Condylar axis position, as determined by the occlusion and measured by the CPI instrument, and signs and symptoms of temporomandibular dysfunction

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Abstract: The importance of occlusion as an etiologic factor in signs and symptoms of TMD has been a source of controversy. Very few studies have examined occlusion-dictated condylar position using instrumentation, and none has compared an ideal sample against an untreated control. The purpose of this study was to determine if there is a relationship between condylar axis position as determined by the occlusion and signs and symptoms of TMD, using the condylar position indicator (CPI). A sample of subjects with ideal occlusions, defined as centric relation approximating centric occlusion, was compared with a control sample of untreated subjects. The comparison was based on written patient histories, clinical exams, and CPI measurements. The ideal sample of 30 subjects was selected from a population that had undergone full-mouth reconstruction using gnathologic principles that included centric relation (CR) being coincident with centric occlusion (CO). The control group consisted of 30 untreated subjects from the general population and was matched with the ideal sample with regard to sex. A duplicate written exam was given to the subjects in the ideal sample to assess symptoms prior to treatment. The CR bite registration technique developed by Roth was used. When the pre- and posttreatment examination scores of the ideal sample were compared, an 84% reduction in symptoms was found after treatment. A high correlation ($p<.001$) between signs and symptoms of TMD and CPI values was documented. Since condylar axis position is dictated upon closure of the dentition into maximum intercuspation and since condylar axis position was shown in this study to be strongly correlated with TMD symptomatology, it can be concluded that a statistically significant relationship exists between occlusion-dictated condylar position and symptoms of TMD.

Key Words: Centric relation, CPI, Condylar displacement, TMD, Occlusion

The ideal position of the mandibular condyle in the glenoid fossa has been a source of interest and controversy over the years. Since condylar position is often determined by the occlusion, it is of particular interest to certain restorative dentists and orthodontists who want to achieve a seated condylar position with their treatment modalities.

Confusion regarding the terms *centric relation* (CR) and *centric occlusion* (CO) exists in the literature. Since they are used extensively in this study, they must be defined. Centric relation describes the position of the condyles in the glenoid fossae when they are in their most anterosuperior position against the eminentia with the articular discs properly interposed. Okeson[1] described this position as the most musculoskeletally stable position of the mandible. Centric occlusion is defined as the maximum intercuspation of the dentition irrespective of condylar position.

The concept that the condyle is ideally positioned when upward and forward against the posterior slope of the eminence is supported by the literature. Moffet,[2] Sicher,[3] and others[1,4] described histologically how the structures of the joint are designed to withstand heavy loads with the condyles in this position. The resultant vector of the elevator muscles is directed anterosuperiorly.[1] Williamson,[5,6] Girardot,[7] Wood,[8] and Gibbs and Lundeen[9] have shown how the action of a healthy musculature positions the condyles in this upward and forward position. Gibbs and Lundeen,[9] using a gnathic replicator, demonstrated how the condyles move to and from this position during the chewing cycle. Electromyographic studies have shown that masticatory muscle function is disrupted by occlusal interferences that prevent the seating of the condyles in CR.[10-12]

Restorative dentists who have successfully used the concept of CR as a desirable treatment goal assert that there is a relationship between unfavorable condylar position, as determined by the occlusion, and temporomandibular dysfunction (TMD).[1,11,13-15] Yet there is controversy in the dental profession regarding the importance of CR. This is due in part to the large body of literature published in recent years that fails to find

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a correlation between occlusion and, in particular, condylar position and TMD. To better understand this apparent contradiction, a close look at the prevailing research, especially the methodology and design, is indicated.

To study the influence of occlusion-dictated condylar position on TMD, it is important to use a method that reduces or eliminates the influence of the occlusion on the neuromusculature. Only then can the mandible be properly positioned in CR.[5,16,17] Several studies have shown that, in most cases, the neuromusculature positions the mandible to achieve maximum intercuspation regardless of the position of the condyles in the fossae.[11,18,19] When occlusal interferences are present, proprioceptive feedback from the periodontal fibers surrounding the involved teeth program muscle function to avoid the interferences.[17,20,21] The resultant muscle function can be so dominant that the acquired mandibular position will often be mistaken by the clinician for the true CR.[14,20] Splint therapy can be effective in "deprogramming" the neuromusculature.[5,22-24] This allows location of the seated condylar position and occlusal analysis that correlates condylar position with tooth contacts. Roth[25] has long held that clinical mandibular manipulation is unreliable in determining condylar position because of the effects of the neuromusculature. This is consistent with Calagna,[19] who stated, "there is no known scientific method available to determine which patients require neuromuscular conditioning."

To further compound the problem created by the neuromusculature, experienced clinicians agree that accurately recording CR is very demanding and technique-sensitive.[14,25] Research performed by inexperienced or unskilled clinicians may produce erroneous or invalid conclusions.

Once the mandible has been positioned in CR, the method of assessment must be appropriate and the instrumentation must be sufficiently accurate to record small changes in condylar position. Measuring changes at the occlusal level, either intraorally or with hand-held study casts, gives very little information about what is occurring at the condylar level. Tomography is unreliable in evaluating condylar position.[7 26 27] A tomograph is a two-dimensional medium that does not image the entire joint and cannot be used to accurately assess a three-dimensional object. Another problem is the variation in soft tissue thickness within the joint, which creates joint space that is not three-dimensionally uniform.[26] The disc, the soft tissue covering of the articular surfaces, and the bony contours of the joint components have been shown to change form in response to functional loads.[28] Any changes that alter the temporomandibular joint space may be interpreted as changes in the condyle/fossa relationship. Hatcher[26] has shown that the evaluation of condylar position is very sensitive to the depth of the cut and that head positioning in the cephalostat is critical. A large variation in condylar position, as seen tomographically, has been found in normal asymptomatic patients.[29,30] McNeill[31] concluded that the use of tomographs to assess condylar position is contraindicated.

Researchers looking for a possible relationship between occlusion and TMD have examined dental conditions such as overbite and overjet and have found the correlation either weak or nonexistent.[32-36] This finding is not surprising, as such occlusal characteristics are poor indicators of condylar position.[9,37,38] One would not expect that studies purporting to evaluate occlusion but failing to accurately assess condylar position would find definitive evidence of the relationship between occlusion and TMD.

Gnathologists propose that a critical factor involved in the relationship between occlusion and TMD is the effect such occlusion has on condylar position. A definitive description of occlusion must include an assessment of condylar position resulting from intercuspation of the teeth.[17,27,39] That is, does the CO position allow the condyles to remain in CR? Such an occlusal scheme promotes optimal neuromuscular function.[10,11,40] In this study, it is hypothesized that the magnitude of condylar distraction by the occlusion from the CR position, as measured with articulator-mounted models, is related to TMD symptomatolgy.[15,18] Or, stated in the null form, there is *no* relationship between condylar position as determined by the occlusion and signs and symptoms of TMD.

In most studies that have failed to show a relationship between occlusion and TMD, instrumentation was not used and other inadequacies are present. Pullinger, Seligman, and Solberg[35,41] evaluated 222 dental and oral hygiene students in a three-part study using a questionnaire, clinical exam, and dental casts. They found no definite relationship between TMD and occlusal factors, such as the slide between RCP (retruded contact position) and ICP (intercuspal position). RCP was determined by passive mandibular manipulation and hand-held dental casts. No instrumentation was used to evaluate condylar position as dictated by the occlusion, and the possible effect of the neuromusculature was not considered.

In their review of the literature, McNamara, Seligman, and Okeson[42] found a relatively low association between occlusal factors and signs and symptoms of TMD. They concluded that although treatment to a gnathologic ideal was a good idea, failure to do so would not result in TMD. In the studies they reviewed, the occlusion was evaluated by chin-point manipulation and intraoral inspection. No attempt was made to override the effects of the neuromusculature, and condylar position was determined by radiographic evaluation. Mounted study casts were not used.

Many clinicians advocate proper mounting of models on an articulator to reduce or eliminate the effects of the neuromusculature on the position of the mandible.[16-18,37,43] The mandibular position indicator (MPI) and the condylar position indicator (CPI) are instruments used with the SAM and Panadent articulators, respectively. They are designed to record the position of the condylar axis in three planes of space and have been demonstrated to be both accurate and reliable.[30,44,45]

The MPI and the CPI measure the difference between the axis of the articulator, representing the terminal hinge axis of the patient (CR), and the mandibular hinge axis in CO—or in the new terminology, maximum intercuspation (MI).[46] The mandibular hinge axis can be described as an imaginary line between two centers of rotation. R. Williams (personal communication, 1995) collected a sample of lateral cephalometric radiographs of over 200 subjects on which the terminal hinge axis had been located and marked with radiopaque material. In all the subjects, the marked terminal hinge axis fell within the area of the condyles as viewed on the lateral headfilm. Since the mandibular hinge axis has been shown to pass through the condyles, any change in axis location would indicate a corresponding change in condylar position as well. Thus, the axis position can also represent condylar position. In 1989, Girardot[7] found that changes indicated by the MPI corresponded to changes observed in the CR/CO shift of the mounted models. Alexander,[30] in his comparison of condylar position with the MPI and magnetic resonance imaging, found the MPI to be an accurate representation of condylar position. These studies suggest that the MPI and CPI instruments are useful tools in assessing the positional change from CR to CO (maximum intercuspation), or CR-CO difference.

As the condylar axis position is shown to represent condylar position, the null hypothesis to be tested in this study can be restated as follows: There is no relationship between condylar axis position as determined by the occlusion and measured in three planes of space by the CPI instrument and signs and symptoms of TMD.

Materials and methods

A sample of subjects with ideal occlusion, defined as having CR approximating CO, was compared with a control sample consisting of untreated subjects. The ideal sample was selected from a population that had undergone full-mouth reconstruction using gnathologic principles that included CR coincident with CO and a mutually protected occlusal scheme (centric stops on all of the posterior teeth and anterior guidance during excursive movements).[14,15,25] A selected sample was used for this group because the incidence of adult occlusion with CR coincident with CO is very low in the general population, making the acquisition of an adequate sample of ideal occlusions by random selection impractical. A control sample consisting of untreated subjects was selected to match the ideal sample as closely as possible according to sex. The selection was made without regard to the incidence of TMD symptomatology. Only adults were included in this study. The average age of the ideal sample was 50.6 years and no attempt was made to match for age. The ideal sample thus represents a highly selected sample, which was used to compare TMD symptomatology and CPI values against an untreated population. The records for both samples consisted of a written patient history, a clinical exam, and study casts mounted on a Panadent articulator using estimated hinge axis. CPI measurements were made on all casts to record the position of the condylar axis in CO relative to the hinge axis of the articulator representing CR.

Sample selection

Initially, a sample of 30 subjects, labeled the *restored ideal*, was obtained from the practices of acknowledged expert clinical gnathologists. This was a sample of convenience, and it was highly selected. The contributing clinicians chose subjects according to their own concept of ideal, and the number selected was determined by the availability and willingness of the subjects to participate. The criteria for inclusion in the study were the following:

- Full-mouth reconstruction or equilibration using the gnathologic principles and goals previously described
- At least 2 years posttreatment
- No history of trauma to the head, neck, or jaws
- No major removable prostheses present
- No complicating medical history
- CPI measurements $\leq$1 mm in either the horizontal (X) or vertical (Z) axis and $\leq$0.5 mm in the transverse (Y) axis

The term *ideal* indicates that CR was within a very small range of CO, although not necessarily coincident. It should be noted that CR coincident with CO is a treatment goal and is rarely, if ever, attained.

CPI criteria for acceptance into the restored ideal sample was derived from data obtained by Roth and Wong (B. Wong, personal communication, 1995) who collected MPI records on 250 consecutive patients before treatment, and from Utt's[24] research. The criteria represent the mean of their CPI measurements plus or minus one standard deviation. The CPI values obtained were larger than those found in earlier studies by Hoffman,[47] Rosner,[48] and Tuppy;[49]

however, in these studies the method of taking the centric relation bite registration was different, with less emphasis on seating the condyles superiorly.

A control sample of untreated subjects, labeled *untreated control,* was then arbitrarily selected from the patients and staff of local dental offices and from pretreatment records from the author's practice. They were selected to match the sex of the restored sample according to the following criteria:

- No extensive restorative dentistry
- No history of trauma to the head, neck, or jaws
- No removable prostheses present
- No complicating medical history

Figure 1
Anamnestic questionnaire given to all subjects. Subects in the restored ideal sample were given an additional copy pertaining to their symptoms prior to treatment

During the last five (5) years:

1. Do you experience headaches in temple area?
   Yes___ No___
   How often ?
   ___Two or less per week ___ More than two per week
   Rate average severity:
   1 mild 5 moderate 10 severe

2. Have you experienced noise (popping, clicking, or grating) in your jaw joints?
   Yes___ No___
   Painful____ Not Painful___

3. Do your jaws frequently feel tired or stiff?
   Yes___ No___
   1 mild 5 moderate 10 severe

4. Do your jaws lock open or closed?
   Yes___ No___
   1 mild 5 moderate 10 severe

5. Do you have any difficulty opening wide?
   Yes___ No___
   1 mild 5 moderate 10 severe

6. Do your jaws hurt when opening, closing, chewing, or yawning?
   Yes___ No___
   1 mild 5 moderate 10 severe

7. Do you have pain in your jaw joint(s) or in front of your ear(s)?
   Yes___ No___
   1 mild 5 moderate 10 severe

8. Do you have pain in your temples or cheek muscles?
   Yes___ No___
   1 mild 5 moderate 10 severe

Instrumentation

Nonperforated Rim-Lock stock trays (Dentsply / Caulk, Milford, Del) and alginate impression material (Kerr Manufacturing Co, Romulus, Mich) were used for all impressions. The casts of the restored sample and the majority of the controls were poured immediately using type IV high-strength dental stone (Vel-Mix, Kerr Manufacturing Co, Romulus, Mich). The maxillary casts were mounted using the split-cast technique. This technique has been used for many years by restorative dentists to verify the accuracy of their mountings; with it, errors greater than .0005 inch can be detected. The subjects selected from pretreatment records in the author's practice did not have maxillary split casts. All casts were mounted on a Panadent articulator (Panadent Corp, Grand Terrace, Calif) that had been standardized using the manufacturer's recommended procedure. The maxillary casts were mounted to an estimated hinge axis using the ear facebow manufactured by Panadent Corporation. All casts were mounted on the articulator using fast-set mounting stone (Snow White Plaster #2, Kerr Manufacturing Co, Romulus, Mich). Condylar position was measured in the horizontal (X), vertical (Z), and transverse (Y) planes using the CPI instrument (Model CPI - 2, Panadent Corp, Grand Terrace, Calif). To reduce the effect of measurement error, three separate measurements were made for each subject and the results were averaged. All readings were made with a 10X magnification loupe with a scale that could be read to the nearest 0.1 mm.

Wax registration

One CO and three CR wax registrations were taken on each subject. The CO bite was taken using 24 gauge (0.55 mm) sheet wax (Shofu Inc, Kyoto, Japan). A single layer was trimmed to the arch form, softened in a water bath, and placed on the maxillary teeth. The patient was then instructed to bite down firmly and tap his or her teeth together. After the wax was cooled with an air syringe it was removed from the mouth.

The CR registrations were taken

with Delar Bite Registration Wax (Delar Corp, Lake Oswego, Ore) and were made in two sections. The procedure was developed by Roth and described by Wood, et al.[8] It has been well documented that an anterior stop, such as that used in Roth's procedure, enables the patient's musculature to seat the condyles in an anterosuperior direction while centric relation records are being taken.[6-8,50,51]

Anamnestic evaluation

A questionnaire (Figure 1) based on the Helkimo index[52] was given to the subjects to categorize and quantify their subjective assessments of their own TMD symptomatology. To standardize data and eliminate operator bias, the same evaluation form was given to all subjects in both samples.

The questions concerned complaints about headache, pain in the TM joints, muscle pain, pain on movement, difficulty in opening the mouth widely, TM joint sounds, locking, muscle fatigue, and awareness of parafunction. Subjects were instructed to include the previous 5 years in their evaluations. Symptoms of TMD are known to be cyclic or episodic,[1] thus it was felt that the evaluation of a 5-year span yielded a more complete and realistic assessment of perceived dysfunction. Subjects in the restored sample were asked to fill out a duplicate form to record their symptoms prior to treatment so that changes in symptoms that were likely the result of treatment could be assessed.

Table 1
Scoring for the clinical and anamnestic evaluations

	Impaired range of motion
	Maximum opening and lateral excursions
0	≥40 mm and ≥7 mm lateral
1	30-39 mm and 4-6 mm lateral
5	< 30 mm and 0-3 mm lateral
	Pain on mandibular movement
0	Absence of pain
1	Pain in 1 movement
5	Pain in 2 or more movements
	Impaired function of the TM joint
0	Smooth movement, no sounds, and deviation on opening or closing ≤2 mm
1	Sounds in one or both joints and/or deviation on opening or closing > 2 mm
5	Locking and/or luxation of the joint
	Muscle pain
0	No tenderness to palpation
1	Tenderness in 1-3 sites
5	Tenderness in 4 or more sites
	TM joint pain
0	No tenderness
1	Lateral tenderness
5	Posterior tenderness
	Occlusal wear
0	No visible wear
1	Wear on either anteriors or posteriors
5	Generalized wear- both anteriors and posteriors

Score Anamnestic questionaire

	#1. Temporal headaches
0	Absence of headaches
1	≤ 2 per week
5	> 2 per week
	#2. Joint noise (popping, clicking, or grating)
0	Absence of noise
1	Painless noise
5	Painful noise
	#3. Mandibular fatigue or stiffness
0	Absence of fatigue or stiffness
1-5	According to severity
	#4. TM joint locking
0	Absence of locking
5	Locking
	#5. Difficulty in opening
0	No difficulty
1	Severity of 1-4
5	Severity > 4
	#6. Muscle pain during function
0	Absence of pain
1-5	According to severity
	#7. TM joint pain
0	Absence of pain
1	Severity ≤4
5	Severity > 4
	#8. Pain in temple or cheek muscles
0	Absence of pain
1-5	According to severity

Clinical evaluation

The clinical examination was also a modification of the exam used for the Helkimo index. All subjects were examined to assess the presence of impaired mandibular movement, impaired function of the TM joints, pain on mandibular movement, pain in the masticatory muscles, pain in the TM joint, and occlusal attrition.

A prescribed protocol was strictly followed and all subjects were examined by the same person to eliminate interoperator error and ensure standardization. Palpation tests were performed carefully so that uniform pressure was applied to each site and to each subject throughout the study.

To evaluate mandibular function and TM joint pain, the subject was asked to open his or her mouth as wide as possible. The maximum opening was measured to the nearest millimeter, and pain or deviation from the midsagittal plane was noted. Maximum opening was defined as the distance between the upper and lower incisal edges minus the amount of vertical overbite. The subject then was asked to move the mandible laterally, with the teeth in contact, as far as possible in both directions. These movements were also measured from the midline to the nearest millimeter. Pain reported in the TM joints or muscles, along with the presence of noise or locking, was noted.

The following muscles were then palpated bilaterally: the anterior, middle, and posterior belly of the temporalis; the superficial and deep belly of the masseter; and the medial pterygoid. To reduce the possibility of error, only muscles that could be easily isolated were included in the exam. For this reason the lateral pterygoids were excluded. The TM joints were palpated both laterally and posteriorly through the external auditory meatus during opening and closing. Occlusal wear was evaluated from the casts.

Table 2
Summary of statistical analysis

Samples compared Accuracy of technique	*p*-value	∝=.01/2	*t*-statistic	*t*-critical two-tail	R	R2
CPI accuracy—						
Intra-, interoperator	0.0552	0.005	1.9366	2.6181		
Wax CO registration and NO WAX registration	0.8964	0.005	0.1306	2.6269		
Symptoms—Ideal and control (outside limits)						
Ideal and control (outside limits) - CPI values	0.0000	0.005	8.1312	2.6718		
Ideal and control (outside limits)*	0.0000	0.005	5.5863	2.6718		
Ideal and control (outside limits)**	0.0000	0.005	5.0014	2.6718		
Combined sample (N=60) of ideal and control						
All subjects in both samples (N=60)* CPI (X- and Z-axes)	0.0000	0.005	4.9873	2.6600	.55	.30
All subjects in both samples (N=60)** CPI (X- and Z-axes)	0.0000	0.005	4.2921	2.6600	.49	.24
All subjects in both samples (N=60)* CPI (X-, Z-, and Y-axes)	0.0000	0.005	5.0619	2.6600	.55	.31
All subjects in both samples (N=60)** CPI (X-, Z-, and Y-axes)	0.0000	0.005	4.2726	2.6600	.49	.24

* Anamnestic questionnaire
** Clinical examination

Scoring the clinical and anamnestic examinations

The results were quantified (Table 1). The anamnestic and clinical data were grouped according to degree of severity as follows:

Anamnestic	Score
No symptoms	0
Moderate symptoms	1-5
Severe symptoms	>5
Clinical	**Score**
No symptoms	0
Moderate symptoms	1-4
Severe symptoms	>4

A subject scoring in the moderate range (anamnestic and/or clinical) would probably not require treatment. A subject with symptoms rated as severe would benefit from treatment.

During the scoring of the anamnestic evaluation it was found that the all-or-nothing respose required by the Helkimo index was not sensitive enough to detect some changes between pretreatment and posttreatment evaluations in the restored sample. For this reason the subject's own subjective assessment of the severity of symptoms was included and quantified on a 1-to-10 scale, which was later converted to 1-to-5 to keep the maximum value equal to 5 for any question.

Accuracy and reliability

Multiple wax registrations

Since none of the subjects in either sample had been deprogrammed with splint therapy prior to the record-taking, neuromuscular avoidance patterns were present in varying degrees, making accurate condylar seating difficult. To minimize the possibility of obtaining an erroneous registration, three separate CR wax registrations were taken and verified using the split-cast technique. Because a true hinge axis was not used, every effort was made to take the registrations at the same thickness. A split-cast check of two or more CR registrations indicated that CR was accurately represented. If the registrations did not match, they were assumed to be inaccurate and were repeated.

Interoperator check with split casts

The same operator took all but one of the wax registrations on the restored sample and 22 of 30 of the untreated sample.

Operators contributing records underwent a standardization test to ensure that their technique was consistent with that of the author. Five wax registrations were taken by each operator and were found to be within split-cast tolerances (.0005 in) of the registration taken by the author.

Multiple CPI readings

Three separate CPI measurements were made and averaged, and all the CPI measurements in this study were made by the author.

Pilot studies

To determine the accuracy and reliability of the CPI instrument and technique, a special jig was fabricated that consisted of an upper and lower model, mounted in CR, from which the occlusal surfaces had been re-

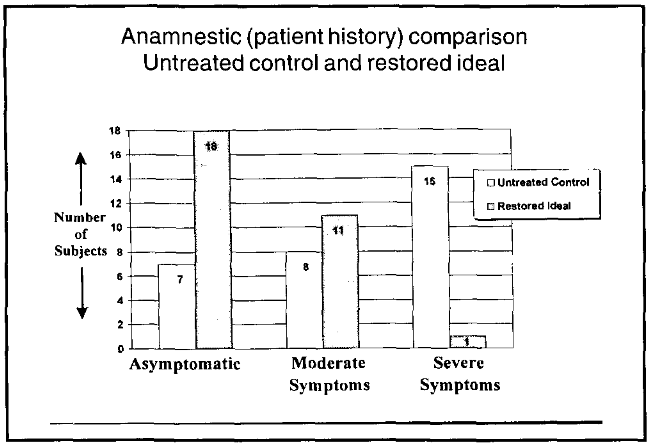

Figure 2A
Subjects in the untreated control and restored ideal samples grouped by severity of anamnestic (patient history) symptoms. Only one subject in the restored ideal sample had severe symptoms.

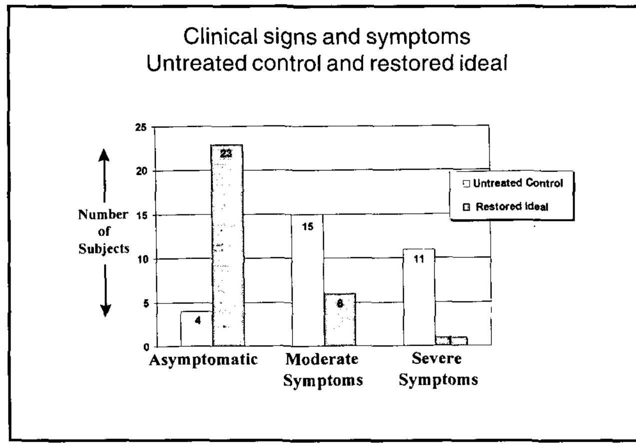

Figure 2B
Subjects in the untreated control and restored ideal samples grouped by severity of clinical signs and symptoms. Note large number of asymptomatic subjects in the restored ideal sample. Only one subject in the ideal sample had severe symptoms.

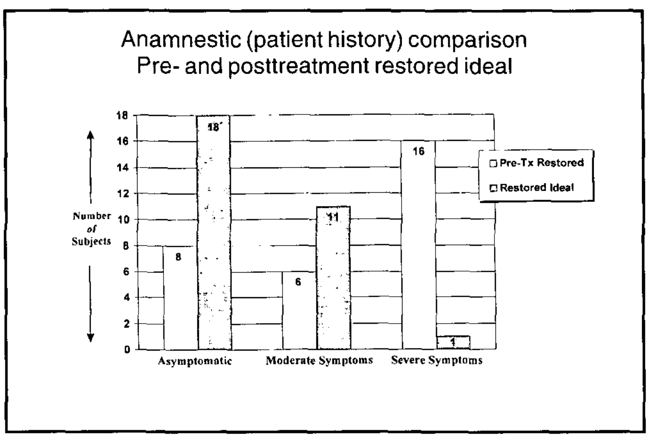

Figure 3
A comparison of pre- and posttreatment anamnestic (patient history) scores of the restored ideal sample demonstrating the probable effects of treatment. The number in each column represents the number of subjects in that category. The number of subjects with severe symptoms decreased from 16 to 1.

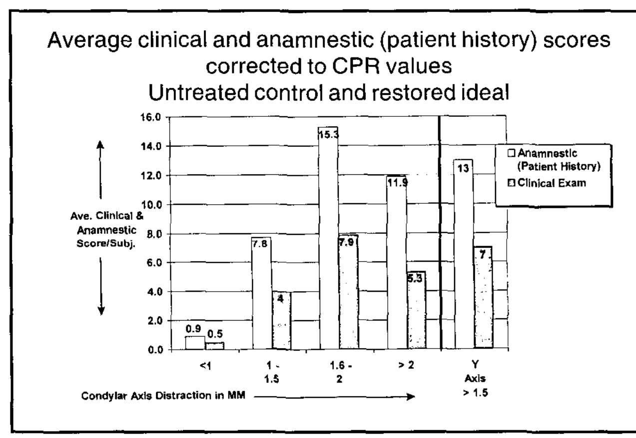

Figure 4
Combined average clinical and anamnestic (patient history) scores plotted against condylar axis distraction (CPI values). Subjects in both the untreated control and restored ideal samples are combined (N=60). Note the increase in signs and symptoms as the magnitude of the condylar axis distraction increases.

moved and replaced with a split-cast. The jig then was transferred to the CPI instrument. The split cast enabled accurate placement of upper and lower members of the CPI instrument, thereby eliminating a major source of error—the CO registration. Twelve different operators made CPI measurements using this procedure to confirm the accuracy of the instrument and reliability of the technique. Twelve CPI measurements were then made by one operator on the same apparatus to evaluate intraoperator error.

Some subjects in the untreated control sample did not have a CO interocclusal wax record, so maximum occlusal interdigitation of the casts was used. It was therefore necessary to compare CPI measurements using two different registrations (wax and maximum interdigitation) to determine their corroboration before the records using maximum interdigitation could be included in this study. Five subjects were selected from each of the two samples (the untreated control and restored ideal), measured with the CPI instrument, and subjected to statistical analysis. No records were accepted without a CO wax registration that did not have good occlusal interdigitation.

Accuracy of the instrumentation

Differences in either intra- or interoperator studies were not statistically significant when subjected to a two-tailed t-test set at the 99% confidence level. As expected, intraoperator results were consistent, with a variance equal to 0.023 mm.

The difference between CPIs measuring CO with a wax registration vs. those using maximum interdigitation of the casts was not statistically significant when subjected to a two-tailed *t*-test set at the 99% confidence level.

Results

Data

Comparison of untreated control and restored ideal samples

The restored ideal and the untreated control samples consisted of 30 subjects each, closely matched by sex. The untreated control sample contained 47% males and 53% females, while the restored ideal sample consisted of 43% males and 57% females. The average age was 38.4 years for the untreated control sample and 50.8 years for the restored ideal. The average posttreatment time was 10.6 years for the restored ideal sample (range 2 to 23 years). When evaluating the anamnestic scores, 76.6% of the untreated control sample had some symptoms of TMD, while the incidence of TMD was 73% in the restored ideal sample prior to treatment.

A comparison of the anamnestic and clinical scores of the untreated control and the restored ideal samples is shown in Figure 2A-B.

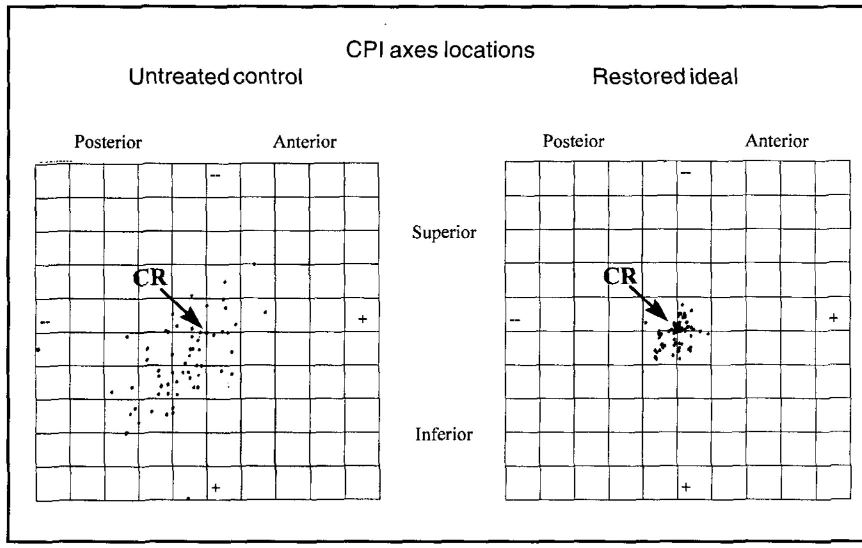

Figure 5
Condylar axes plotted on a 1 mm grid. All the axes of the restored ideal sample are within 1 mm of hinge axis of the articulator axis representing CR (arrow). Seventy percent of the axes of the untreated control sample were located in the posterior-inferior quadrant, indicating that these condyles were distracted down and back, away from the eminentia in CO.

Pretreatment and posttreatment restored ideal evaluation

The pre- and posttreatment anamnestic records of the restored ideal sample were compared. The results are shown in Figure 3. No pretreatment clinical examination information was available. The total anamnestic score decreased from 395.5 before treatment to 63 after treatment, indicating an 84% reduction. A shift of subjects out of the severe category created increases in the asymptomatic and moderate categories. The number of subjects having no symptoms increased from 8 to 18, or 125%, and the moderate category increased by 5, or 83%. The number of subjects in the restored ideal sample with severe symptoms prior to treatment was 16, and only 1 subject had severe symptoms after treatment, a decrease of 94%. The anamnestic score did not increase for any of the subjects.

Untreated control and restored ideal combined evaluation

To determine the possible relationship between condylar axis displacement (CPI measurements) and the anamnestic and clinical symptoms of TMD, the subjects from the untreated control and restored ideal samples were combined, yielding a group of 60. This group was subdivided according to the magnitude of condylar axis displacement in the horizontal (X) and vertical (Z) axes. There were four subdivisions: The first group had distractions equal to or less than 1 mm (this was considered optimal). The second and third groups were those with distractions increasing in 0.5 mm increments. The fourth group consisted of subjects with distractions greater than 2 mm. The results can be seen in Figure 4.

Condylar position

The CPI measurements of the 30 subjects in the restored ideal sample fell within the range of the previously established ideal. A summary of the axes locations can be seen in Figure 5. In the restored ideal sample, at CO the axes of all 60 condyles were located within 1 mm of the articulator axis, which represents CR. The condylar axes of the untreated control sample were located farther from CR, on average, than the restored ideal sample, and only 5 subjects (16.6%) were within the ideal range. Seventy percent of the condylar axes of the untreated controls were located in the posteroinferior quadrant.

Statistical analysis

All tests were run at the 99% confidence level.

Table 2 compares the clinical and anamnestic scores and CPI measurements of the restored ideal and the untreated control samples. The restored ideal sample and the subjects in the untreated control sample who had CPI values outside the ideal range (within 1 mm of CR) were compared using the two-tailed *t*-test. The CPI values and the anamnestic and clinical scores were smaller in the restored ideal sample than in the untreated control ($p<.001$). The control subjects within the ideal range were excluded from the statistical analysis because their number (5) was too small to be statistically significant. Their clinical and anamnestic scores were, however, similar to those of the restored ideal sample, as shown in Figure 4.

The restored ideal and the untreated control samples were combined into one group and retested, using both the two-tailed *t*-test and the regression analysis. The tests were run twice, first using the horizontal (X) and vertical (Z) axes, then using the horizontal (X), vertical (Z), and transverse (Y) axes. The transverse axis (Y) was omitted from the first run because the values of this axis are usually smaller than those of the other two axes. Both tests showed a high correlation between symptoms, both anamnestic and clinical, and CPI values ($p<.001$).

The null hypothesis was rejected in all cases. In addition, the alternative hypothesis, "There is a relationship between condylar axis position as determined by the occlusion and measured in three planes of space by the CPI instrument, and signs and symptoms of TMD" was statistically significant at μ level =.01 ($p<.001$). The coefficient of determination (R^2) indicated that 31% of the anamnestic symptoms and 24% of the clinical findings can be attributed to the CPI values.

Discussion

The accuracy and reliability of the MPI and CPI instruments have been documented. The high reproducibility of the CR registration was established by Wood and Elliott,[38] and the accuracy and repeatability of the MPI was confirmed by Wood and Korne.[44] Finally, the reliability of the methodology and the repeatability of the CPI were verified in the thesis by David Lavine.[45]

The condylar distractions of the untreated control sample were generally of greater magnitude with a higher percentage of CO registrations more inferior to CR (80%) than those recorded in the previous studies by Hoffman,[47] Rosner,[48] and Rosner and Goldberg.[53] The difference between studies may be due to the different methods used in obtaining the CR registration (chin guidance vs. muscular seating of the condyles). The condylar distractions in this study were in closer agreement, both in location and magnitude, with those found by Wood and Elliot,[38] Wood and Korne,[44] Wood and Shildkraut,[37] Girardot,[7] and Utt.[24]

Since it is generally accepted that the condyles cannot be positioned above the seated position (CR) due to the anatomical limitations of the joint structures, a CPI registration above CR should be considered an artifact. The superior position of some of the CPI registrations in this study could be due to either the use of an estimated hinge axis or the presence of muscle splinting, as none of the subjects in either group had been deprogrammed prior to taking the CR registration.

In this study, when comparing the untreated control and the restored ideal samples before treatment, a similarity was found with respect to age. The average age of the two samples was within 1.8 years when the average posttreatment time (10.6 years) was subtracted from the average age of the restored ideal sample (50.8 years). Sex was closely matched (within 4%). These similarities suggest that the untreated control and the pretreatment restored ideal samples are comparable.

The incidence of TMD was higher in the untreated control and pretreatment restored ideal samples than in most epidemiological studies; however, Helkimo[54] points out that epidemiologic results are sensitive to both the selection process and the scoring technique. It must be noted that significant modifications in the Helkimo index were made in this study, and the selection process did not follow epidemiological guidelines; thus, close comparisons with previous epidemiological studies would not be valid. The purpose here was to compare two samples with each other, and to compare pre- and posttreatment symptoms in one of the samples. It is interesting that the incidence of symptomatology (from the anamnestic questionnaire) was slightly higher in the untreated control than in the pretreatment restored ideal, as one would expect the opposite to be true. This, however, may be due to the fact that the subjects in the restored ideal group were asked to recall symptomatology 10.6 years prior, on average, and may have underestimated their true severity. It was noted that 60% of the restored subjects sought treatment for reasons other than TMD pain, but it is also important to note that these subjects had far fewer symptoms after treatment than the controls.

The long average posttreatment time (10.6 years) and the nature of the anamnestic questionnaire reduced the importance of the episodic nature of TMD, giving ample time to test the stability and permanency of the effects of the treatment. Also, according to some studies,[54,55] the older age of the restored ideal sample would tend to bias the results toward having more symptoms than the younger untreated control sample.

Although RCP-ICP slides measured at the occlusal level do not accurately reflect what is happening at the level of the condyles, a large slide usually indicates a condylar deflection or CR-CO discrepancy. Seligman and Pullinger[36] found large RCP-ICP slides associated with TMD and osteoarthrosis and questioned whether the slide or the arthrosis was the primary etiologic factor. While arthrosis may be a factor in the development of a large slide, along with symptoms of TMD, the data from this study suggest that large CR-CO discrepancies can be present in the absence of arthrosis and the symptoms can be controlled by the reduction of the magnitude of the discrepancy. Furthermore, if the slides had been caused by arthrosis in the restored ideal sample, the corrections to CR would not be expected to remain as stable as they were.

Occlusal attrition was originally included in the list of TMD symptoms to be evaluated. However, when we examined the casts, it became apparent that the subjectivity of the evaluation was too high for the scores to be included in this study. While the evidence is not conclusive, certain trends were noted. Twenty-three subjects (77%) in the untreated control sample showed obvious wear facets, but only 13 (43%) of the restored ideal did. Furthermore, of the 8 subjects in the restored ideal sample who underwent treatment specifically to restore severe occlusal attrition, 4 showed no evidence of new attrition years later, and the other 4 presented with only mild to moderate attrition (Figure 6). A relationship between occlusal attrition and condylar position as determined by the occlusion is hypothesized; however, further research is needed. In this study the number of subjects who underwent treatment specifically for attrition was not statistically valid, and no methodology was used to measure the amount of attrition. However, a protocol similar to the one used in this study could be used with a selected sample showing attrition prior to restoration to determine if there is a relationship between attrition and occlusion-dictated condylar position.

Figure 6
A subject in the restored ideal sample 23 years posttreatment for occlusal attrition. Left: Maximum intercuspation. Right: Left lateral excursive movement. Note absence of attrition on anterior teeth after 23 years. Occlusal attrition was less prevalent in the restored ideal sample in comparison with the untreated controls.

Possible error sources

Possible sources of error in this study include the CR and CO registration and the use of the estimated hinge axis.

CR and CO registration

The ideal protocol would call for completely deprogramming all subjects with splints prior to taking the CR registration. This was not practical in a study of this magnitude. The wax registration technique used in this study was developed to obtain the best seated condylar position possible on the day the registration was taken, and its effectiveness has been documented.[8,38] It must be noted that the CR-CO discrepancies (CPI values) usually increase during deprogramming, particularly with symptomatic individuals. The presence of effusion and/or inflammation in the joints would also prevent complete seating of the condyles.

Those who use the MPI or CPI instrumentation find that the CO registration may be a source of error. In this study the CO bite registration error was minimized by the use of a thin interocclusal wax registration. However, there was no significant difference between the CO records taken with thin wax and the ones taken using hand-held models in cases having a positive intercuspal position with all or most of the teeth in contact.

Use of the estimated hinge axis

The use of an estimated hinge axis instead of a true hinge axis can introduce errors in the CPI measurements. If the estimated axis does not coincide with the true hinge axis, the two arcs of closure will be different, thereby changing the initial point of occlusal contact and the CPI value. Rosner[48] demonstrated how the arc of closure would vary according to the position of the estimated axis relative to the true hinge axis. The greatest difference resulted from an error in the horizontal dimension.

Wood and Korne[44] published the first study that actually compared MPI readings from estimated and true hinge axes. They found the differences in condylar position to be small, especially if the error was in the vertical dimension. In our study, CPI measurements of the restored sample were closely grouped. Thus, the error introduced by the use of an estimated axis was small.

The literature contains few studies that evaluate condylar axis position as determined by the occlusion and TMD using an articulator. In 1986, Rosner[53,56] compared condylar position and TMD in a two-part study. The condylar axis was measured using a method similar to the Denar Veri-Check, and subjects were evaluated with a questionnaire; there was no clinical evaluation. His group consisted of 75 dental patients and symptoms were evaluated with respect to condylar position. Rosner also compared his groups with Hoffman's group[47] of asymptomatic normals and found a relationship between TMD and condylar position. In 1989, Cacchiotti[57] studied 40 patients seeking treatment for TMJ disorders and found that the MPI-measured CR-CO discrepancies of patients with TMJ complaints were significantly larger than those of a control group consisting of 40 noncomplaining dental students. He concluded that the MPI may be useful in diagnoses of TMJ disorders, but that more research was needed. In 1989, Girardot[7] used the MPI to measure the discrepancy between CR and CO in 19 subjects and found that the condyles were displaced inferiorly in the majority of TMD patients. He also found a reduction of symptoms as the condyles moved toward a more "seated" position (CR).

The restored sample averaged over 10 years out of treatment, and some in the sample were 20-plus years. The long-term stability and generally low incidence of symptomatology are both a tribute to the clinicians who performed the work and an argument against those claiming that CR is neither stable nor important, especially in light of the fact that many of the restored subjects were symptomatic TMD patients prior to treatment.

The data from this study establishes a statistically significant relationship between TMD and the condylar axis position as determined by the occlusion. The null hypothesis is rejected and the alternative hypothesis, "There is a relationship between condylar axis position as determined by the occlusion and measured in three planes of space by the CPI instrument, and signs and symptoms of TMD," is statistically significant at the μ level = .01 ($p<.001$).

The results of this study suggest that an individual's tolerance to condylar distractions may be smaller than previously believed. Figure 4 demonstrates how symptomatology, both clinical and anamnestic, increases dramatically as the CPI values increase from 1 to 2 mm. This suggests that it may be in the best interests of both the patient and the clinician to reduce the discrepancy as much as possible. Several other authors[1,15,18,39,58,59] have suggested that CR=CO may be an ideal treatment objective, and the findings of this paper further support the use of the seated condylar position as a final treatment goal.

Numerous studies have been published recently indicating that orthodontic treatment has little or no effect on either the development or the successful treatment of TMD.[60-64] It is valid to consider orthodontic treatment the equivalent of full-mouth reconstruction, as the principles involved are the same. Thus, orthodontically treated cases should be compared with gnathologically restored cases and not with an untreated population. The same functional goals that apply to those restoring the dentition should apply to orthodontists. Orthodontists should assume they could have a positive effect on TMD symptomatology, as indicated by the findings of this study. While it is unlikely that orthodontists can achieve CR coincident with CO with the same precision as restorative dentists, this study suggests that the closer the orthodontist can come to achieving this goal, the less will be the likelihood that symptoms will develop. This study indicates that a condylar displacement of a relatively small magnitude, greater than 1 mm horizontally or vertically dimension or .5 mm transversely, may have an adverse effect on the patient.

Summary and conclusions

Centric relation position of the condyles as indicated by the axis position is not coincident with the axis position as determined by maximum intercuspation of the teeth in a large percentage of the untreated control sample (83.3%). The discrepancy between centric relation and maximum intercuspation condylar axis position was compatible with the criteria established for the measurement system for 16.7% of the sample.

In untreated subjects, the condylar axis is distracted downward and forward or downward and backward from the most superior anterior position in the fossa by maximum intercuspation of the teeth in the majority of the subjects. Downward and backward condylar axis displacement from centric relation position due to the occlusion predominated in this study (70%).

In the restored ideal sample, the condylar axis position as determined by the occlusion was found to be stable over periods ranging from 2 to 23 years, with a mean posttreatment time of 10.6 years, in patients who had undergone gnathologic full-mouth rehabilitation. This means that neither the occlusion nor the temporomandibular joints changed on a clinical level during that period of time.

The null hypothesis for this study,"There is no relationship between condylar axis position as determined by the occlusion and measured in three planes of space by the CPI instrument, and signs and symptoms of TMD," was rejected at the μ level = .01 ($p<.001$).

The alternative hypothesis, "There is a relationship between condylar axis position as determined by the occlusion and measured in three planes of space by the CPI instrument, and signs and symptoms of TMD," was statistically significant at the μ level = .01 ($p<.001$).

Since condylar axis position is dictated upon closure of the dentition into maximum intercuspation, and since condylar axis position was shown in this study to be strongly correlated with TMD symptomatology, it can be concluded that a very strong, statistically significant, relationship exists between occlusion-dictated condylar position and symptoms of TMD.

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