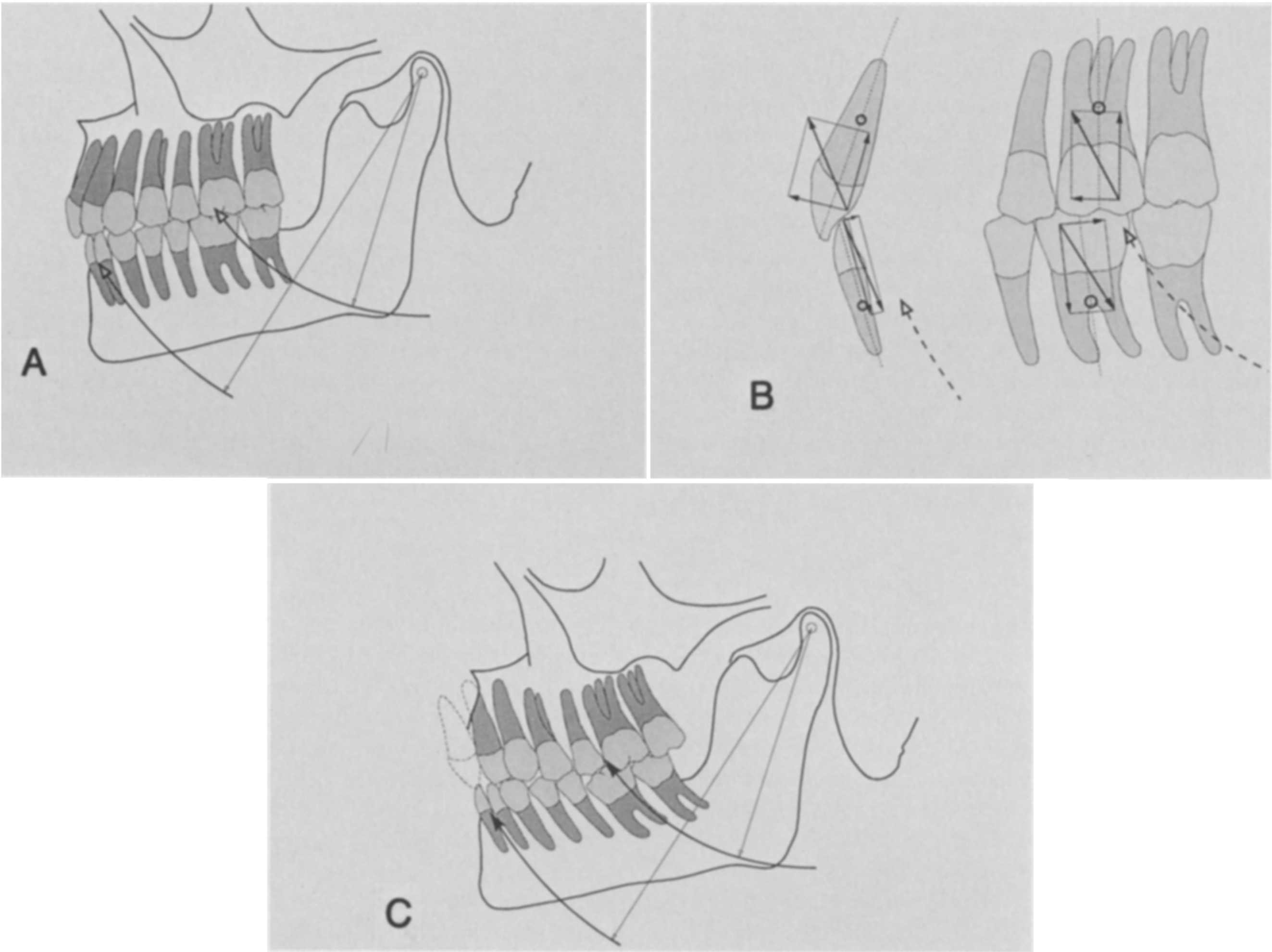

Fig. 4. A, Rotational movement of mandible on closure. **B,** Detailed view of **A.** Schematic drawing of force vectors likely to appear on clenching. Resulting tilting movements of teeth may vary according to point of application of load and location of center of rotation of tooth. As drawn, resulting force on clenching causes maxillary teeth to tilt forward but actually generates "posterior component of force" on mandibular teeth. **C,** Hypothetic angulation of roots inside skull if loading was applied along longitudinal axes of roots.

they described a trend toward an anterior and lateral displacement of the RCP. An anterosuperior shift after occlusal plane therapy was also demonstrated in another study on a group of normal subjects, in which the mean change was 1 mm with a range of 0.3 to 3.4 mm.[50] In another investigation,[51] an initial anterior movement followed by a gradual retrusion was described; however, the amount of scattering relative to the small amount of variation (0.1 mm) makes the data somewhat questionable. Furthermore, the control group (no occlusal plane therapy) also demonstrated a shift in the posterior direction.[51]

Recordings

A number of studies have dealt with the consistency of duplicate hinge-axis assessments.[52] It emerges that RCPs can usually be duplicated within a range of 0.1 to 0.4 mm. This range is a constant finding even though the conclusions drawn may vary among authors. Inconsistencies in the vicinity of 0.1 mm were found by Helkimo et al.[53] and Kantor et al.[54] Larger values were reported by Smith[55] (0.22 mm) and Simon and Nicholls,[56] who used a fairly complex recording apparatus. In the latter study a spread of up to ±0.5 mm in hinge axis recordings was reported. It is therefore suggested that the TMJ is not a precision-engineered tool. Like any other living tissue it does present anatomic variations over time and will not allow absolute duplication of repeated measurements.

FORCES

A number of authors seem to support the notion of a control of the forces that act on the teeth by way of specific designs of the occlusal surfaces.[36, 57, 58] Such a premise re-

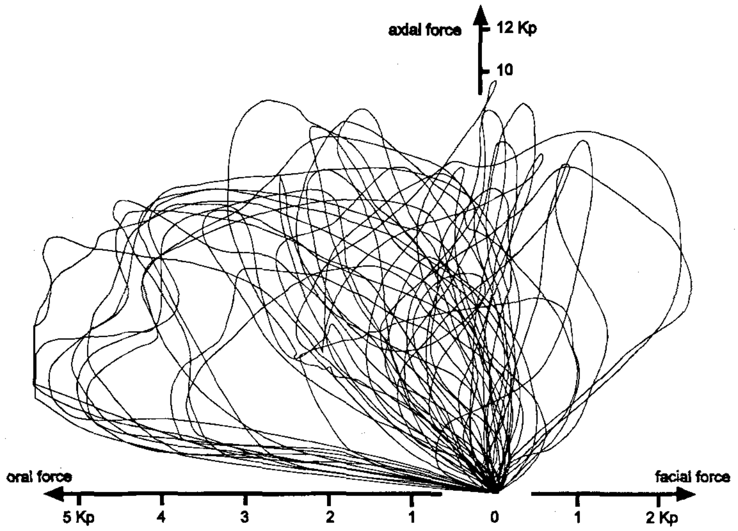

Fig. 5. Force vectors applied to molar on chewing. As depicted (difference in scaling on *x* and *y* axes), loading of teeth is roughly equal in axial and buccolingual directions. (Adopted from Graf and Geering, Oral Sci Rev 1977;10:1-10.)

quires closer scrutiny of the force systems that are active in the mouth: the forces caused by mastication, those that are active over prolonged periods of time, and those that are developed during parafunctional activity.

Functional forces

It is accepted that the main force vectors should be directed along the longitudinal axes of the teeth.[59] An early study revealed the pain threshold to lateral force application to be approximately one third of the force required to elicit pain when the vector was applied along the longitudinal axis.[60] This experiment, however, is only a partial reflection of reality. In 1923, a report by Stallard[61] diagrammatically analyzed resulting forces during clenching. Owing to the location of the roots in the skull relative to the rotational path of the mandible, he demonstrated the presence of an anterior tilting movement of the teeth. The resulting vectors were grouped into what was named "anterior component of force" and supposedly explained the anterior migration of the teeth in the human dental arch (Fig. 4, *A* through *C*). The position of the maxillary incisors relative to the closure path of the mandible forces these teeth labially during chewing. The magnitude of this movement has been reported to be in the 0.02 to 0.05 mm range.[62]

Masticatory movements, as projected on the frontal plane, nearly always show lateral displacement of the mandible.[63] *Therefore the force vectors applied to the teeth during mastication present a lateral component and are directed along the longitudinal axes of the roots.* In an experiment by Graf and Geering,[64] force transducers were mounted in an edentulous space and the subjects were asked to chew various foods. Applied forces were recorded in the vertical and horizontal planes. As illustrated in Fig. 5, their intensity along the buccolingual axis was roughly equal to their magnitude along the longitudinal axes of the teeth. The authors concluded that during function the teeth are actually "jiggled in several directions."[64]

Thus during clenching or chewing the teeth are not loaded axially only; horizontal force vectors are also present.

Long-term forces

Long-term forces have been discussed extensively in the orthodontic literature and can be subdivided into three groups: (1) the forces generated by the muscles of the tongue (in a facial direction) and cheeks (in a lingual direction), (2) the forces caused by the transseptal periodontal fiber system; and (3) the eruptive forces of the teeth.

Muscular forces. In broad terms, the shape of the dental arch is determined by the reciprocal pressure of the tongue and the cheeks. The teeth are stabilized at a location where the resultant force is zero.[65] This concept dates back to Tomes (1873) who stated that "the agency of the lips and tongue is that which determines the position of the teeth themselves."[66] Indeed there is some circumstantial evidence to support this claim: children with congenital aglossia have extremely constricted dental arches.[67, 68] Also, the teeth are tipped lingually when the lips are "hardened" by scarring[66]; conversely, they splay bucally when the perioral musculature has been destroyed.[69]

However, when the forces were actually measured, a preponderance of the lingual forces was consistently apparent. Whereas earlier studies focused on forces developed during function,[70, 71] the newer approach concentrates on resting forces. Efforts to explain this buccolingual discrepancy by integrating the forces over longer periods[72] or by correlating the forces with the shape of the dental arch[73] brought the force vectors closer to balance, but were still unsatisfactory. One hypothesis calls for the periodontal ligament to produce "active" and not just "passive" stabilization,[68] in which the teeth are capable of resisting pressures of up to 5 to 10 gm/cm.[2] This assumption differs from findings of earlier experiments by Harmon,[74] who placed 2 mm thick plates on buccal or lingual tooth surfaces. It was established that an additional force of only 1 to 2 gm was acting on these teeth, which after 90 days had moved 0.25 mm in the direction opposite to the plate. Several interarch tooth relationships (malocclusions) may be stable[65] and thus "there can be no doubt that there is an equilibrium."[75] Its components, however, have yet to be established.

Transseptal forces. Transseptal force is clinically proven by the tendency for teeth that are adjacent to an extraction socket to approximate after extraction.[76] In an experiment by Picton and Moss,[77] the periodic elimination of the transseptal fibers reduced the approximal drift to nearly zero. It was thus concluded that the transseptal fiber system was responsible for space closure when interproximal tooth contacts were artificially opened. In an intact arch, the interproximal force has been determined as averaging 36.7 gm. This pressure increases to 57.29 gm after the chewing of food.[78]

Eruptive forces. The exact origin of the eruptive forces of the teeth is still a topic of controversy,[79, 80] but their existence is affirmed.[81] In an experimental model on tooth eruption in rabbits, Proffit and Sellers[82] were able to establish the growth rate of these teeth (50 μm/hour initially) and also the pressure/time ratio that would cause them to stop erupting (3 gm pressure every other second). By extrapolating data on the rate of "submersion" of ankylosed teeth, the speed of eruption can be quantified to 2 μm per day in children.[83] With the use of sophisticated video equipment, Proffit et al.[84] found eruption rates of 11 to 14 μm/day when the teeth were close to occlusion. On a 24-hour basis, the teeth erupted relatively fast until mealtime when chewing food either halted their movement or intruded them into their socket. Drifting, tipping, supraeruption, and segmental alveolar bone growth may occur when intra-arch and interarch stabilization are lost because of extractions.[85] Compagnon[86] investigated the behavior of periodontally sound unopposed molars and documented a continuous eruption of these teeth that averaged about 1 mm per decade. Clinically, wide variations exist as to the behavior of unopposed teeth. It might be hypothesized that the pressure of the tongue at rest is the parameter that determines the stability of unopposed dental arch segments. To some extent, eruption is a reversible phenomenon as shown in an experiment by Anderson and Myers[87] in which 0.5 mm thick overlays were fitted to molars and caused intrusion of the teeth. After removal of the overlay, rapid relapse to the original position was observed.

Parafunctional forces

Parafunctional forces are still incompletely understood but are thought to represent a combination of the previously described forces. High-intensity forces of long duration (repeated phases of bruxism) lasting up to 5 minutes have been reported[88] and longer episodes are conceivable. In a noninflamed periodontium, depending on the magnitude, the direction (unidirectional or back and forth) and possibly genetically determined characteristics of the supporting structures, might cause either abrasion, mobility, or migration of teeth.

It appears that two different force systems are active in the mouth. A high-intensity but short-acting system exists that might cause fractures of prosthodontic structures but that is fully dissipated because of the shock-absorbing function of the periodontal ligament.[89, 90] This system has no effect on an orthodontic-type tooth movement. Conversely, low-grade but long-lasting forces will determine a rearrangement of the supporting apparatus and cause migration of the teeth until a new state of equilibrium is reached. For this system to be active, its duration must exceed 4 to 6 hours per day in humans.[91] The effects of parafunctional forces must be evaluated along similar guidelines. Such forces will cause teeth to move if their duration exceeds the threshold for movement.

CHEWING EFFICACY

Anthropologists divide mastication into puncturing, cutting, tearing, compression crushing, and crushing by rolling[92] whereas in the dental literature trituration of food has been compared with the action of a pestle in a mortar.[3]

A number of publications have described the relationship between the number of occluding surfaces and chewing efficacy. Some authors believe that 20 occluding units in a continuous arch may be adequate for chewing,[93] whereas others found that masticatory function was significantly impaired in subjects with fewer than 20 remaining teeth.[94] Available clinical data on the relationship between occlusal anatomy and chewing, however, are limited to an early review by Yurkstas.[27] For equal numbers of opposing teeth, the total OC area had the strongest correlation with chewing efficacy (namely, degree of comminution of food relative to the number of chewing strokes). By extension, opposing totally flat teeth would present the best masticatory performance. Interestingly, the number of remaining teeth per se was reported to be a poor predictor of chewing efficacy because of the individual adaptive capacity of the patients. More recent published data suggest the total surface of functional occlusal contacts has no bearing on the preferred chewing side.[63]

It thus appears that optimal masticatory efficacy is obtained by flat occlusal surfaces. The "prophylactic reduction of cusps" to improve chewing has been discussed.[95]

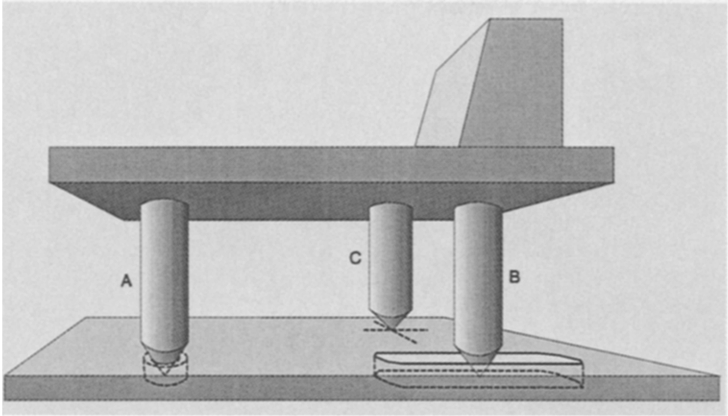

Fig. 6. Mechanical equivalent of tripodized occlusal contact. Device is stabilized by pins *A* and *B* and pin *C* rests on plate. It can be repositioned to accuracy of $\pm 3 \mu m$.

Interestingly occlusal surfaces in primitive man wore along a "helicoidal plane," which somewhat fits the lower portion of the Monson sphere (Fig. 3).[96] Nevertheless, it seems difficult to accept Begg's "attritional occlusion" as anatomically correct.[97] Therefore flat occlusal surfaces cannot be considered a treatment objective.

MECHANICS

Tripods

Examination of the tripodizing principle proves it to be a demanding exercise. Its mechanical equivalent is illustrated in Fig. 6. Such a device can be repositioned to an accuracy of approximately 5 μm (Wiskott, unpublished observation). This order of magnitude would appear to lie far beyond the degree of reproducibility of hinge axis locations. Further, if immediate disclusion is to be obtained on lateral excursions, that is, the OCs should not glide the slightest on each other, an absolute point contact must be obtained for each tripod. In other words, the OC surface should tend toward zero. Such a requirement, however, is at odds with the physical principle that specifies that pressure is equal to the force divided by the surface of application. If the surface tends toward zero, pressure approaches infinity. Also, the slightest lack of contact or movement of the teeth acting as discluders (generally the canines) will create a gliding contact on the posterior teeth. Therefore it would be senseless to establish tripods in dentitions without immediate anterior disclusion. The mechanical principle of tripodizing implies a degree of accuracy that conflicts with available data on the stability of the joint, registration methods, functional mobility of the teeth, and wear of the discluding surfaces.

Stabilization

A common conception holds that tooth intercuspation would necessarily have a stabilizing effect. Although some bracing could be expected from profound keying of opposing teeth, final tooth position depends on the overall state of equilibrium between the teeth housed in their alveolar bone and the surrounding muscles of the tongue and the cheeks. As depicted in Fig. 7, despite optimized occlusal relationships after active orthodontic treatment, a malocclusion is likely to recur if the muscular environment is not in balance.[98]

Joint variability

An "outward" translation of the working condyle was presented by Bennett in 1908.[99] This movement will exist as soon as a Bennett angle is present. More important for occlusal design is the amount of immediate side-shift because it has a bearing on the concavity of the occlusal surfaces in the posterior segments.[100] Some treatment concepts rely heavily on refined registration techniques. The articulators that have been programmed by such means are then used to create occlusal schemes in which the opposing cusps glide in between each other (near-miss chewing concept).[57] However, the dynamics of the mandible do not allow absolute programming. The variations in OC intensity have been described. Also, the mandible deforms on opening[101] and, most important, the amount of medial movement of the working condyle (immediate side-shift) is subject to variation. When pantographic recordings were obtained while the balancing condyle was forced medially by the operator, the amount of side-shift increased by up to 0.6 mm on average as compared with the amount found in nonassisted recordings.[102] With a similar experimental method, on unstrained movements, a balancing contact was present in about 30% of the patients investigated. This proportion increased to 90% when operator-induced mandibular excursions were performed.[103] From an anatomic standpoint, an inward movement can also be produced on contraction of the lateral pterygoid muscle, an event that may occur during a bruxistic episode. It follows that unstrained registrations of lateral mandibu-

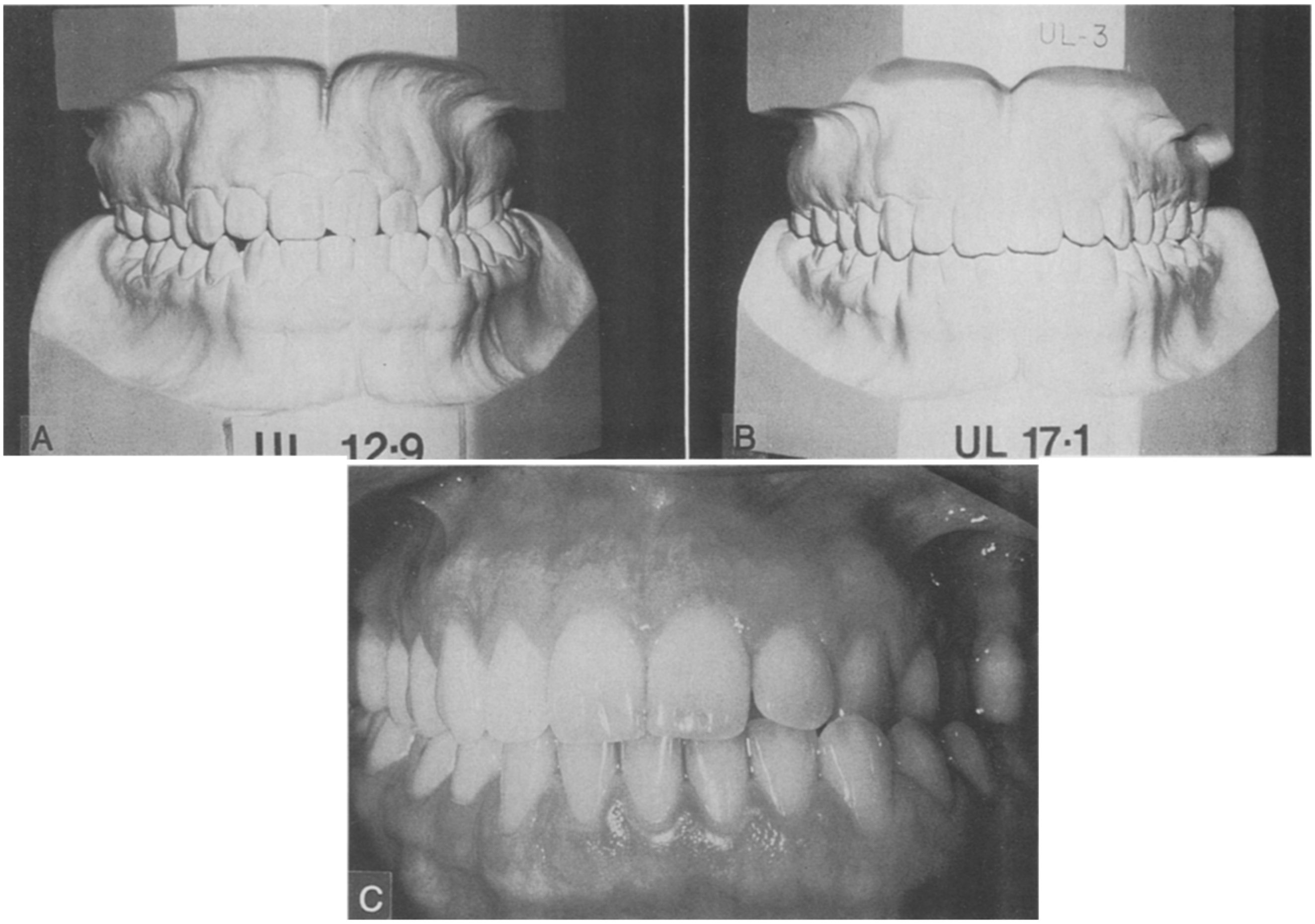

Fig. 7. Potential for relapse of malocclusion. **A,** Pretherapy cast. **B,** Orthodontic treatment was completed at age 17 and resulted in optimal interarch relationships. **C,** Patient at age 33 years. Despite adequate intercuspation of teeth, muscular environment was not in balance and crossbite recurred. (Courtesy of Department of Orthodontics, University of Washington, Seattle, with permission.)

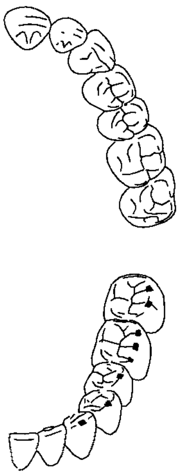

Fig. 8. Proposed simplified pattern of OCs. Interarch OCs are only present on buccal cusps of lower teeth.

lar movements as occur during classic pantograph tracings will not record the full envelope of motion and should be used with caution when one evaluates cusp paths and clearances toward the opposing arch on an articulator. Similarly it would seem appropriate not to record a functionally, but a "dysfunctionally," generated path.[104]

The anatomic structures of the mouth are not as stable as the plaster of Paris of the working cast and the injection-molded aluminum of the articulator. The occlusal anatomy of the teeth should incorporate a "safety leeway" for alterations in cusp paths beyond what may be shown on an articulator. Modifications in mandibular movements caused by parafunction or slight structural changes in the TMJ should be preplanned during design of the occlusal surfaces. Indeed, no harm will occur to the masticatory system if clearance between the opposing arches is maximized within the boundaries of a functional anterior guidance.

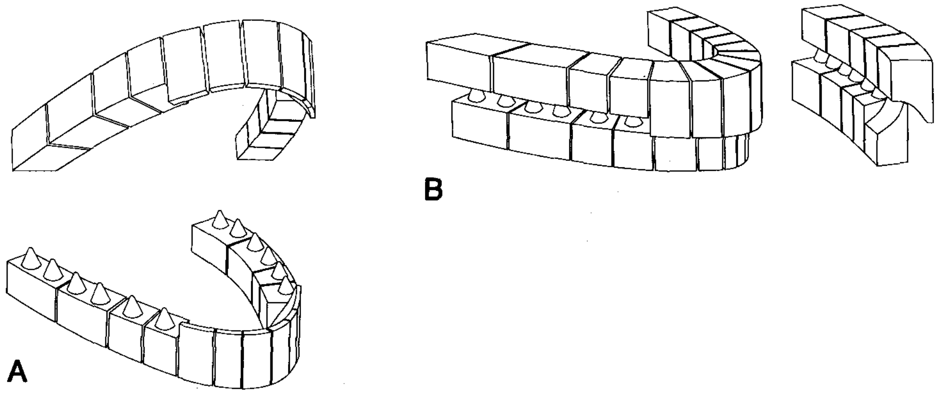

Fig. 9. **A,** Schematic drawing of dentition reduced to its functional elements and without respect for cosmetic attributes. In simplified occlusal pattern, at least one occlusal cusp per tooth contacts opposing flat plane. **B,** Because of overlap and shape of palatal aspect of upper anterior teeth, posterior teeth disclude during excursive movements of mandible.

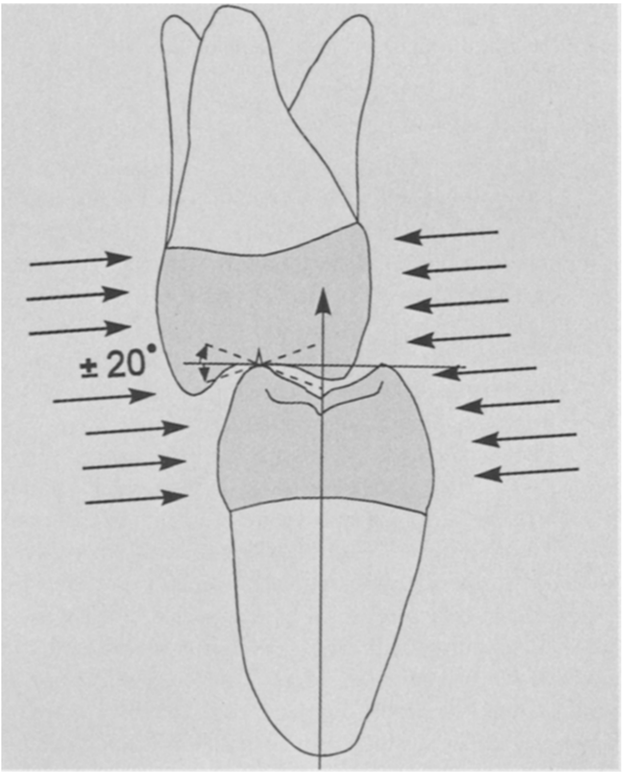

Fig. 10. Force vectors that stabilize tooth. Forces of eruption must be neutralized by plane on opposing tooth. As shown, this plane can lie in range of up to 20 degrees off perpendicular to tooth eruption. Both teeth are stabilized buccolingually by reciprocal action of muscles of tongue and cheeks.

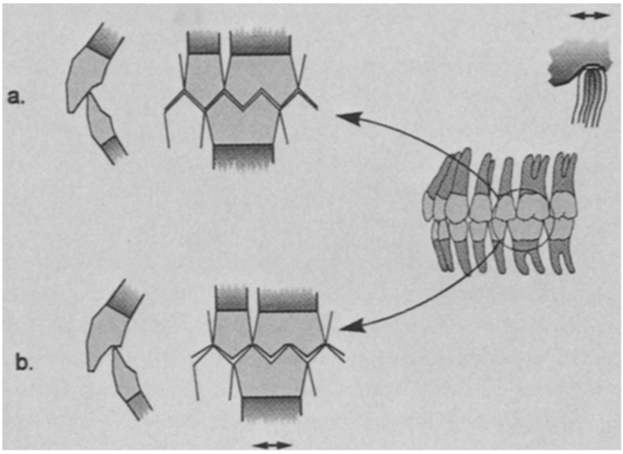

Fig. 11. Effect of anteroposterior inconsistency of TMJ. Locked tooth design as in **a** does not accommodate for changes in position of condyle. Flexible, long centric design as in **b** is recommended.

A SIMPLIFIED OCCLUSAL SCHEME: CLINICAL GUIDELINES

The following observations can be made for natural dentition: (1) relative to idealized schemes, the OCs are few and not ideally placed, (2) functional and parafunctional forces are not directed along the longitudinal axes of the teeth only, (3) the terminal hinge axis is neither absolutely stable nor absolutely reproducible, (4) unstrained lateral movements have a smaller envelope of motion than strained movements, and (5) the position of the teeth depends on forces of low intensity and long duration. Tooth stability is mostly independent of occlusal relationships.

Therefore the proposed simplified pattern of OCs should follow the preceding guidelines while satisfying the following criteria: allow adequate function, satisfy esthetic demands, be applicable to small and extensive restorations, and ensure occlusal stability.

Contact pattern

The considerations mentioned herein led to the pattern depicted in Fig. 8. As shown, all OCs that do not fulfill a

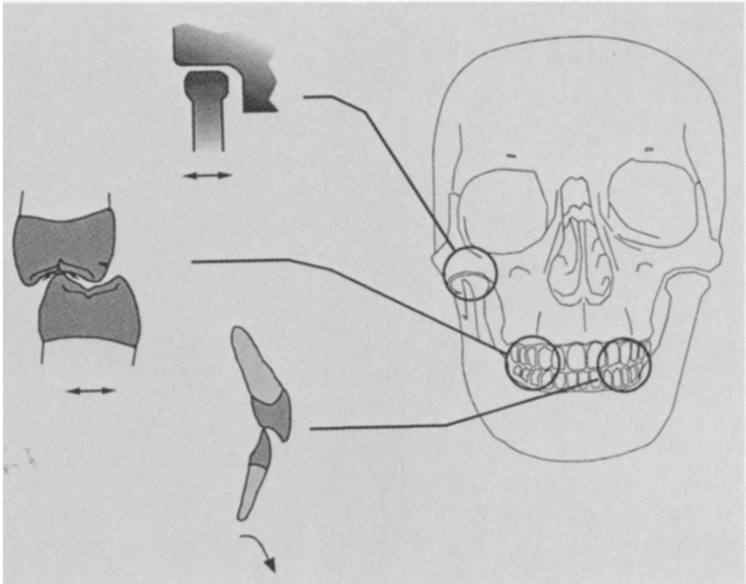

Fig. 12. Effect of mediolateral inconsistency of TMJ. Lateral shift of condyle combined with progressive anterior disclusive angle will determine a flat area on occlusal surface of posterior teeth.

justifiable purpose have been eliminated. The primary characteristics of this scheme may be summarized as follows:

1. The buccal cusps of the mandibular posterior teeth occlude in the central fossa of the maxillary posterior teeth. There must be at least one occlusal contact per tooth to ensure axial stability by neutralizing the eruptive forces of the periodontium. From a mechanical standpoint, it is irrelevant whether the OC is established between the buccal cusp of a mandibular tooth and the central fossa of a maxillary tooth or the lingual cusp of a maxillary tooth and the central fossa of a mandibular tooth. From an esthetic viewpoint, however, the former is desirable inasmuch as establishing contact on the lingual cusps of the maxillary teeth generally leads to a "hanging cusp" effect.
2. Proximal contacts stabilize the teeth mesiodistally by antagonizing the effect of the transseptal fibers.
3. An anterior guidance should provide for disclusion of the posterior arch segments on excursive movements.

To demonstrate the fundamental principles of this occlusal design, two arches were reduced to their functional elements and all nonpertinent anatomic features were eliminated (Fig. 9, *A*). Because of the anterior overlap, excursive movements will cause the posterior teeth to disclude (Fig. 9, *B*). The occluding cusps make contact on a flat opposing surface. Again, whether this cusp-plane arrangement is located on the upper, the lower, or a combination of both arches is of secondary importance. In essence, this occlusal design is equivalent to the technique applied for occlusal plane therapy.[25] During restorative procedures functionally nonsignificant occlusal anatomic features (nonoccluding cusps, fossae, ridges, and grooves) have to be placed on the occlusal surface. They must be arranged in a manner that eliminates any chance of interference on the posterior segments of the dental arches.

Occlusal contacts

Reduced in number, in the present occlusal design OCs must adhere to the following rules.

1. *They must effectively counteract the eruptive forces of the teeth.* The mechanics of the system would require the opposing flat plane to be at a right angle to the direction of tooth eruption. Clinically, however, this direction is difficult to assess and a range of up to 20 degrees off the perpendicular has proved to be acceptable. Such a range will considerably facilitate the design of a restoration or occlusal adjustment procedures. There is a diffuse belief among practitioners that one contact only may not adequately stabilize the teeth, which could somehow "escape" in a buccal or lingual direction. Such a movement is highly unlikely because, as previously discussed, the teeth are in a state of equilibrium between the tongue and the cheeks (Fig. 10).
2. *They must be so designed as to provide the room necessary for the variability inherent to a biologic structure such as the TMJ.* Fig. 11 shows this effect in the sagittal plane. Given a functional anterior guidance, anteroposterior changes in condylar positions in a range of ± 0.5 mm will necessarily affect the dimensions of the contacting surfaces on the teeth. Because the teeth are linked by a

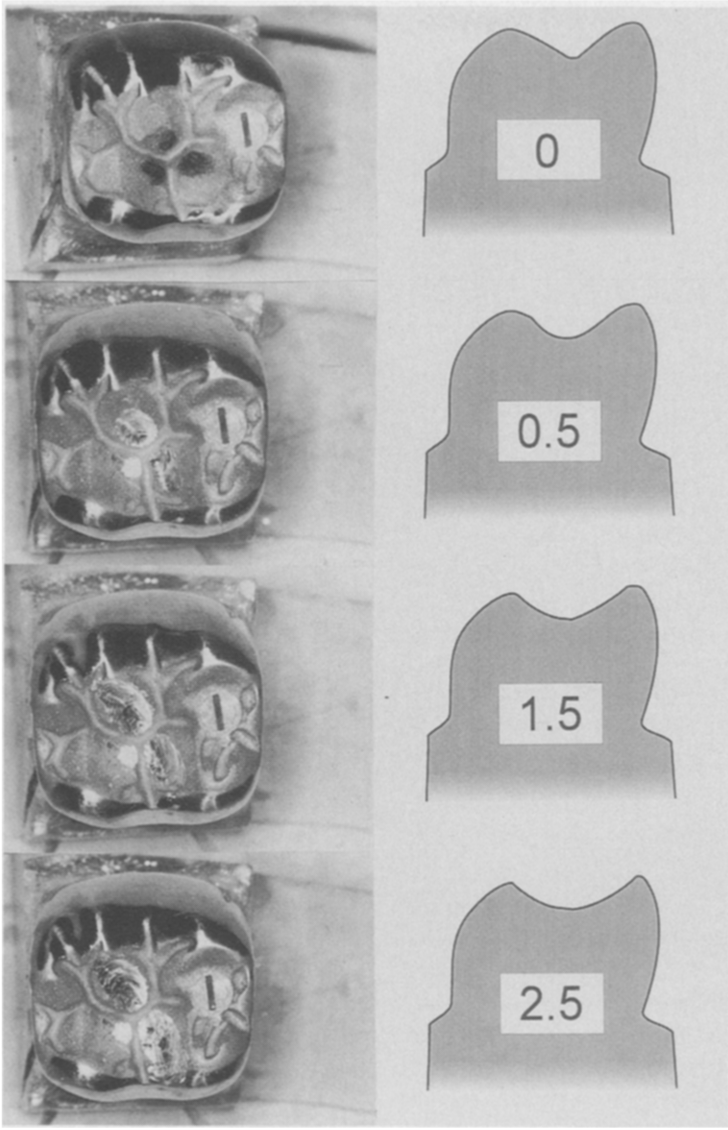

Fig. 13. Effect of alterations in ISS on occlusal anatomy of molar. In *left row*, cusp was replaced by rotating bur that ground its way into internal slopes of opposing molar as ISS was increased. *Right row* shows transverse views of sectioned teeth. Note resulting concave anatomy of occlusal surface. (From Mani et al. Schweiz Monatsschr Zahn Med 1983;93:325-34. Reprinted with permission.)

common bone (namely, the mandible) a similar argument can be made as to the room that is required in the transverse plane (Fig. 12). The occluding surface should further provide for possible alterations beyond what might have been registered at one point in time. A possible slight posterior displacement of the condyle should be planned for when the restoration is fabricated. The implications of an increase in immediate side-shift are discussed in the following section.

3. *Because an elementary law of physics states that the pressure is equal to the force divided by the surface of application, the occluding cusp should present a definite bearing surface so as to decrease the amount of force per surface area and reduce wear.*

Occlusal anatomy

For the sake of clarity, the following definitions will be used. A Bennett shift is the lateral movement of the working condyle on excursive movements, and the medial movement of the balancing condyle is termed immediate

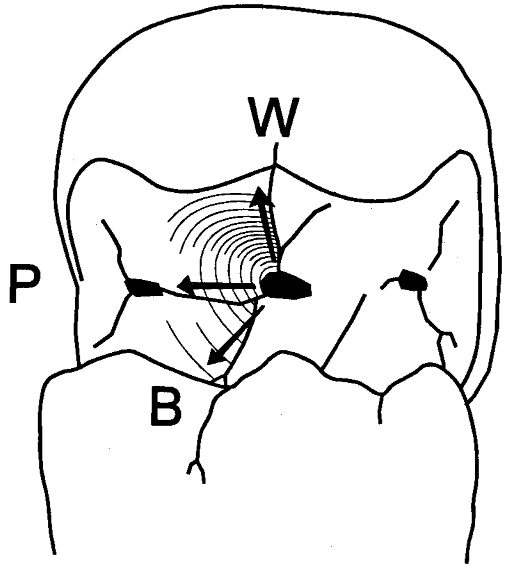

Fig. 14. Principle of occlusal planning. Because of physiologic confinement of mandibular movements on working *(W)*, balancing *(B)*, and protrusive *(P)* excursions, occlusal topography mesial to upper bearing surface should be rendered concave and thus permit unimpeded movement of lower cusp.

side-shift (ISS). A Bennett movement will exist when the Bennett angle is nonzero and independent of the presence of an ISS.

Internal cusp slopes do bulge toward the central fossae of the teeth and the vast majority of the world population accommodates itself to such an occlusal configuration. However, this appears to be a prime example of the inadequacy of form and function because deep intercuspation of the teeth invites posterior interferences. This has been graphically shown by Lundeen and Wirth[105] and in a three-dimensional model by Mani et al.[106] In the latter experiment, a cusp was replaced by a rotating bur. While the anterior guidance remained unaltered, the ISS was increased up to 2.5 mm. As illustrated in Fig. 13, the bur ground its way into the internal surfaces of the cusps. Under similar conditions, patients are likely to brux, wear away tooth substance, and possibly fracture structural elements of the teeth. It follows that an occlusal anatomy designed to accommodate larger amounts of ISS without interference should be concave and not convex. This occlusal topography is a slight departure from commonly accepted schemes but it will readily accommodate situations in which the anterior or posterior determinants of occlusion, or both determinants, are not favorable.

A basic principle of work simplification states that (1) only two structural elements of the teeth (that is, occluding cusps and interproximal contacts) are essential for function and occlusal stability and (2) occlusal surfaces should be designed according to a "worst case scenario." No harm will occur if occlusal surfaces are designed to provide patients with more space between the arches during excursive movements than the bare minimum shown on an articulator. Expressed in clinical terms, an occlusal surface should be designed as if the patient needed a larger amount of anteroposterior freedom, had a rather flat condylar guidance, and a significant ISS.

During the laboratory phase of extensive rehabilitations, this can be achieved by setting the condylar guidance to approximately 25 degrees[105] and the ISS to 1.5 to 2 mm.[102] In smaller restorations or single crowns, the traveling path of the opposing cusps should be evaluated and an appropriate leeway designed into the restoration. As shown in Fig. 14, because of the physiologic confinement of mandibular movements on working, balancing, and protrusive excursions, the occlusal topography mesial to a maxillary bearing surface should be rendered concave and thus permit unimpeded movement of the mandibular cusp. A similar topographic design should be created on the distal aspect if the bearing surface is located on the lower arch.

CONCLUSIONS

When adequate anterior guidance is provided, benefits result from the use of the system described.[107]

1. It satisfies functional requirements. The system maintains vertical dimension and allows chewing. It provides for optimal clearance on the posterior arch segments during eccentric movements.
2. It will satisfy esthetic demands. The system requires a slight adaptation of the occlusal topography. However, when contemporary ceramic layering techniques and internal staining are applied, the depth of the occlusal anatomy can be built into the porcelain and the requirement for concaveness respected (Fig. 15, *A* through *C*).
3. It is applicable to small and extensive restorations. The system can be applied on a tooth-by-tooth basis because it can readily be adapted to the anterior guidance at hand. When an entire arch is restored, the articulator should be adjusted to worst-case settings. For smaller restorations, that is, when tooth guidances are still present, the technician should provide the opposing cusps with more space during excursive movements by designing concave internal cusp slopes.
4. It ensures occlusal stability. Forces exerted during mastication will not influence tooth position. Only forces caused by tooth eruption and by the resting pressures of the tongue and the cheeks will determine buccolingual stability (Fig. 10). One OC per tooth (to neutralize eruptive forces) and adequate interproximal contacts (that act against the transseptal fibers) will determine arch stability.

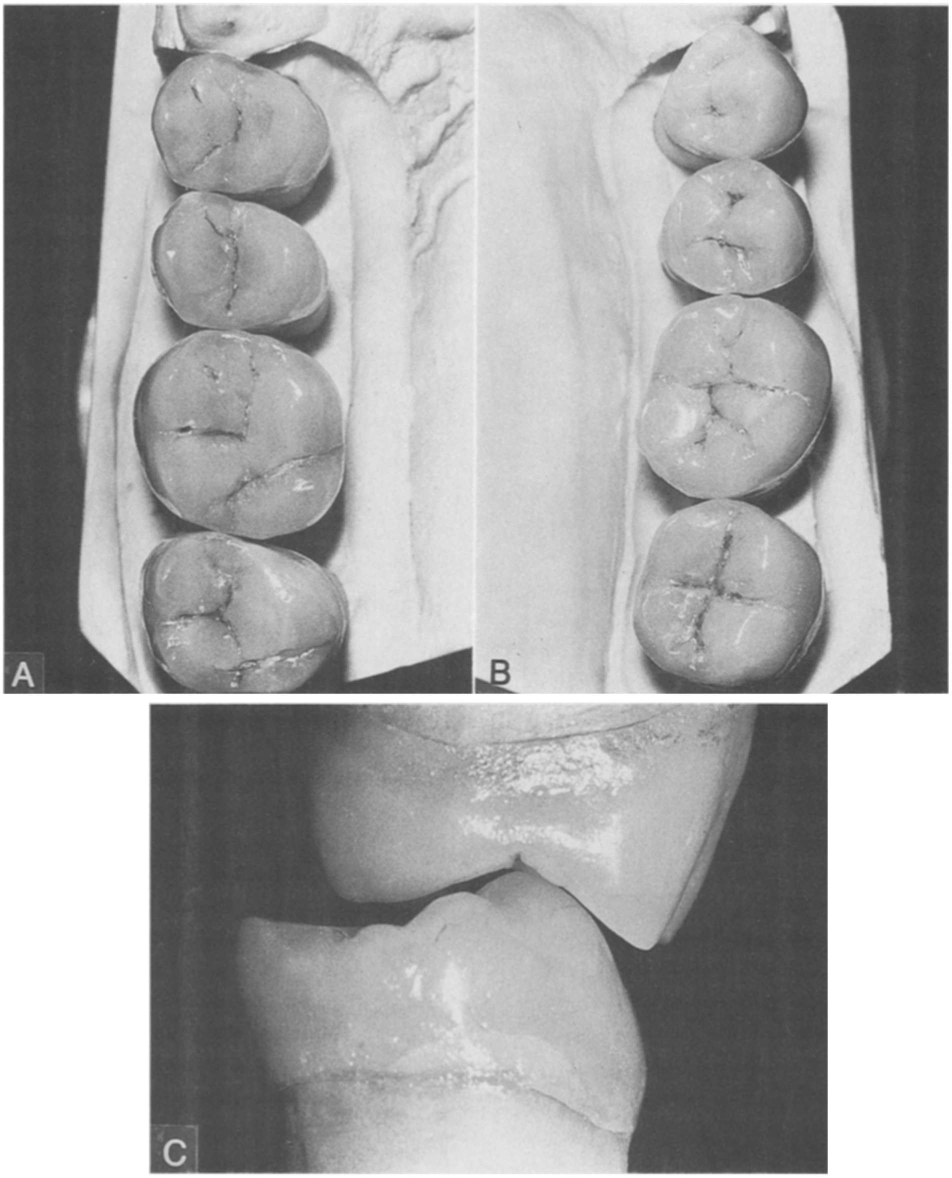

Fig. 15. **A** through **C,** By use of contemporary ceramic layering techniques, overall anatomy of teeth can be designed as concave surface while optical depth of fossae and grooves is maintained.

5. It is flexible. The system only requires one OC per tooth, which under ideal conditions should be located in a central fossa. This will allow the design of an esthetically pleasing occlusal surface. From the standpoint of mechanical stability, the location of the OC is not actually critical. Further, the system can be adapted to most anterior guidances and to varying degrees of group function if so desired.

6. Adjustment is uncomplicated. At the trial stage, the intensity of the OC can easily be corrected by applying the technique illustrated in Fig. 16. The pointed shape of the contacting cusp should be maintained or a locked intercuspation will be created. A deepening of the opposing surface should be accompanied by appropriate reshaping of the adjacent internal slopes to maintain concaveness.

7. Fabrication is significantly less complex inasmuch as the number of contacts is reduced.

We thank Mr. D. Vinci, CDT, for fabricating the restorations shown.

REFERENCES

1. Stallard H, Stuart CE. What kind of occlusion should recusped teeth be given? Dent Clin North Am 1963;7:591-606.

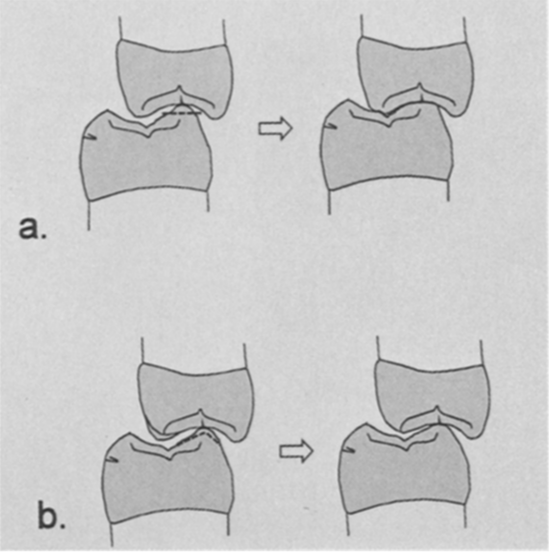

Fig. 16. Principle of occlusal adjustment. *a*, Supporting cusp should not be ground flat or locking intercuspation will result. *b*, Occluding cusp is decreased in height and its pointed shape is retained. Nonoccluding cusps are also reduced to maintain clearance and avoid possible interferences.

2. Lucia V. The gnathological concept of articulation. Dent Clin North Am 1962;6:183-97.
3. Stuart CE. Good occlusion for natural teeth. J PROSTHET DENT 1964;14:716-24.
4. Schuyler CE. Freedom in centric. Dent Clin North Am 1969;13:681-6.
5. Schuyler CH. Fundamental principles in the correction of occlusal disharmony, natural and artificial. J Am Dent Assoc 1935;22:1193-202.
6. Kurth IE. Balanced occlusion. J PROSTHET DENT 1954;4:150-67.
7. Beyron HL. Characteristics of functionally optimal occlusions and principles of occlusal rehabilitation. J Am Dent Assoc 1954;28:648-59.
8. Schuyler CH. The function and importance of incisal guidance in oral rehabilitation. J PROSTHET DENT 1963;13:1011-29.
9. Stuart CE, Stallard H. Principles involved in restoring occlusion to natural teeth. J PROSTHET DENT 1960;10:304-13.
10. Spee F. Die Verschiebungsbahn des Unterkiefers am Schädel. Arch Anat Physiol Physiol Anat Abt 1890;16:285-294. (The condylar path of the mandible along the skull. J Am Dent Assoc 1980;100:670-5).
11. Hanau RL. Articulation defined, analyzed and formulated. J Am Dent Assoc 1926;13:1694-709.
12. Thielemann K. Biomechanik der Paradentose. Leipzig: Meusser, 1938.
13. Monson GS. Applied mechanics to the theory of mandibular movement. Dent Cosmos 1932;11:1039-53.
14. Pankey LD, Mann AW. Part II: reconstruction of the upper teeth using a functionally generated path technique. J PROSTHET DENT 1960; 10:151-62.
15. Wilson GH. Dental prosthetics. Philadelphia: Lea & Febiger, 1917.
16. Dempster WT, Adams WJ, Duddles RA. Arrangement in the jaws of the roots of the teeth. J Am Dent Assoc 1963;67:779-97.
17. Andrews LF. The six keys to normal occlusion. Am J Orthod 1972;62:296-309.
18. Price RB, Kolling JN, Clayton JA. Effects of changes in articulator settings on generated occlusal tracings. part I—condylar inclination and progressive side shift tracings. J PROSTHET DENT 1991;65:237-43.
19. Woda A, Vigneron P, Kay D. Nonfunctional and functional occlusal contacts: a review of the literature. J PROSTHET DENT 1979;42:335-41.
20. Hildebrand GY. Studies in mandibular kinematics. Dent Cosmos 1936;78:449-58.
21. Pameijer JHN, Brion M, Glickman I, Roeber FW. Intraoral occlusal telemetry: IV—tooth contacts during swallowing. J PROSTHET DENT 1970;24:396-400.
22. Clayton JA, Kotowitz WE, Zahler JM. Pantographic tracings of mandibular movements and occlusion. J PROSTHET DENT 1971;25:389-96.
23. Friel S. Occlusion: observation on its development from infancy to old age. Int J Orthod 1927;13:323-42.
24. Lundeen HC. Occlusal morphologic considerations. Dent Clin North Am 1973;15:649-61.
25. Ramfjord SP, Ash MM. Occlusion. 3rd ed. Philadelphia: Saunders, 1983.
26. Black GV. Descriptive anatomy of the human teeth. 4th ed. Philadelphia: SS White Dental Mfg. Co., 1902.
27. Yurkstas AA. The masticatory act: a review. J PROSTHET DENT 1965; 15:248-62.
28. Anderson DJ. Experimental malocclusion. In: Anderson DJ, Eastoe JE, Melcher AH, Picton DCA, eds. Mechanisms of tooth support. Bristol: Wright, 1967:126-30.
29. Hochman N, Erhlich J. Tooth contact location in intercuspal position. Quintessence Int 1987;18:193-6.
30. Plasmans PJJM, Kuipers L, Vollenbrock HR, Vrijhoef MMA. The occlusal status of molars. J PROSTHET DENT 1988;60:500-3.
31. Korioth TWP. Number and location of occlusal contacts in intercuspal position. J PROSTHET DENT 1990;64:206-310.
32. Körber KH. Periodontal pulsation. J Periodontol 1971;41:382-90.
33. Riise C, Ericsson SG. A clinical study of the distribution of occlusal tooth contacts in the intercuspal position at light and hard pressure in adults. J Oral Rehabil 1983;10:473-80.
34. Molligoda MA, Abuzar M, Berry DC. Measuring diurnal variation in occlusal contact areas. J PROSTHET DENT 1988;60:235-8.
35. Berry DC, Singh BP. Daily variations in occlusal contacts. J PROSTHET DENT 1983;50:386-91.
36. McHorris WH. Occlusal adjustment via selective cutting of natural teeth: part I. Int J Periodont Rest Dent 1985;5:9-25.
37. Shafagh I, Yoder JL, Thayer KE. Diurnal variance of centric relation position. J PROSTHET DENT 1975;34:574-82.
38. Mills JN. Human circadian rhythms. Physiol Rev 1966;46:128-71.
39. Moffet BC, Johnson LC, McCabe JB, Askew HC. Articular remodeling in the adult human TMJ. Am J Anat 1964;115:119-42.
40. Woodside DG, Metaxas A, Altuna G. The influence of functional appliance therapy on glenoid fossa remodeling. Am J Orthod Dentofac Orthop 1987;92:181-98.
41. Stöckli PW, Willert HG. Tissue reactions in the temporomandibular joint resulting from anterior displacement of the mandible in the monkey. Am J Orthod 1971;60:142-55.
42. Posselt U. Studies in the mobility of the human mandible. Acta Odontol Scand 1952;10 (Suppl 10).
43. Celenza FV. The centric position, replacement and character. J PROSTHET DENT 1973;30:591-8.
44. Isberg AM, Isacsson G. Tissue reactions of the temporomandibular joint following retrusive guidance of the mandible. J Craniomandib Pract 1986;4:143-8.
45. Tewson HTK, Heath JK, Meikle MC. Biochemical and autoradiographical evidence that anterior mandibular displacement in the young growing rat does not stimulate cell proliferation or matrix formation at the mandibular condyle. Arch Oral Biol 1988;33:99-107.
46. Mongini F. Dental abrasion as a factor in remodeling of the mandibular condyle. Acta Anat 1975;92:292-300.
47. Calagna LJ, Silverman SI, Garfinkel L. Influence of neuromuscular conditioning on centric relation conditioning. J PROSTHET DENT 1973; 30:598-604.
48. Weinberg LA. The role of muscle deconditioning for occlusal corrective procedures. J PROSTHET DENT 1991;66:250-5.
49. Kovaleski WC, De Boever J. Influence of occlusal splints on jaw position and musculature in patients with temporomandibular joint dysfunction. J PROSTHET DENT 1975;33:321-7.
50. Williamson EH, Evans DL, Barton WA, Williams BH. The effect of bite plane therapy use on terminal hinge axis location. Angle Orthod 1977;47:25-32.
51. Serrano PT, Nicholls JI, Yuodelis RA. Centric relation change during therapy with corrective occlusion prosthesis. J PROSTHET DENT 1984; 51:97-105.
52. Winstanley RB. The hinge-axis: a review of the literature. J Oral Rehabil 1985;12:135-59.

53. Helkimo E, Carlsson GE, Helkimo M. Chewing efficacy and state of the dentition. Acta Odontol Scand 1978;36:33-41.
54. Kantor ME, Silverman SI, Garfinkel L. Centric-relation recording techniques: a comparative investigation. J PROSTHET DENT 1972; 28:593-600.
55. Smith HF. A comparison of empirical centric relation records with location of terminal hinge axis and apex of the Gothic-arch tracing. J PROSTHET DENT 1975;33:511-20.
56. Simon RL, Nicholls JI. Variability of passively recorded centric relation. J PROSTHET DENT 1980;44:21-6.
57. Thomas PKT, Tateno G. Gnathological occlusion. Tokyo: Sorin Co., 1980.
58. Dos Santos J, Blackman RB, Nelson SJ. Vectorial analysis of the static equilibrium of forces generated in the mandible in centric occlusion, group function, and balanced occlusion relationships. J PROSTHET DENT 1991;65:557-76.
59. Dawson PE. Evaluation, diagnosis, and treatment of occlusal problems. St Louis: Mosby, 1989:88-9.
60. Adler P. Sensibility of teeth to loads applied in different directions. J Dent Res 1947;26:279-89.
61. Stallard H. The anterior component of force of mastication and its significance to the dental apparatus. Dent Cosmos 1923;65:457-74.
62. Parfitt GJ. The dynamics of a tooth in function. J Periodontol 1961; 32:102-7.
63. Wilding RJC, Lewin A. A computer analysis of normal human masticatory movement recorded with a Sirognathograph. Arch Oral Biol 1991;36:65-75.
64. Graf H, Geering AH. Rationale for clinical application of different occlusal philosophies. Oral Sci Rev 1977;10:1-10.
65. Weinstein S, Haack DC, Morris LY, Snyder BB, Attaway HE. On an equilibrium theory of tooth position. Angle Orthod 1963;33:1-26.
66. Proffit WR. The biological basis of orthodontic therapy. In: Profitt WR. Contemporary orthodontics. St. Louis, Missouri: Mosby, 1986.
67. Eskew H, Shepard E. Congenital aglossia. Am J Orthod 1949;35:116-9.
68. Gardiner JH. Congenital partial aglossia. Dent Pract 1960;10:83-7.
69. Moss JP, Picton DCA. Experimental mesial drift in adult monkeys *(Maccaca Irus)*. Arch Oral Biol 1967;12:1313-20.
70. Kydd WL. Maximum forces exerted on the dentition by the perioral and lingual musculature. J Am Dent Assoc 1957;55:646-51.
71. Posen AL. The influence of maximum perioral and tongue force on the incisor teeth. Angle Orthod 1972;42:285-309.
72. Lear CSC, Moorrees CPA. Buccolingual muscle force and dental arch form. Am J Orthod 1969;56:379-93.
73. Brader AC. Dental arch form related with intraoral forces: PR = C. AM J Orthod 1972;61:541-61.
74. Weinstein S. Minimal forces in tooth movement. Am J Orthod 1967; 53:881-903.
75. Proffit WR. Equilibrium theory revisited: factors influencing the position of the teeth. Angle Orthod 1978;48:175-86.
76. Hirschfeld I. The individual missing tooth: a factor in dental and periodontal disease. J Am Dent Assoc 1937;24:67-82.
77. Picton DCA, Moss JP. The part played by the trans-septal fibre system in experimental approximal drift of the cheek teeth of monkeys *(Macacca irus)*. Arch Oral Biol 1973;18:669-80.
78. Southard TE, Southard KA, Tolley EA. Periodontal force: a potential cause of relapse. Am J Orthod Dentofac Orthop 1992;101:221-7.
79. Berkovitz BKB. Theories of tooth eruption. In: Poole DFG, Stack MV, eds. The eruption and occlusion of teeth. London: Butterworth & Co, 1976:193-204.
80. Sutton PRN. The blood vessel thrust theory of tooth eruption and migration. Med Hypotheses 1985;18:289-95.
81. Ness A. Movements and forces in tooth eruption. Adv Oral Biol 1964; 1:33-75.
82. Proffit WR, Sellers KT. The effect of intermittent forces on eruption of the rabbit incisor. J Dent Res 1986;65:118-22.
83. Darling AI, Levers BG. Submerged human deciduous molars and ankylosis. Arch Oral Biol 1973;18:1021-40.
84. Proffit WR, Prewitt JR, Baik HS, Lee CF. Video microscope observations of human premolar eruption. J Dent Res 1991;70:15-8.
85. Kaplan P. Drifting, tipping, supraeruption, and segmental alveolar bone growth. J PROSTHET DENT 1985;54:280-3.
86. Compagnon D. Mesure de l'égression de la première molaire supérieure humaine en l'absence de dent antagoniste. Journal de Parodontologie 1990;9:57-63.
87. Anderson JR, Myers GE. Nature of centric occlusion in 32 adults. J Dent Res 1971;50:7-13.
88. Trenmouth MJ. The relationship between bruxism and temporomandibular joint disfunction as shown by computer analysis of nocturnal tooth contact patterns. J Oral Rehabil 1979;6:81-7.
89. Bien SM. Fluid dynamic mechanisms which regulate tooth movement. Adv Oral Biol 1966;2:173-201.
90. Mandel U, Dalgaard P, Viidik A. A biomechanical study of the human periodontal ligament. J Biomech 1986;19:637-45.
91. Profitt WR. On the aetiology of malocclusion. Br J Orthod 1986;13:1-11.
92. Osborn JW, Lumsden AGS. An alternative 'theogosis' and a re-examination of the ways in which mammalian molars work. Neues Jahrbuch für Geologische und Paläontologische Abhandlungen 1978;156:371-92.
93. Käyser AF. Shortened dental arches and oral function. J Oral Rehabil 1981;8:457-62.
94. Helkimo M, Ingervall B, Carlsson GE. Variation of retruded and muscular position of mandible under different recording conditions. Acta Odontol Scand 1971;29:424-37.
95. Owen CP. The prophylactic reduction of cusps: is it desirable? J Oral Rehabil 1986;13:39-48.
96. Osborn JW. Helicoidal plane of dental occlusion. Am J Phys Anthropol 1982;57:273-81.
97. Cordato M. A discussion of Begg's attritional model as correct occlusion. Aust Orthod J 1990;11:190-4.
98. Riedel RA. A review of the retention problem. Angle Orthod 1975;45:179-94.
99. Bennett NG. A contribution to the study of the movements of the mandible. Proc R Soc Med Sec Odont 1908;1:77-95. (J PROSTHET DENT 1958;8:41-54).
100. Lundeen HC, Shryock EF, Gibbs CH. An evaluation of mandibular border movements: their character and significance. J PROSTHET DENT 1978;40:442-52.
101. Gates GN, Nicholls JI. Evaluation of mandibular arch width change. J PROSTHET DENT 1981;46:385-92.
102. Tupac RG. Clinical importance of voluntary and induced Bennett movement. J PROSTHET DENT 1978;40:39-43.
103. Okeson JP, Dickson JL, Kemper JT. The influence of assisted mandibular movement in the incidence of nonworking tooth contact. J PROSTHET DENT 1982;48:174-7.
104. 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.
105. Lundeen HC, Wirth CG. Condylar movement patterns engraved in plastic blocks. J PROSTHET DENT 1973;30:866-75.
106. Mani G, Brender P, Pastant A, Spirgi M. Le mouvement latéral immédiat-expérimentations de laboratoire sur l'articulateur Panadent. Schweiz Monatsschr Zahnmed 1983;93:325-34.
107. Levinson E. Requirements for ideal restorative posterior tooth occlusal anatomy: a working clinical hypothesis. Alpha Omegan 1985;78:82-6.

Reprint requests to:
DR. H. W. A. WISKOTT
DEPARTMENT OF FIXED PROSTHODONTICS
SCHOOL OF DENTISTRY
UNIVERSITY OF GENEVA
19, BARTHELEMY-MENN
1211 GENEVA 4
SWITZERLAND