ORIGINAL ARTICLE

Three-dimensional analysis of models articulated in the seated condylar position from a deprogrammed asymptomatic population: A prospective study. Part 1

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Introduction: The seated condylar position (SCP), also known as centric relation (CR), is considered the most reliable and reproducible reference point for accurately recording the relationship of the mandible to the maxilla. Therefore, a determination of the SCP/CR is a prerequisite for the analyses of the dental interarch, condylar position, and skeletal relationships. The purpose of this prospective study was to statistically evaluate the 3-dimensional nature of dental interarch displacement and condylar displacement between the SCP/CR and maximum intercuspation or centric occlusion (MIC/CO). **Methods:** The records of 596 consecutive asymptomatic patients having routine orthodontic treatment in a private practice were used. The initial premature occlusal contact and 3-dimensional dental interarch displacement were measured by the analysis of models, mounted on an articulator (Panadent, Grand Terrrace, Calif) in the SCP/CR, by using the modified (nonmanipulated) 2-piece wax SCP/CR recording method with deprogramming. Three-dimensional condylar displacement was measured by analysis of the graphic registrations, produced by condylar position instrumentation, and evaluated for frequency, direction, and magnitude of displacement. **Results:** The dental interarch discrepancy in the SCP/CR was significantly different from that observed in MIC/CO, with posterior premature contacts (94.0%), increased overjet, decreased overbite, midline differences, and Angle classification changes. A difference in condylar position between the SCP/CR and MIC/CO in at least 1 plane was detected for every asymptomatic patient and every condyle. The most prevalent types of directional change in condylar position were inferior (down) (97.0%) and distal (posterior) (66.7%) when the teeth were brought into MIC/CO. The mean difference in condylar position between the SCP/CR and MIC/CO was .86 mm in the horizontal plane, 1.80 mm in the vertical plane, and .26 mm in the transverse plane. No correlation was found between a patient's age or sex and the magnitude of condylar displacement. **Conclusions:** There is a significant difference in the occlusion when it is dictated by the teeth and when it is dictated by the condyles. This difference is quantifiable at both the occlusal and condylar levels. (Am J Orthod Dentofacial Orthop 2006;129:619-30)

In the natural dentition, the seated condylar position/centric relation (SCP/CR) does not usually coincide with the position the mandible assumes when the teeth are in maximum intercuspation/centric occlusion (MIC/CO).[1-41] This positional difference is a source of contention and conflicting judgments by clinicians attempting to diagnose and rehabilitate dental occlusions. It is, therefore, an important topic for further study and greater understanding.

The SCP is anatomically determined; it is repeatable and reproducible.[1,2,9,42-45] Okeson[42] describes it as the most orthopedically and musculoskeletally stable position of the mandible, whereas Sicher,[45] Hylander,[46] Lundeen,[18] and Lundeen and Gibbs[47] consider it to be the essence of optimal temporomandibular joint form and function. It is the most reliable reference point for accurately recording the relationship of the mandible to the maxilla.[1,10,20-22,42,48-55] Among authors, clinicians, and educators recognized for their knowledge of gnathic function, there is agreement that the SCP is a desirable physiologic goal for orthodontic correction.[1,2,9,10,18-20,22,23,34,35,38,42,45-50,52-61] Therefore, a determination of the SCP/CR is a prerequisite for the analyses of dental interarch, condylar position, and skeletal relationships.

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It is agreed that a difference exists between the 3-dimensional (3D) dental interarch relationship in MIC/CO, determined by full intercuspation of opposing teeth, and when the condyles are in SCP/CR.[9,14,16-19,24-33,50,62] It is also generally agreed that a difference exists between the 3D condyle position in MIC/CO (occlusion-dictated condylar position) and SCP/CR (3D condyle position when the condyles are seated).[3-8,11-17,19-33,49,56,57] This positional difference is known as condylar displacement.[3-8,11-17,19,21,22,24,62]

Attempts to assess the CR-CO shift in the general population through intraoral visual estimation are not reliable, because of the muscles and nerve reflexes that protect the teeth by overriding the joint's guidance.[1,10,14,17-20,25-33,36] Also, the observation of a slide or shift at the level of the occlusion might not accurately represent the 3D change in position of the condylar axis.[3-8,11,13-17,19,21,22,24,44] Therefore, a definitive description of occlusion includes an assessment of not only models, articulated accurately in the SCP/CR, but also condylar position resulting from intercuspation of the teeth.[19,43,60]

Even though a fundamental aspect of orthodontic correction is the coordination of tooth position with jaw function,[1,6-10,13-17,23,24,34,35,42,51,56,57,60,61] orthodontists have traditionally not regarded condylar seating as a treatment goal and have used a bite registration coincident with maximum intercuspation to hand-articulate unmounted casts. The problem with this approach is that the position of the condyles in maximum intercuspation has proven to be different from the SCP in almost all patients.[1-41] When the teeth bite into maximum intercuspation, the condyles move from the reference position of the SCP/CR, most commonly in a posterior-inferior direction.[6,14,17,19,21,23,34,35] In the SCP/CR, overjet is increased, overbite is decreased, and Angle classification can change.[15,17,21,22] These significant dental interarch position changes can affect diagnosis and treatment necessary for correction of the malocclusion because the magnitude of the skeletal and dental discrepancy that is due to possible mandibular displacement is more clearly evident.[1,3-19,21,22,24,34,35,37,38,40-42,52-55,60,61,63-65]

To date, few studies of dental-arch spatial relations and condylar position have incorporated neuromuscular deprogramming before registering the SCP/CR. This is an important distinction, because neuromuscular deprogramming before registering the SCP/CR might give the clinician a more accurate representation of the 3D dental interarch and condyle position spatial relationships as a result of more complete condylar seating.[1,9-12,14,17,18,20,24-33,36,37,39,41,61,64,65]

The magnitude and direction of any discrepancy between the SCP/CR and MIC/CO is determined with condylar position instrumentation, designed to record, measure, and compare the positional changes of the condylar axis between the SCP/CR and MIC/CO in all 3 spatial planes, and its accuracy, reproducibility, and reliability have been confirmed.[3-8,11,13-17,19,21-24,34,35,40] Several articulator systems incorporate this type of instrumentation; the condylar position indicator (CPI) (Panadent, Grand Terrace, Calif) was used here.

This prospective study is a descriptive survey, designed to establish patterns of variance between the maxillary and mandibular dental arches, as well as between each condyle from the SCP/CR to MIC/CO, determining a range for normal, healthy, deprogrammed subjects in the horizontal, vertical, and transverse dimensions. The purpose of this prospective study was to statistically evaluate the 3D nature of dental interarch displacement and condylar displacement between the SCP/CR and MIC/CO in a large deprogrammed asymptomatic population.

MATERIAL AND METHODS

The records of 596 consecutive asymptomatic patients having routine orthodontic treatment in a private practice in Worthington, Ohio, were used. All patients were screened for overt temporomandibular dysfunction with medical and dental histories and clinical examinations.

For this study, "asymptomatic" was defined as "without temporomandibular dysfunction," meaning absence of the following signs and symptoms: muscle contraction headache; facial muscle pain; muscle fatigue; limited range of motion; pain, noise, or locking in the joints; pain upon movement; parafunction (clenching, grinding); or occlusal wear or attrition. Selected were 596 patients, 325 female and 271 male. Their mean age was 16 years 6 months, ranging from 9 years 4 months to 58 years 3 months (females, 17 years 2 months; range, 9 years 7 months to 58 months 3 months; males, 15 years 11 months; range, 9 years 4 months to 50 years 11 months).

Pretesting records for each subject included written medical and dental histories, a clinical examination, maxillary and mandibular models, a bite registration in MIC/CO (to prevent rocking of the casts during recording of the CPI), a bite registration in the SCP/CR (after deprogramming), an estimated hinge axis facebow transfer (Panadent) for mounting maxillary and mandibular casts on the Panadent articulator in the SCP/CR, and 3D condylar position registrations.

All patients were neuromuscularly deprogrammed at the chair before registration of the SCP/CR by biting

continually with a moderate pulsating biting force (5 seconds clench, 5 seconds relax) on a wooden tongue depressor for 5 to 10 minutes.

The wax registration of the SCP/CR immediately followed neuromuscular deprogramming. The SCP/CR bite registration was taken by the modified (nonmanipulated) Roth centric registration technique (Appendix). The method avoids tooth contact and allows the patient's own mandibular elevator muscles to seat the condyles in a reproducible (neuromuscular) position without dental interferences. No attempt was made to manipulate the subject's mandible.

After mounting, the 3D model analysis was conducted as follows: the initial premature occlusal contact in the SCP/CR was marked with colored articulating paper (GHM Occlusion Test Foil, Hanel-GHM, Nurtingen, Germany), and the following parameters were measured to the nearest 0.1 mm with a gauge in the SCP/CR and MIC/CO: (1) horizontal: overjet and Angle classification at canine and first molar, right and left; (2) vertical: overbite; (3) transverse: dental midline.

The 3D condylar position registration conducted for each mounting has been described previously.[3-8,11,13-17,19,21-24,34,35,40] All measurements were recorded in multiples of 0.1 mm.

Statistical analysis

All tests were run at the 95% confidence level (CI). A statistical report was created from the dental arch and CPI data and used in the analysis. Three-dimensional dental arch and condylar displacements were measured and evaluated for frequency, direction, and magnitude of displacement between the SCP/CR and MIC/CO. Correlation between Angle classification differences, the magnitude of condylar displacement, and the relationship between condylar displacement and patient age and sex were determined.

Intraoperator error for the reproducibility of the SCP/CR registration technique, dental interarch measurements, and condylar position registrations were determined by having the same operator perform the dental interarch measurements and the CPI registrations on the same instrument from 2 different sets of SCP/CR registrations of 20 patients at 2 sessions within 3 weeks. The new SCP/CR registration was used to remount the initial mandibular cast. Dental interarch measurements and CPI registrations were compared for the 2 mountings.

The 95% confidence level was used to test for statistical significance. (CIs are given as CI lower confidence bound [LCB].95 and upper confidence bound [UCB].95.) The Wilcoxon signed rank test was used to determine statistical significance between measures in MIC/CO and the SCP/CR.

RESULTS

The pretest reliability study showed no statistical difference between the 2 sets of dental interarch measurements or SCP/CR registrations. By using the reliability of measures, it was found that the registration technique described was highly repeatable for all variables measured. The intraclass correlation coefficient (ICC) was 1.000 for midline CR, midline CO, midline agreement, Angle class right first molar, Angle class left first molar, Angle class right canine, and Angle class left canine. ICCs were 0.980 for overjet-CR; 0.997 for overjet-CO; 0.994 for overbite-CR; 0.989 for overbite-CO; 0.965 for horizontal-right; 0.970 for horizontal-left; 0.968 for vertical-right; 0.957 for vertical-left; and 0.716 for transverse ($\alpha = 0.05$).

The low error in the error study (high ICC value) confirms the repeatability and reproducibility of the registration technique in previous studies.[4,6,17,21,34,35,40] It also indicates that obtaining a registration of the SCP/CR and transferring this relationship to the articulator can be accomplished with a high degree of accuracy. The accuracy and reliability of the mandibular position indicator (MPI) and CPI instruments have been documented.[4,5,6,17,21,34,35,40] The mean difference in each dimension (horizontal, vertical, transverse) of the condylar position registrations derived from the 2 mountings was calculated and found to be less than .21 mm in any direction.

The standard errors of double measurement for each dimension of the condylar position registrations were also calculated, by using Dahlberg's equation, standard error = $\sqrt{\Sigma Sd^2/2n}$, where Sd^2 is the sum of the squared differences between the 2 mountings, n is the number of subjects included in the error study (Tables I, II, and III). These values agree with error measurements in previous studies, including Girardot[15] (.25 mm), Karl and Foley[17] (.19 mm), Utt et al[8] (.25 mm), Wood and Elliott[21] (.3 mm), Wood and Korne[34] (.20 mm), Rosner and Goldberg[40] (.16 mm), and Shafagh and Amirloo[39] (.15 mm), confirming the repeatability of the SCP/CR registration technique (Fig 1). The estimated error found in previous studies and the actual error measured herein implies reproducibility of the method and that certain observations of condylar movement can be made if carefully interpreted.

In 560 of the 596 (94%) asymptomatic subjects, the premature occlusal contact occurred on the most posterior tooth (CI 91.7, 95.7).

In 592 subjects (99.3%), overjets were larger in the SCP/CR when compared with MIC/CO. No subject had

Table I. Error study. Mean difference for each component of CPI for 2 separate CPI registrations (initial and remounted casts) (mm, n = 20)

Component	*Mean*	*SD*
Horizontal-right	.18	.11
Horizontal-left	.17	.10
Vertical-right	.21	.11
Vertical-left	.20	.09
Transverse	.10	.07

Table II. Reliability of laboratory technique. Standard errors of double measurement for 2 separate CPI registrations (initial and remounted casts) (mm, n = 20)

Component	*Error*
Horizontal-right	.15
Horizontal-left	.14
Vertical-right	.17
Vertical-left	.15
Transverse	.08

an overjet that was the same in the SCP/CR and MIC/CO. In 4 subjects, the overjet was less in the SCP/CR; these were Angle Class III subjects, who had anterior shifts from the SCP/CR to MIC/CO. The mean overjet in SCP/CR was 5.19 mm (SD = 2.46) (CI 5.00, 5.39); the mean overjet in MIC/CO was 2.78 mm (SD = 1.68) (CI 2.65, 2.92). The mean increase in overjet in the SCP/CR was 86.7% (2.41 mm). A statistically significant ($P < .0001$) difference was found between overjet in the SCP/CR and MIC/CO.

Of the asymptomatic subjects, 40.9% (244) (CI 36.9, 45.0) had changes in Angle classification at either the canine or the first molar between the SCP/CR and MIC/CO. This change was evenly distributed among the 4 areas investigated (right first molar, 158; right canine, 159; left canine, 167; left first molar, 160). A statistically significant ($P < .0001$) difference was found in the Angle classification change between the SCP/CR and MIC/CO.

In 593 subjects (99.5%), overbites were smaller in the SCP/CR when compared with MIC/CO. No subject had an overbite that was the same in the SCP/CR and MIC/CO. The mean overbite in SCP/CR was 2.06 mm (SD = 1.51) (CI 1.94, 2.18); the mean overbite in MIC/CO was 4.04 mm (SD = 1.68) (CI 3.91, 4.18). The mean decrease in overbite in the SCP/CR was 49.0% (1.98 mm). A statistically significant ($P < .0001$) difference was found in overbite between the SCP/CR and MIC/CO.

In 70.0% of the subjects (417), dental midlines were centered when the condyles were seated in the SCP/CR (CI 66.1, 73.7); in 65.6% (391), the midlines were centered when the condyles were displaced into MIC/CO (CI 61.6, 69.4). The difference was statistically significant ($P = .0022$). In 78.7% of the subjects (469), dental midlines were coincident. (CI 75.2, 81.9); in 21.3% (127), the midlines were different. A statistically significant ($P = .0022$) difference was found in dental midline between the SCP/CR and MIC/CO.

Table III. Reliability of laboratory technique. Error measurements of condylar position in 3 planes

	Component and error (mm)		
Investigator (y)	*Horizontal*	*Vertical*	*Transverse*
Shafagh and Amirloo (1979)	.15		
Rosner and Goldberg (1986)	.16	.16	.23
Wood and Korne (1992)	.19	.21	
Wood and Elliott (1994)	.27	.30	
Utt et al (1995)	.25	.25	.10
Karl and Foley (1999)	.17	.19	.19
Girardot (2001)	.25	.25	
Cordray (2003)	.15	.16	.08

Nearly every subject (571, or 95.8%) had a vertical (inferior) condylar displacement of both condyles. Of the 1192 condyles, 1156 (97.9%) exhibited a vertical (inferior) condylar displacement in the MIC/CO position. Of the condylar displacements, 66.7% (796) were in a posterior/inferior direction, 25.4% (303) were anterior/inferior, and 5.7% (68) were straight inferior displacements. Therefore, the condyle was almost always vertically displaced or distracted from the SCP/CR and most often positioned distally (posteriorly) when the teeth were brought into MIC/CO. No MIC/CO condyle position was found to be located superior to the SCP/CR.

Further examination of the condylar movements showed that 555 subjects (93.1%) had vertical displacements greater than the horizontal displacement at the right condyle, 550 subjects (92.2%) had vertical displacements greater than the horizontal displacement at the left condyle, and 525 subjects (88.1%) had vertical displacements greater than the horizontal displacement at both condyles.

Only 69 of the 596 subjects (11.5%) had horizontal displacements (anterior or posterior) without vertical components.

The mean horizontal condylar displacement (absolute value) for the right condyle in this deprogrammed asymptomatic patient population was .83 mm (SD = .63) (CI .78, .88) (range, 0-4.3 mm). The mean horizontal condylar displacement (absolute value) for the left condyle was .89 mm (SD = .65) (CI .84, .94) (range, 0-4.4 mm). The mean vertical condylar dis-

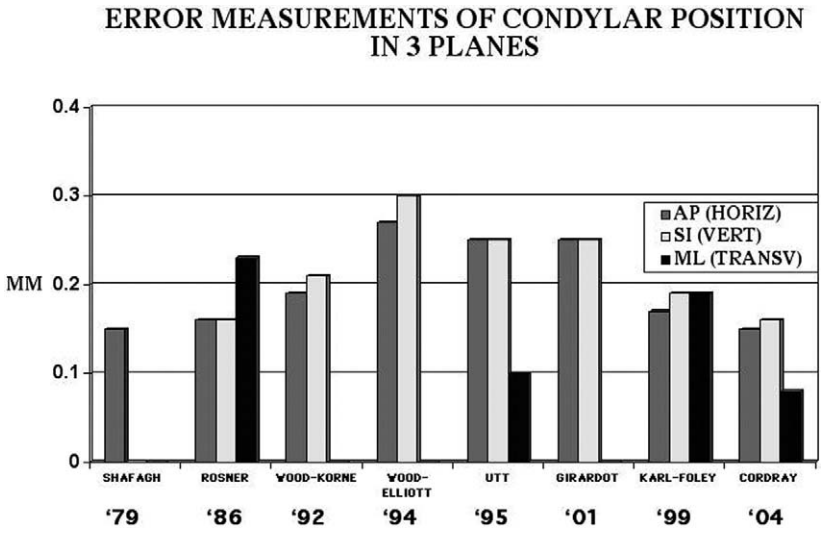

Fig 1. Error measurement table. Measurement error for each directional component of CPI graphic recordings for condylar position were ≤.21 mm, which agrees with 7 previous studies of this type over 24 years, all of which reported measurement error of ≤.3 mm.

placement (absolute value) for the right condyle was 1.84 mm (SD = 1.03) (CI 1.76, 1.92) (range, 0-6.1 mm). The mean vertical condylar displacement (absolute value) for the left condyle was 1.77 mm (SD = 1.07) (CI 1.69, 1.86) (range, 0-5.4 mm). Therefore, the mean magnitude of the vertical component was more than 2 times greater than the horizontal component in most of the sample. The mean transverse condylar displacement (absolute value) was .26 mm (SD = .15) (CI .25, .27) (range, 0-.8 mm). No subject had a condylar position that was coincident in MIC/CO and the SCP/CR; ie, none of the 1192 condyles had a position in MIC/CO that was coincident with the SCP/CR. All 1192 condyles had displacements between the SCP/CR and MIC/CO in either the horizontal, vertical, or transverse planes.

Discrepancies of ≥1.6 mm in the horizontal plane, ≥2.0 mm in the vertical plane, and ≥0.5 mm in the transverse plane were considered clinically significant.[6-8,14,15,17,19,21-23] By using these parameters, it was found that 19.6% (117) of the patients had a discrepancy of ≥1.6 mm in the horizontal plane (CI 16.5, 23.1), 53.0% (316) had a discrepancy of ≥2.0 mm in the vertical plane (CI 48.9, 57.1), and 10.7% (64/596) had a transverse discrepancy of ≥5 mm (CI 8.4, 13.5). With these criteria, 57.5% of the subjects (343) exhibited a significant shift/displacement at the condylar level in at least 1 plane.

In previous studies, discrepancies of ≥2.0 mm in the horizontal plane, ≥2.0 mm in the vertical plane, and ≥0.5 mm in the transverse plane were considered clinically significant.[6-8,14,15,17,19,21-23] In this study, the horizontal or vertical discrepancy was found to be ≥2.0 mm in 53.6% of this sample (320 patients), and 22.9% (137) had horizontal or vertical condylar displacements of ≥3 mm.

The correlation of vertical condylar displacement ≥2.0 mm with a change in Angle classification at either the canine or the first molar was statistically significant ($P < .0001$). Of the subjects, 26.0% (155) had significant vertical condylar displacements (≥2.0 mm) and discrepancies at the occlusal level, as evidenced by a change or deviation in Angle classification at either the canine or the first molar between the SCP/CR and MIC/CO (CI 22.5, 29.7).

The correlation of horizontal condylar displacement ≥1.6 mm with a change in Angle classification at either the canine or the first molar was statistically significant ($P < .0001$). Of the subjects, 1.1% (7) had significant horizontal condylar displacements (≥1.6 mm) and discrepancies at the occlusal level, as evidenced by change or deviation in Angle classification at either the canine or the first molar between the SCP/CR and MIC/CO (CI .004, 2.4). The correlation of transverse condylar displacement ≥.5 mm, with a change in Angle classification at either the canine or the first molar was statistically significant ($P < .0001$). Of the subjects, 3.8% (23) had significant transverse condylar displacements (≥.5 mm) and discrepancies at the occlusal level, as evidenced by a change or deviation in Angle classification at either the canine or the first molar between the SCP/CR and MIC/CO (CI 2.4, 5.7).

The correlation of significant condylar displacement in any of the 3 planes (vertical, ≥2.0; horizontal, ≥1.6 mm; or transverse, ≥5 mm), with a change in Angle classification at either the canine or the first molar was statistically significant ($P < .0001$). Of the subjects, 26.6% (159) had significant condylar displacements and changes or deviations in Angle classification at either the canine or the first molar between the SCP/CR and MIC/CO (CI 23.1, 30.4).

No correlation was found between a patient's age or sex and the magnitude of condylar displacement between the SCP/CR and MIC/CO. All ages and both sexes had a full range of condylar displacements (Tables IV and V). No difference in age, sex, Angle classification, ANB angle, or mandibular plane angle was reported previously in a study of this type.[6,8] Therefore, these parameters are not accurate predictors of condylar displacement.

Table IV. Condylar displacement–age correlation study

Parameter	P *value*
Horizontal-right	.4679
Horizontal-left	.8564
Vertical-right	.0249*
Vertical-left	.2326
Transverse	.5282

No strength of relationship exists between age and magnitude of condylar displacement for any areas statistically evaluated.
*Statistically significant but clinically meaningless.

Table V. Condylar displacement–sex correlation

Parameter	P *value*
Horizontal-right	.9195
Horizontal-left	.5738
Vertical-right	.0137*
Vertical-left	.1955
Transverse	.4251

No strength of relationship exists between sex and magnitude of condylar displacement for any areas statistically evaluated except vertical-right.
*Statistically significant ($P = .0137$) but clinically not meaningful.

DISCUSSION

From the results of this study and previous investigations, it can be concluded that the following prerequisites must be accomplished to achieve a more complete condylar seating and subsequently study the dental interarch and condyle positional changes between MIC/CO and the SCP/CR: neuromuscular deprogramming with a hard anterior stop, followed by a 2-piece registration, incorporating a hard anterior stop and voluntary muscle contraction.

Neuromuscular deprogramming

To accurately seat the condyles and study the dental arch and condyle positional changes between MIC/CO and the SCP/CR, a method must be used that reduces or eliminates the influence of the occlusion on the musculature. Many studies have shown that the neuromusculature positions the mandible to achieve maximum intercuspation, regardless of the position of the condyles.[1,9-12,14,17,18,20,24-33,36-39,41] As a result, the acquired mandibular position (the occlusion-dictated condylar position) will often be mistaken by the clinician for the SCP. Therefore, clinical mandibular manipulation is unreliable in determining the SCP because of the effects of the neuromusculature.[1,10,14,17-20,25-33,36] This is consistent with the statement of Calagna et al[31] that "there is no known scientific method available to determine which patients require neuromuscular conditioning." Neuromuscular deprogramming is the key to reproducibility.

Splint therapy can be effective in deprogramming the neuromusculature.[10,11,14,17,18,20,24,31-33,36-38,41] Ideal protocol calls for complete deprogramming of all subjects with splints before registering the SCP/CR. Such deprogramming was not practical in a study of this magnitude, and it is not practical in a busy orthodontic practice. Therefore, other methods are indicated. It was shown in this study that 5 to 10 minutes of chair-side neuromuscular deprogramming with a hard tongue blade can be as effective for initial deprogramming as a longer procedure. It is also more efficient and is therefore recommended for its practicality.

Karl and Foley[17] found a larger discrepancy between the SCP/CR and MIC/CO than had been reported previously, using a hard anterior flat plane jig for neuromuscular deprogramming. They also found that, although there is an 18% chance of detecting a CPI-articulated condyle measurement of more than 2 mm in either the horizontal or vertical direction with the Roth registration technique alone, this figure more than doubled to 40% with the addition of a hard anterior deprogramming appliance before registration of the SCP/CR.

Dental interarch analysis

Most humans have a premature occlusal contact on the most posterior tooth.[1-8,11,13-17,19,21-23,34,35,39,40] This finding is supported by this study: 94.0% (560) of the neuromuscularly deprogrammed asymptomatic subjects were found to have premature occlusal contacts on the most posterior tooth. Traditional orthodontic study models, hand-articulated in MIC/CO, do not reflect this

scientific fact. Due to muscle splinting, it is not possible to reliably detect this premature occlusal contact with either intraoral visual estimation or models hand-articulated in MIC/CO.[1,9-11,14,17,18,20,24,36-38] Sears[66] and later Okeson[42] reported that a premature posterior contact can cause the condyle to displace from the disc as the mandible pivots from this premature occlusal contact and moves into maximum intercuspation. Seating the condyle moves the mandibular body and dentition distally.[3-8,15,17,21,23,34,35,56,57]

Previous studies showed that, when a discrepancy exists between the SCP/CR and MIC/CO, overjet increases and overbite decreases.[3-8,17,21,23] These findings are supported by this investigation; overjet increased by an average of 86.7%, and overbite decreased by an average of 49.0% (4.04-2.06 mm), in almost exact agreement with Karl and Foley,[17] who found that overbite decreased by 53.8% (4.14-1.91 mm) between MIC/CO and the SCP/CR. In addition, 40.9% of the subjects had changes in Angle classification at either the canine or the first molar between the SCP/CR and MIC/CO (Fig 2).

In 21.3% of the subjects (127), dental midlines were different in the SCP/CR when compared with MIC/CO. This reflects a mandibular shift from the SCP/CR to accommodate the maximum intercuspation bite. However, when the condyles are seated, the dental midlines are most likely to be coincident, unless there is dental-arch or skeletal asymmetry.

The results of this study demonstrate that most models, taken from a neuromuscularly deprogrammed asymptomatic patient population and accurately mounted in the SCP/CR, will show the following dental interarch characteristics when compared with the dental interarch relationship seen intraorally or from models hand-articulated in MIC/CO (Fig 3): (1) premature occlusal contact on the most posterior tooth; (2) horizontal: more Class II posteriorly, possible change in Angle classification at the canine or the first molar, and increased overjet anteriorly; (3) vertical: more open (decreased overbite); (4) transverse: dental midlines coincident (unless there is true dental arch or skeletal asymmetry).

The apparent slide at the occlusal level does not accurately reflect the 3D nature of the displacement at the condylar level.[3-8,11,17,19,21,23,34,35,40,43,56,57,67] Hodge and Mahan[68] showed that only a small part of the horizontal component of an SCP/CR to MIC/CO slide, as seen at the incisal level, is due to horizontal translational displacement of the condyles. Rosner[4] stated that "the difficulty in aligning occlusal landmarks in a sagittal plane, when a slide from the SCP/CR to the MIC/CO position is present, does not entirely reflect the amount

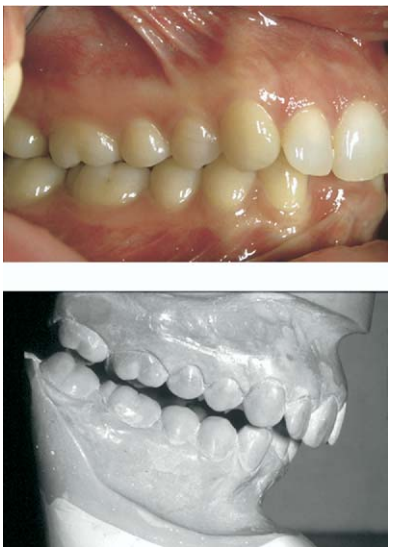

Fig 2. A, Pretreatment right lateral intraoral view of occlusion in maximum intercuspation. Class 1 bilaterally in maximum intercuspation (MIC/CO). B, Right lateral view of models mounted in SCP/CR from same patient (after chair-side neuromuscular deprogramming). Note molar premature occlusal contact of right second molars. Angle classification has changed from Class 1 bilaterally in maximum intercuspation (MIC/CO) to Class II in SCP/CR. Magnitude of horizontal and vertical interarch discrepancies has increased.

Fig 3. A, Common dental interarch characteristics of accurate mounting in SCP/CR. Right lateral view of models. B, Intraoral right lateral view of same patient in maximum intercuspation.

of translation of the hinge axis between those two points. . . . Significant translation of the hinge axis can occur due to rotation of the mandible, without obvious movement in the anterior region of the dentition." Rosner and Goldberg[69] stated further: "From our analysis of the condylar position in 3 dimensions, it is difficult to determine asymmetric condylar movement when measuring the dental midline displacement between the SCP/CR and MIC/CO. The complex way that movement is transmitted to the condylar centers of rotation in the form of skew, tilt, length of vertical and horizontal rotational distances, and medial/lateral displacement—in combination with the degrees of freedom—make it difficult to determine condylar movements by observation or measurement of the dental midline displacement between the SCP/CR and MIC/CO."[40]

Previous studies that fulfill the criteria of a defined sample with a sufficient number of subjects to permit analysis of condylar position are given in Table VI. This investigation supports earlier results: every subject and all condyles had displacements between the SCP/CR and MIC/CO. This supports previous findings that the SCP/CR and the MIC/CO position of the condyles are distinctly different positions in almost all patients.

The direction of the condylar displacement—posterior-inferior (66.7%), anterior-inferior (25.4%), straight inferior (5.7%)—closely agrees with that found by Wood and Korne,[34] Wood and Elliott,[21] Shildkraut et al,[23] Utt et al,[6] Girardot,[14,15] Slavicek,[22] Crawford,[19] Karl and Foley,[17] and Hidaka et al[8] and supports the concept of vertical condylar displacement as a result of posterior premature occlusal contacts (Fig. 4).[9,10,42,43,60]

In this study, the magnitude of the mean horizontal (.86 mm) and vertical (1.80 mm) condylar displacements were higher than reported previously for asymptomatic subjects (Table VI).[3-8,14-17,19,21,23,34,35,40] The magnitude of the discrepancy was found to be ≥2 mm in 53.6% of this sample (320 subjects); this is larger than was reported previously (Hidaka et al[8] [16%], Utt et al[6] [19%], and Esmay[7] [33%]). This is most likely due to methodology. Chair-side deprogramming with a hard anterior stop before taking the 2-piece SCP/CR registration, which incorporates a hard anterior stop, promotes capturing a more seated condyle position (Fig 5) than traditional chin-point guidance alone (without deprogramming).[3-8,15,19,21,23,34,35,40] The mean vertical condylar displacement (1.80 mm) almost exactly agreed with Karl and Foley,[17] who found a mean of 1.76 mm after deprogramming.

A central question must be considered from this data: does the measured discrepancy between the SCP/CR and MIC/CO, at either the occlusal or the condylar level, have a clinical impact on the daily practice of orthodontic diagnosis and treatment planning? Previous investigators have concluded that it is difficult, if not impossible, to quantitatively assess a clinical discrepancy between the SCP/CR and MIC/CO at the occlusal level.[1,3-25,27-35,37-41,43,47-59,61,63] This study has shown that not only did neuromuscular deprogramming and mounting models in the SCP/CR show a significant (vertical, ≥2.0 mm; horizontal, ≥1.6

Table VI. Measurements of condylar position in 3 planes (mm)

	Component			
Investigator (y)	*Horizontal*	*Vertical*	*Transverse*	*n*
Hoffman et al (1973)	.28	.25	.10	52
Rosner and Goldberg (1986)	.56	.84	.34	75
Wong (unpublished)	.7	1.0	.3	250
Wood and Korne (1992)	—	1.2	—	39
Alexander (1993)	.25	.3	.3	28
Utt et al (1995)	.61	.84	.27	107
Esmay (1995)	.63	1.53	.37	46
Hicks and Wood (1996)	—	1.2	.27	37
Girardot (2001, brachy)	.66	1.2	—	19
Girardot (2001, dolicho)	1.21	1.7	—	19
Hidaka et al (2002)	—	1.0	.00	150
Karl and Foley (1999)*	1.54	1.76	.51	40
Cordray (2003)*	.86	1.80	.26	596

Magnitude either not measured or averaged, using − and + values instead of absolute values.
*Deprogramming used before registration of SCP/CR.

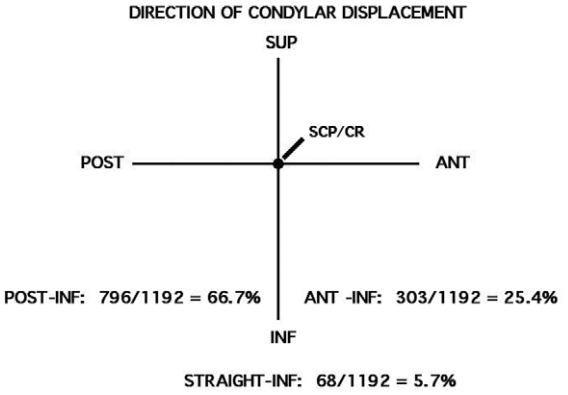

Fig 4. Direction of condylar displacement in 3 planes of space from sample of 596 asymptomatic patients.

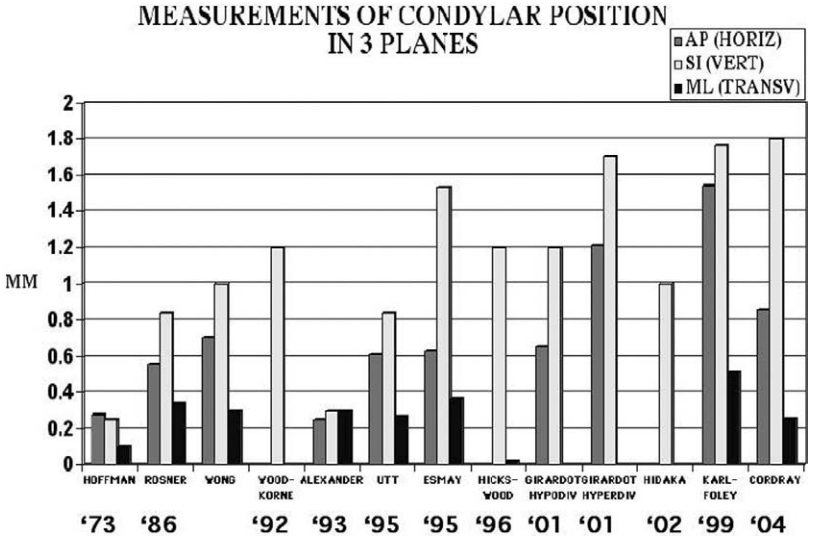

Fig 5. Magnitude of condylar displacement in 3 planes of space. Comparison of 12 studies conducted over 30 years.

mm; or transverse, ≥5 mm) condylar discrepancy in 57.5% of the subjects (342), but it also showed clinically significant deviations at the level of the occlusion, as evidenced by posterior premature occlusal contacts, increased overjet, decreased overbite, and deviations in midline and Angle classification. The dental interarch discrepancy in the SCP/CR was significantly different from the dental interarch discrepancy observed in MIC/CO. These findings are important diagnostically, because they might determine whether treatment options will include extractions or orthognathic surgery.

The clinical significance of these findings is how this information affects orthodontic diagnosis and treatment planning, particularly from a tooth-movement standpoint. In a significant percentage of patients, the magnitude of the dental interarch discrepancy in the horizontal and vertical planes was more severe when the condyles were more fully seated. For example, a significant percentage (40.9%) of the asymptomatic patients with, in the horizontal plane, a Class 1 dental relationship in MIC/CO were really Class II in the SCP/CR. Yet there are more subtle clinical situations where the discrepancy does not show up in this 40.9% figure. Although an outright change in Angle cassification might be observed between the SCP/CR and MIC/CO, the *magnitude* of the dental interarch discrepancy in the horizontal and vertical planes might be more severe when the condyles are fully seated. This information can dramatically affect the anchorage requirements for Class II correction in the horizontal plane; ie, mild to moderate anchorage requirements in MIC/CO might actually be maximum anchorage cases in the SCP/CR (Fig 6). Also, a significant percentage of patients with normal to mild overbite in the vertical plane might actually have moderate to severe open bites in the SCP/CR, thus affecting vertical control mechanics.

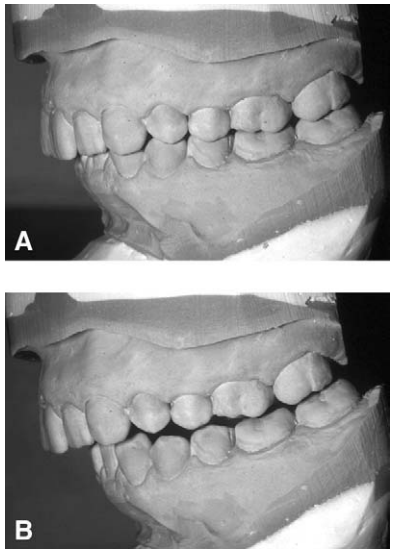

Fig 6. A, Left lateral view of models hand-articulated in MIC/CO. Angle classification is Class II bilaterally. **B,** Left lateral view of same models articulator-mounted in SCP/CR. Angle classification has not changed, but magnitude of horizontal interarch discrepancy has increased. Anchorage requirements in extraction correction might be affected.

In this neuromuscularly deprogrammed asymptomatic group, 342 subjects (57.5%) had significant (vertical, ≥2.0 mm; horizontal, ≥1.6 mm; or transverse, ≥.5

mm) condylar discrepancies. This represents over half of the sample and agrees with Shildkraut et al,[23] who found that 52% (68 of 131) of their sample had discrepancies of ≥2 mm in either the horizontal or vertical plane. If accurate measurements of the skeletal and dental interarch relationships are desired, it is recommended to convert the lateral cephalogram from MIC/CO to the SCP/CR when a vertical difference of ≥2 mm or horizontal difference of ≥1.6 mm is observed.[6,22,23,56,57,61]

From the statistically significant differences in 3D dental interarch relationships and condylar positions in this study, it is apparent that the following decision-making areas in orthodontic correction might be affected: (1) diagnosis: magnitudes (mm) of the horizontal dental-arch discrepancy (Class II, Class III) to be corrected, of the vertical dental-arch discrepancy (open bite, deep bite) to be corrected, and of the transverse dental-arch discrepancy to be corrected, direction of mandibular growth, and direction of mandibular rotation expected with treatment; (2) treatment planning: extraction versus nonextraction, and nonsurgical versus surgical plans; (3) anchorage requirements (minimum, moderate, maximum); (4) treatment mechanics (dictated by all of the above, especially the diagnosis and anchorage requirements); (5) occlusal finishing (arch coordination in 3 planes of space); (6) evaluation of orthodontic treatment effects; and (7) evaluation of orthodontic relapse.[54,65]

CONCLUSIONS

The articulator mounting of models in the SCP/CR, by using the modified nonmanipulated SCP/CR registration technique with neuromuscular deprogramming, is an accurate, reproducible, and effective method, showing discrepancies between a subject's occlusion when the condyles are seated and when the occlusion is dictated by the intercuspation of the teeth. Neuromuscular deprogramming is an important adjunct to accurate registration of the SCP/CR. It is an easy procedure that can be accomplished at chair-side with little clinician time, little expense, and no compliance problems.

Not only did deprogramming and mounting models in the SCP/CR show a significant (vertical, ≥2.0 mm; horizontal, ≥1.6 mm; or transverse, ≥5 mm) condylar discrepancy in 57.5% of the asymptomatic subjects (342), but it also showed clinically significant deviations at the occlusal level, as evidenced by premature posterior occlusal contacts, increased overjet, decreased overbite, and midline and Angle classification deviations. The dental interarch discrepancy in the SCP/CR was significantly different from the discrepancy observed in MIC/CO. These facts illustrate the importance of deprogramming and mounting models in the SCP/CR in making an accurate diagnosis of the skeletal and dental discrepancies of each patient. The clinician cannot assume that the condyles are seated before treatment merely because the patient is asymptomatic.

The results of this prospective study demonstrate clearly that neuromuscular deprogramming, registering the SCP/CR, and mounting orthodontic study casts in the SCP/CR on a semiadjustable articulator enhance the diagnosis by yielding information that is not available from intraoral visual estimation or models hand-articulated in maximum intercuspation.

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APPENDIX

Modified Roth nonmanipulated SCP/CR registration technique with deprogramming

The overall technique is, in part, a clinical application of the findings of many investigators, including Kovaleski and DeBoever,[33] Huffman and Regenos,[20] Beard and Clayton,[41] Williamson et al,[12] Girardot,[14] Fenlon and Woeffel,[30] Wood and Elliott,[21] and Karl and Foley.[17]

The bite registration is taken immediately after deprogramming. A 2-piece wax registration is taken with anterior resistance (hard anterior stop), which generates muscular activity of the mandibular elevator muscles, thereby aiding in seating the condyles. There is no effort by the clinician to direct mandibular closure or influence condylar position.

The wax bite is taken with Blue Bite Registration Wax (Delar, Lake Oswego, Ore) within the hinge axis rotation phase of closure (10-15 mm) and is prepared in 2 sections. The anterior section is made by folding over the softened wax to form 4 layers (more, in case of anterior openbite). The anteroposterior dimension is dictated by the overjet, and the width should include both the maxillary and mandibular anterior teeth (canine to canine). The posterior section is 2 layers thick. The anteroposterior dimension is trimmed wide enough to include the first molar and the second premolar, and it does not extend too far buccally to be distorted by the cheek or too far anteriorly to interfere with the anterior section.

The procedure

1. The patient is seated in the dental chair and positioned at a 45° angle to the floor.
2. The patient is instructed to bite continually with a moderate pulsating biting force (5 seconds clench,

5 seconds relax) on a wooden tongue depressor for 5 to 10 minutes to modify the neuromuscular engram. The wax registration of the SCP/CR is taken immediately after deprogramming.

3. The anterior section of wax (4 thicknesses) is softened in a water bath at 135°F, and then placed and held against the maxillary anterior teeth with 1 hand. As the operator uses gentle chin-point guidance with the thumb of the free hand (to prevent mandibular protrusion, not to manipulate mandibular closure), the middle and index fingers lightly support the angle of the mandible bilaterally. The patient is then instructed to "lightly close on your back teeth" and allowed to close without protrusion on a reproducible mandibular arc until approximately 2.0 mm of posterior vertical separation/clearance is observed between the maxillary and mandibular posterior-most teeth. The patient is instructed to hold this position. The anterior section of wax is chilled with air, hardened so that it can be removed without distortion, and removed. The anterior section is further hardened in ice water and trimmed to allow passive indexing of the mandible into the SCP/CR position. The patient is not permitted to close the teeth into maximum intercuspation until the registration is completed.
4. The posterior section (2 thicknesses) is heated in a water bath until it is completely soft (offers no resistance to closure) and placed on the maxillary teeth and supported with the fingers on the buccal surfaces. With the posterior section in place, the chilled anterior section is replaced on the maxillary anterior teeth without contacting the posterior section. This can be supported with the same hand that is holding the posterior section.
5. The mandible is guided into the SCP/CR as above with the free hand. The mandibular anterior teeth should index into the hardened anterior section of wax without any (anterior) slide into the indentations. As the patient closes into the hardened anterior section, he is instructed to "close firmly and hold." The condyles seat as the patient closes into the hardened anterior stop, and the posterior teeth hinge closed against no resistance. The posterior section is chilled with air. When the posterior section has hardened sufficiently to avoid distortion upon removal, both wax sections are removed. Both sections are further hardened in ice water.
6. The 2-piece wax record is inspected to ensure the absence of cusp penetration through the wax. It is then trimmed with a sharp scalpel blade only to the incisal edge for cusp tip indexing when mounting the lower cast.

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