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Registration of the Seated Condylar Position (SCP/CR): Part II: Technique: The Two-Piece Wax Bite Registration

Frank E. Cordray[1,2,3,4,5*], Vito Caponigro[6,7,8,9]

[1]Department of Orthodontics, Ohio State University, Columbus, Ohio, USA
[2]Department of Orthodontics, West Virginia University, Morgantown, West Virginia, USA
[3]Department of Orthodontics, Children's National Medical Center, Washington, DC, USA
[4]Department of Orthodontics, ATSU, Mesa, Arizona, USA
[5]Department of Orthodontics, Universite de Strausbourg, Strausbourg, France
[6]Advanced Prosthodontics, Ohio State University, Columbus, Ohio, USA
[7]Director Comprehensive Care Unit, ATSU, Mesa, Arizona, USA
[8]Implant Clinic, Ohio State University, Columbus, Ohio, USA
[9]Director Fixed Prosthodontic Clinic, University of Pittsburgh, Pittsburgh, Pennsylvania, USA
Email: *cordrayortho@aol.com

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Abstract

The purpose of this paper is to present the technique for registration of the Seated Condylar Position (SCP)/Centric Relation (CR) position of the condyles: a two-piece wax bite registration with deprogramming and no mandibular manipulation.

Keywords

Dental Arch Displacement (DAD), Condylar Displacement (CD), Seated Condylar Position (SCP), Maximum Intercuspation (MIC), Intercuspal Position (ICP), Musculo-Skeletal Dysfunction, Temporo-Mandibular Dysfunction (TMD), Common Muscle Contraction Headache (CMCH)

1. Introduction

From the results of previous investigations it can be concluded that the following four pre-requisites must be completed in order to:

1) Achieve more complete condyle seating;

2) Accurately record the SCP/CR;

3) Study the dental inter-arch and condyle positional changes between the SCP/CR and the IP/MIC/CO.

The four pre-requisites for accurate registration of the SCP/CR are:

1) Neuromuscular deprogramming;

2) Mandibular closure without deflection/tooth contact;

3) Voluntary muscle contraction: NO mandibular manipulation;

4) Two-piece registration incorporating a hard anterior stop.

Each of these four elements is essential to achieve more complete condylar seating when registering the SCP/CR.

2. Neuromuscular Deprogramming

Clinical mandibular manipulation is unreliable in determining the seated condylar position because of the effects of the neuromusculature, which is consistent with Calagna's [1] statement that "there is no known scientific method available to determine which patients require neuromuscular conditioning." To study the dental arch and condyle positional changes between the IP/MIC/CO and the SCP/CR it is important to use a method that reduces or eliminates the influence of the occlusion on the musculature. Only then can the condyles be accurately seated.

Eliminating the influence of the neuromusculature on condylar seating and accurately registering the SCP/CR as a reference allows for a determination of the dental inter-arch relationship and occlusion-dictated condylar position in three spatial planes. The identification and full extent of deflective occlusal contacts and resultant condylar displacement may be hidden by guarding of the neuromusculature. Thus, it is recommended that subjects (both symptomatic and asymptomatic) be deprogrammed prior to occlusal and condylar position evaluations. Deprogramming for both asymptomatic and symptomatic subjects prior to the registration of the SCP/CR eliminates the subject's neuromuscular response to the habitual occlusion.

Neuromuscular deprogramming is the key to reproduciblilty [2]-[23]. Deprogramming allows location of the SCP/CR and occlusal analysis that correlates condylar position with tooth contacts (**Figure 1**). Splint therapy has proven to be

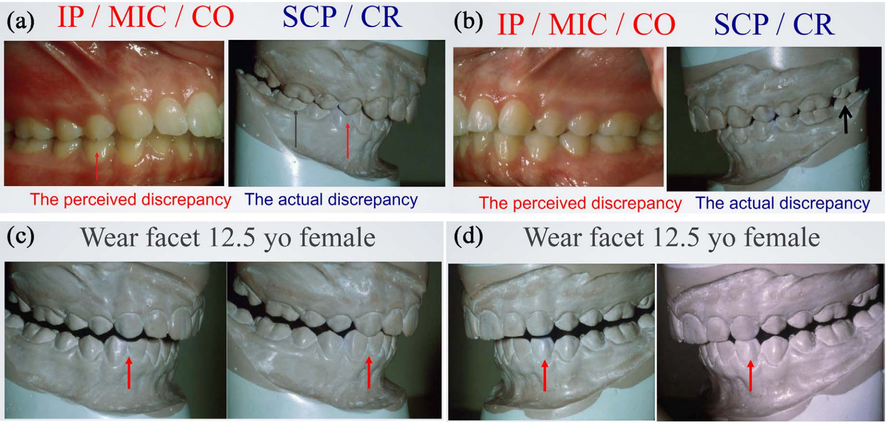

Figure 1. Deprogramming allows location of the SCP/CR and occlusal analysis that correlates condylar position with tooth contacts.

the most effective technique for deprogramming the neuromusculature [3] [4] [5] [6] [8] [11]-[17] [24]. Numerous studies have shown that properly conducted splint therapy for neuromuscular deprogramming reveals previously undetected occlusal contacts as a result of masticatory muscle relaxation and subsequent mandibular repositioning [3] [5] [6] [11] [12] [13] [14] [15] [17] [25]-[45].

The dual functions of splint therapy are:

1) Therapeutic:

a) an attempt to address/alleviate the symptoms of TM dysfunction;

b) test the patient's response to an altered occlusal scheme.

2) Diagnostic: to reveal deflective contacts/occlusal interferences and the actual maxillo-mandibular relationships previously hidden by guarding of the neuromuscular system.

Various types of deprogrammers have been used in dentistry for neuromuscular relaxation. These include cotton rolls, anterior jig, leaf guage/bite stick/tongue blade, anterior bite plane/NTI, and full coverage occlusal stabilization splint.

The most reliable deprogramming is achieved through full-time wear of a full-coverage upper stabilization splint constructed in the SCP/CR, especially in patients who present with signs and symptoms of temporo-mandibular joint dysfunction [3] [4] [5] [6] [8] [11]-[15] [17] [24] [46] [47] (**Figure 2**).

Occlusal splint therapy has been shown to be an effective treatment in the relief of symptoms associated with craniomandibular disorders [48] [49]. Kemper and Okeson also proved that it is an effective treatment modality for the relief of common muscle contraction headache (CMCH) pain [50].

In 1989 Girardot [3] deprogrammed 19 symptomatic subjects with full-time wear of a full-coverage upper stabilization splint until symptoms were relieved, and tracked condylar position before and after splint therapy with measurements obtained with condylar position instrumentation (MPI, Great Lakes Orthodontics). Study casts articulated post-stabilization splint therapy revealed initial occlusal contacts on the distal-most molars in all 19 subjects. The direction of condylar displacement in TMD patients was found to be primarily downward (inferior) and backward (distal) and secondarily downward (inferior) and forward (anterior). The condyles moved superiorly as symptoms were relieved with

(a) (b)

Figure 2. Upper gnathologic splint with even posterior contacts and anterior and lateral guidance.

stabilization splint therapy. Thus decreasing the condylar displacement (seating the condyles with stabilization splint therapy) positively correlated with the relief of TM dysfunction ($P < 0.001$).

Williamson [14] utilized condylar position instrumentation with true hinge axis recordings and studied the effect of full-time wear of a full-coverage upper stabilization splint on the location of the mandibular hinge axis in both asymptomatic and symptomatic subjects. He found that the axis moves anterior-superiorly with deprogramming, and that the axis locations following two different periods of stabilization splint wear were highly reproducible. Williamson concluded that "with relaxed musculature [e.g., deprogramming] the hinge axis location is highly reproducible."

However, in a busy dental practice it is often not practical to deprogram numerous patients with stabilization splint wear for 2 wks. to 3 mos. prior to registration of the SCP/CR. The usefulness of an adjunct deprogramming procedure which separates the posterior teeth, deprograms the neuromusculature, and eliminates premature occlusal contacts/tooth interferences that guide the mandible into maximum intercuspation (IP/MIC/CO) is dependant, in part, upon its ease of fabrication, cost-effectiveness, and minimal patient compliance required for effectiveness. Slavicek [9] and Dawson [51] advocate having the patient bite on cotton rolls for deprogramming prior to registering the SCP/CR. However, a soft material that can be distorted by tooth indentations is not as effective in deprogramming as a hard occlusal stop. Therefore, the anterior jig advocated by Lucia [18] [20] [52], the leaf gauge advocated by Long [21], Williamson [42], Woeffel [23] and others [6] [12] [13] [19] [22], and the anterior flat plane jig utilized by Calagna [11], Karl and Foley [15], and Greco and Vanarsdall [24] are examples of registration techniques incorporating more effective anterior deprogrammers which separate the posterior teeth, deprogram the neuromusculature, and prevent deflective occlusal contacts that guide the mandible into the IP/MIC/CO.

An important registration consideration is that if the condyles have been displaced out of the fossae for an extended period of time, as with orthdontic appliances that displace the mandible anteriorly and vertically in an attempt to "stimulate condylar growth," it has been shown that it takes a year or more of consistent splint wear for the condyles to seat, due to scar tissue buildup in the retro-discal area over the duration of mandibular displacement appliance use. Thus it is difficult and time consuming to deprogram these patients and register the SCP/CR when the condyles have been displaced out of the fossae by forward positioning appliances [53] [54].

3. Mandibular Closure without Deflection/Tooth Contact

94% of the human population presents with an initial occlusal contact on a terminal tooth [44] [45] [55].

1) Models hand-articulated in the IP/MIC/CO;

2) Scans/imaging conducted in the IP/MIC/CO;

3) Radiographs taken in the IP/MIC/CO do NOT reflect this scientific fact [4] [7] [14] [15] [16] [23] [32] [33] [34] [35] [36] [44] [45] [49] [56] [57] [58] [59] [60].

This is especially evident post-stabilization splint therapy. Practitioners experienced in splint therapy are well aware that vertical condylar displacements result in initial terminal tooth contact [3] [10]-[17] [32] [33] [34] [35] [37] [53]. In other patients who present with large AP dental arch displacements (DAD), initial occlusal contacts are often seen on premolars after splint therapy, due to a lack of arch width coordination between the upper and lower dental arches when the condyles are seated and the lower apical base moves posteriorly.

Proprioception orients the mandible in space as the teeth approach occlusal contact/the IP/MIC/CO.

It has been demonstrated that the neuromusculature positions the mandible to achieve maximum intercuspation/the IP/MIC/CO, overriding condylar seating [3] [11] [12] [13] [27] [31]-[43]. Attempts to assess dental arch displacement (DAD) in the general population through intraoral visual estimation are unpredictable, because the muscles of mastication and neuromuscular reflexes protect the teeth by superseding the guidance of the joint [3] [7] [8] [11] [12] [13] [15] [17] [18] [19] [21] [22] [23] [32].

Engrams (muscle splinting) develop due to repetitive closure in the intercuspal position, causing the proprioceptive neuromuscular system to become patterned to the deviated closure. The resultant muscle function becomes so dominant that the acquired mandibular position (the perceived discrepancy) as a result of the occlusion dictated condylar position will often be mistaken by the clinician as the mandibular position in the seated condylar position (the actual discrepancy). As Lerman states, The engram (the masticatory "muscle memory") is a conditioned reflex reinforced and stored in the masticatory muscles at every swallow, adjusting masticatory muscle activity to guide the mandible and lower dental arch unerringly into its ICP. These muscle adjustments compensate for the continually changing internal and external factors that affect the mandible's entry into the ICP," masking the DAD between the IP and the SCP [61].

Occlusal contacts on a small number of teeth are inefficient functionally and create discomfort (both physical and psychic) causing the subject to subconsciously shift the mandible to an IP/MIC/CO position where contact between the upper and lower teeth is maximized.

The neuromuscular response to the habitual occlusion has been described in the occlusion literature as the neuromuscular protective mechanism by Hannam [30] and proprioceptive guidance by Roth [10] [62] [63] [64]. Thus the occlusal position observed intra-orally (the IP/MIC/CO) is an accomodated mandibular postion with condylar displacement (CD). As soon as the upper and lower teeth approach close contact, the neuro muscular protective mechanism/proprioceptive guidance is elicited. Subjects subconsciously occlude in the IP/MIC/CO, avoiding the initial occlusal contact and closing into maximal tooth contact (the

IP/MIC/CO), leading the clinician to perceive that it is the patient's actual occlusion. This is also the mechanism that prevents clinicians from observing most DAD's intra-orally.

Tooth position and the occlusal surfaces of the teeth dictate condylar position at the end of closure. Suffice it to say, deflective occlusal contacts/interferences require condylar displacement (CD) to achieve the IP/MIC/CO. Thus the occlusal position observed intra-orally is an accommodated mandibular position with condylar displacement and condylar position is determined by the dentition at the IP as a result of deflective contacts. It is therefore necessary to keep the posterior teeth separated (by 2.5 - 3 mm) when registering the SCP/CR in order to prevent triggering this mechanism, which guides the mandible into a position that results in maximal tooth contact (the IP/MIC/CO). The posterior section of the bite registration, be it wax, impression material, ZOE, or other bite registration material, must offer no resistance to closure.

4. Voluntary Muscle Contraction: NO Mandibular Manipulation

The clinician is NOT "manipulating" or "guiding" the mandible into the seated position. The PATIENT'S OWN musculature (temporalis, masseter, internal pterygoid—(sup head), and external pterygoid) seats the condyles. The clinician does NOT push the chin back in an attempt to "guide" the mandible into the SCP.

As soon as the clinician pushes on the patient, the reciprocal reaction is that the patient will push back.

The clinician is merely assuring that the mandible is passively rotating/in the rotational phase of closure (0 - 25 mm of opening) and the mandible is not protruding.

The importance of voluntary muscle contraction in condylar seating cannot be overemphasized.

McMillen [65] used pantographic tracings to prove the importance of muscle tonicity in positioning the condyles in their superior-most position. In this study the true hinge axis was recorded and with the hinge axis instrument still in place, the subject was placed under general anesthesia and given succinylcholine. The condyles dropped from the seated position and vertical mandibular manipulation applied during anesthesia to the angles of the mandible was insufficient to reposition the condyles to their original seated position in the glenoid fossae. Thus with general anesthesia and a hinge axis recording of the SCP the investigators could not seat the condyles fully with mandibular manipulation alone. They concluded that voluntary muscle contraction is necessary to fully seat the condyles superiorly into the seated position.

5. Two-Piece Registration Incorporating a Hard Anterior Stop

The neuromuscular protective mechanism/proprioceptive guidance is also why it is not accurate to attempt to register the SCP/CR with a one-piece registration.

Williamson [42] utilized a leaf gauge anteriorly (hard anterior stop) with posterior tooth separation (no posterior contact) when registering the SCP/CR and concluded that the SCP/CR is a muscle determined position, not an operator-guided position. From clinical experience, as soon as the clinician pushes on the patient, the reciprocal reaction is that the patient will push back.

The anterior jig advocated by Lucia [18] [20], the leaf gauge advocated by Long [21], Williamson [42], Woeffel [23] and others [6] [12] [13] [19] [22], and the anterior flat plane jig utilized by Calagna [11], Karl and Foley [15] and Greco and Vanarsdall [24] are examples of registration techniques incorporating anterior deprogrammers as hard anterior stops with posterior tooth separation.

Calagna [11] evaluated four neuromuscular conditioning techniques—the insertion of cotton rolls, and deprogramming with either the myomonitor, an anterior jig, or a maxillary biteplane. He found that deprogramming with the maxillary biteplane revealed a condylar displacement that was, on average, twice the displacement found with the other three methods, all of which found comparable displacements. Greco and Vanarsdall [24] found that the function of the masseter and temporalis muscle muscles significantly decreased after the patient wore a Hawley biteplane or superior repositioning splint 8 hours per day for 2 weeks. Karl and Foley [15], utilizing deprogramming and condylar position instrumentation, found a larger discrepancy between the SCP/CR and the IP/MIC/CO than had been reported previously by using a hard anterior flat plane jig for deprogramming prior to registering the SCP/CR. They also found that while there was an 18% chance of detecting a condylar displacement of more than 2 mm in either the horizontal (AP) or the vertical (SI) planes with the Roth two-piece wax registration technique alone, this percentage more than doubled (to 40%) with the addition of a hard anterior deprogramming appliance prior to registration of the SCP/CR. They concluded that deprogramming provides a registration of condylar position that reveals a greater condylar displacement from the IP/MIC/CO than a registration taken without prior deprogramming. Johnston and Huffman [66] deprogrammed 92 orthodontically treated subjects and 83 controls with full-time wear of a full-coverage upper stabilization splint and found that the mean DAD for both groups, as measured from articulated study models, was slightly higher than that found in previous studies. They attributed this finding to "unmasking the discrepancy with splint wear."

Deprogramming, accurate registration of the SCP/CR, articulator-mounted study models, and condylar position instrumentation are required to determine condylar position and the associated dental arch displacement accurately in three dimensions.

6. The Two-Piece Wax Bite Registration Technique with Deprogramming and No Mandibular Manipulation

The overall technique is, in part, a clinical application of the findings of numerous investigators, including Lundeen [17], Williamson [14], Huffman [8], Beard and Clayton [5], Teo and Wise [67], Lucia [18], Girardot [3], Howat, Capp, and Barrett [7], Fenlon and Woeffel [23], Wood [37], Roth [10] [68], Karl and Foley [15], Greco and Vanarsdall [24] and Dawson [2].

To seat the condyles to the most orthopedically-stable joint position, the registration technique utilizes:

1) Neuromuscular deprogramming;

2) Mandibular closure without deflection/tooth contact;

3) Voluntary muscle contraction: NO mandibular manipulation;

4) A two-piece registration incorporating a hard anterior stop.

The advantages of this technique are:

1) Allows mandibular closure without dental interference (avoids posterior tooth contact and possible mandibular deflection);

2) Allows patient's own mandibular elevator muscles to seat the condyles: no mandibular manipulation is utilized (thus not as technique sensitive as other "manipulation" technics).

The bite registration is taken immediately after neuromuscular deprogramming (relaxation). A 2-piece wax registration incoporating anterior resistance (a hard anterior stop) and no posterior resistance generates activity of the mandibular elevator muscles and avoids posterior tooth contact, allowing condylar seating in a reproducible musculo-skeletal position without dental interference or deflection. No attempt is made to direct mandibuar closure or influence positioning of the mandibular condyles.

The wax bite is taken with Blue Bite Registration Wax (AD2 Advanced Dental Designs, Moreno Valley, CA https://www.ad2usa.com/ 800.232.2849, Great Lakes Dental Technologies, Tonawanda, NY https://www.greatlakesdentaltech.com/ 800.828.7626) within the hinge axis rotation phase of closure (<25 mm) and is prepared in two sections. The anterior section is made by folding over the softened wax to form 4 layers (more, in case of anterior open bite). The antero-posterior dimension of the anterior wax section is dictated by the overjet (AP difference in upper to lower incisor teeth anteriorly), and the width should include both the upper and lower anterior teeth (cuspid to cuspid). The posterior section is two layers thick. The antero-posterior dimension is trimmed wide enough to include the first molar and second premolar teeth, and it does not extend too far buccally to be distorted by the cheek nor too far anteriorly to interfere with the anterior section of wax (**Figure 3**).

7. The Procedure

1) The subject is seated in the dental chair and positioned at a 45-degree angle to the floor.

2) The subject 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

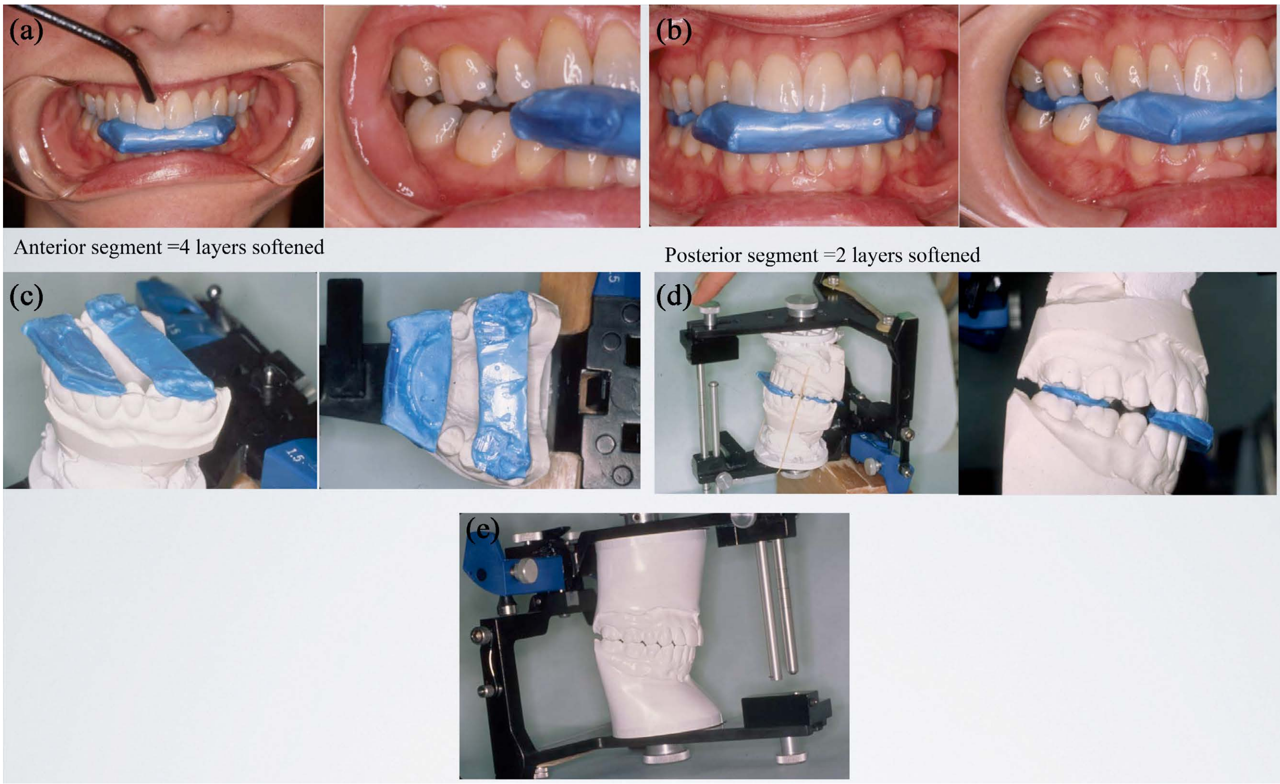

Figure 3. The two-piece wax bite registration taken after deprogramming and with no mandibular manipulation.

SCP is taken immediately following deprogramming.

3) The anterior section of wax (4 thicknesses) is softened in a water bath at 135 degrees Fahrenheit, then placed and held against the maxillary anterior teeth with one hand. The operator places the thumb of the free hand lightly on the chin while the middle and index fingers lightly contact the angle of the mandible bilaterally. No pressure is applied to the chin: just assure that subject is in the repeatable rotational phase of closure (<25 mm).

The subject is then instructed to "Close lightly on your back teeth" and is allowed to close without protrusion on a reproducible mandibular arc until approximately 3 mm of posterior vertical separation/clearance is observed between the upper and lower posterior-most teeth. The subject is instructed to hold this position. The anterior section of wax is chilled with air, hardened to the point where it can be removed without distortion, and is then removed. The anterior section is cooled in cold water and trimmed to allow passive indexing of the mandible into the SCP position. The subject is NOT permitted to close the teeth together into intercuspation (the IP) until the registration is completed.

4) The posterior section (two thicknesses) is heated in the water bath until it is completely soft (would offer no resistance to closure) and then placed across the upper molars and supported with the fingers on the buccal surfaces. While holding the posterior section in place, the chilled anterior section is replaced on the upper 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 allowed to close into the SCP as above with the free hand. The lower anterior teeth should index into the hardened anterior section of wax without any (anterior) slide into the indentations. As the subject closes into the hardened anterior section, he/she is instructed to "close lightly on your back teeth and hold." The condyles seat as the subject closes into the hardened anterior stop and the posterior teeth hinge closed without resistance and without posterior tooth contact. Observe that lower incisors index into same indentations in the anterior wax section. The posterior section is chilled with air. When the posterior section has hardened sufficiently to avoid distortion upon removal, both wax sections are removed and cooled in cold 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 to the incisal edge for cusp tip indexing for articulator mounting the lower dental cast into the SCP.

7) It is recommended that the maxillary position in three planes is registered with a facebow (EZ-bow^{R} or ear bow) for orientation of the maxillary cast in the articulator.

8. Common Dental Arch Characteristics of Casts Accurately Articulated in the SCP/CR

From the two-part study conducted by this author on 596 asymptomatic [44] and 596 symptomatic [45] subjects, the following findings were reported.

1) In 1122/1192 = 94.1% of the total sample (CI 92.1, 96.0) of asymptomatic and symptomatic subjects the initial occlusal contact occurred on the posterior-most tooth in the SCP/CR. The bicuspids do NOT contact. **Figure 4** Traditional dental casts collected for diagnosis and treatment planning which are hand-articulated into intercuspation, as well as scans and radiographs taken in the IP/MIC/CO do not reflect this scientific fact [44] [45] [69] [70] [71]. Thus, if the bicuspids are contacting in the articulated casts, in all likelihood the condyles were not fully seated during registration of the SCP/CR.

2) The three-dimensional study of DAD in the SCP/CR as compared to the DAD in the IP/MIC/CO revealed:

a) Horizontal (AP): Mandible more Class 2 (retrusive), possible change in occlusion pattern/classification at the canine or first molar. Increased incisor overjet

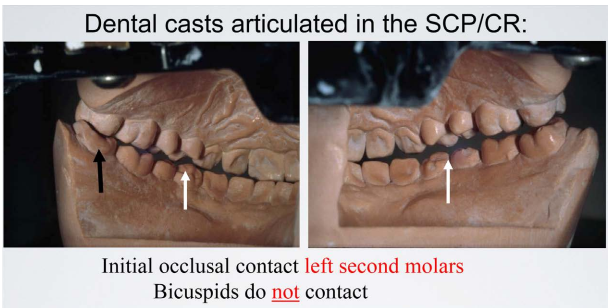

Figure 4. Characteristics of dental casts articulated in the SCP/CR.

(OJ) anteriorly;

b) Vertical (SI): Bite more open (decreased incisor overbite (OB) vertically) (**Figure 5**);

c) Transverse (ML): Dental midlines coincident (unless a dental arch asymmetry or skeletal asymmetry).

9. How are Dental Casts Articulated in the SCP/CR Utilized in Dental Correction?

Dental casts articulated accurately in the SCP/CR are utilized to:

1) Diagnose the exact/actual inter-arch discrepancy (dental arch displacement/DAD) in the SCP.

Articulating dental casts in the SCP/CR reveals the magnitude (mm) of the actual discrepancy to be corrected. For example, is the dental inter-arch relationship a Class 1 or Class 2? If Class 2, is it a 3 mm, 5 mm, or 7 mm Class 2 in the horizontal (AP) plane? In dental correction, knowledge of the magnitude (mm) of the actual discrepancy (DAD) to be addressed is essential when:

a) Restoring the dentition with multi-unit restorations.

b) Restoring posterior occlusal stability with tooth restoration or occlusal adjustment.

c) Treating mandibular dysfunction.

d) Treating patients with complete denture prosthetics.

e) Treating patients orthodontically.

f) Positioning the condyles during orthognathic surgery.

Caveat: an observation from articulating dental casts in the SCP [44] [45]: the majority of Class 2 subdivision cases (presenting as Class 2 unilaterally in the IP/MIC/CO) are actually a half cusp (3.5 mm) Class 2 on the apparent Class 1 side and a full cusp (7 mm) Class 2 on the Class 2 side when the condyles are seated. These cases are often a mandibular apical base retrusion and asymmetry with lower dental midline toward the more Class 2 side. A maxillary skeletal asymmetry is rarely present.

2) Measure the condylar displacement between the SCP/CR and the IP/MIC/CO (**Figure 6**).

Generally discrepancies between the SCP/CR and the IP/MIC/CO have the appearance of HORIZ/AP discrepancies when observed intra-orally (DAD), giving the impression that they are also HORIZ/AP discrepancies at the joint

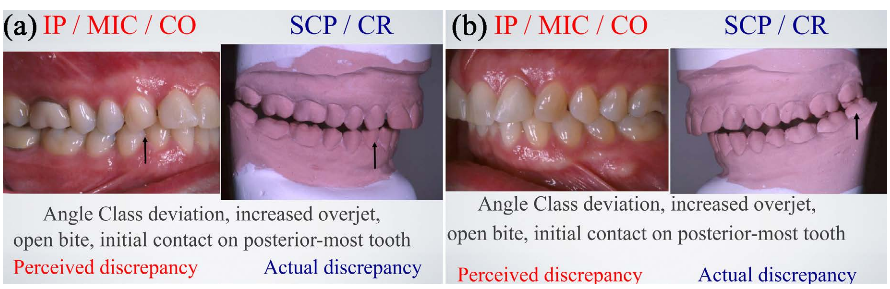

Figure 5. Characteristics of dental casts articulated in the SCP/CR.

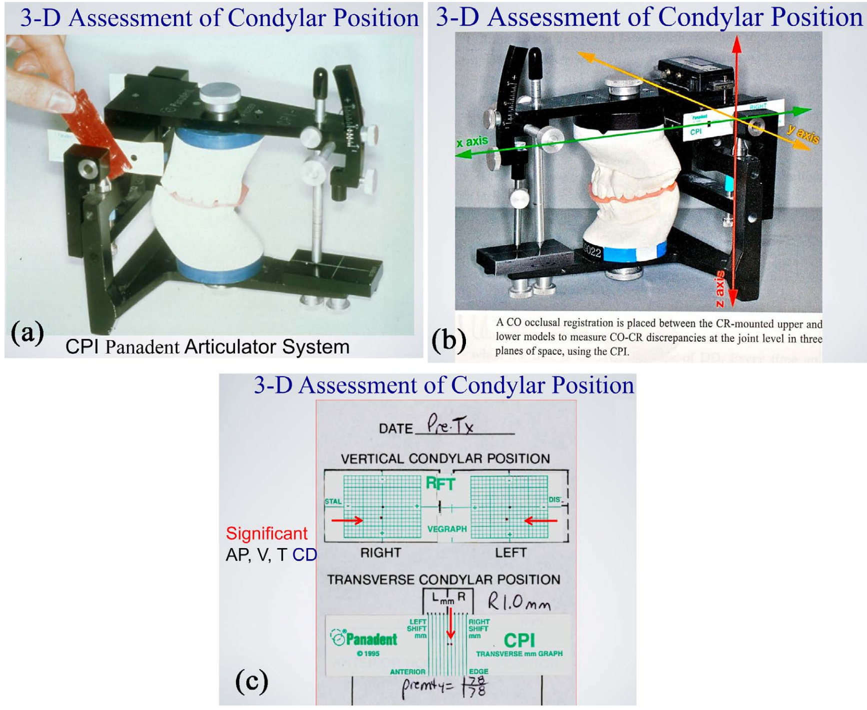

Figure 6. 3D assessment of condylar displacement between the SCP/CR and the IP/MIC/CO with dental instrumentation and condylar graph recordings.

level (CD). Dental correction has focused on HORIZ/AP discrepancies observed in the mouth in an attempt to address the seeming HORIZ/AP inter-arch discrepancy. However, quite the opposite is true. Studies utilizing joint space condylar position data [72] [73] and condylar graph instrumentation [3] [9] [10] [14] [15] [32]-[41] [44] [45] [62] [69] [70] [71] reveal that many discrepancies that appear to be HORIZ/AP displacements intra-orally (the DAD) are actually a result of VERTICAL condylar displacements (CD). Most often the condyles are displaced VERTICALLY (downward and backward) [3] [36] [44] [45] [69] [70] [71] and correction of the HORIZ/AP inter-arch discrepancy is rather tied to vertical control treatment mechanics that attempt to seat the condyle with treatment (to improve/decrease the vertical CD).

3) Convert the lateral cephalogram, a common plain film taken in orthodontics for skeletal and dental analysis, from the IP/MIC/CO to SCP/CR, thus displaying the actual DAD and maxillo-mandibular relationship present (**Figure 7**).

4) Fabricate splints and tooth positioners.

5) Treatment plan orthognathic surgical cases, in which it is absolutely critical to achieve full condylar seating when repositioning the skeletal elements/segments.

10. Conclusion

The ability to more reliably register the SCP/CR has important ramifications for dental correction. Dental and orthodontic treatment goals can be quantified (mm) with measurable criteria, allowing for more accurate diagnosis, more precise treatment planning, more efficient treatment mechanics, improved treatment

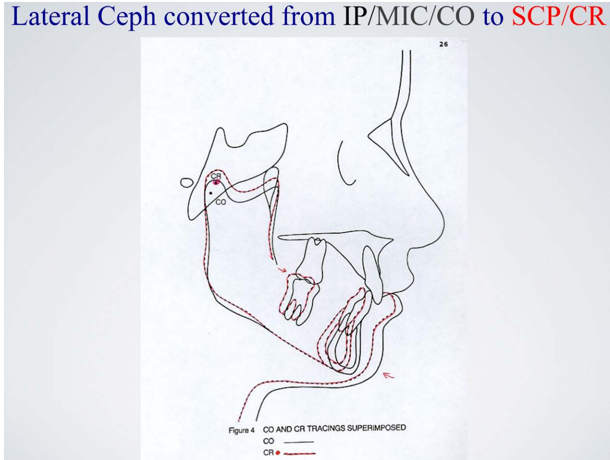

Figure 7. Converting the lateral cephalogram, a common plain film taken in orthodontics for skeletal and dental analysis, from the IP/MIC/CO to the SCP/CR demonstrates the actual DAD and maxillo-mandibular relationship present.

results, more accurate analysis of treatment outcomes, and fewer Stage III treatments (re-treatments, TMD, or maintenance of correction).

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We would like to acknowledge Dr. Robert Wassell and his seminal research article entitled "Do occlusal factors play a part in temporomandibular dysfunction?" J Dent June, 1989: Vol 17: 3, 101-110. This paper is the basis for this subsequent series of papers as we attempt to add to the knowledge base on this subject of paramount importance to the practice of dentistry and orthodontics.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Calagna, L.S., Silverman, S.I. and Garfinkel, L. (1973) Influence of Neuromuscular Conditioning on Centric Registrations. *Journal of Prosthetic Dentistry*, **30**, 598-604.

[2] Ramfjord, S.P. (1961) Bruxism, a Clinical and EMG Study. *The Journal of the American Dental Association*, **62**, 21-44.
https://doi.org/10.14219/jada.archive.1961.0002

[3] Girardot, R.A. (1987) The Nature of Condylar Displacement in Patients with TM Pain-Dysfunction. *Orthod Review*, **1**, 16-23.

[4] Clayton, J.A. (1976) A Pantographic Reproducibility Index (PRI) for Detection of TMJ Dysfunction. *Journal of Dental Research*, **55**, 161.

[5] Beard, C.C. and Clayton, J.A. (1980) Effects of Occlusal Splint Therapy on TMJ Dysfunction. *Journal of Prosthetic Dentistry*, **44**, 324-335.
https://doi.org/10.1016/0022-3913(80)90021-9

[6] Solberg, W.K., Clark, G.T. and Rugh, J.D. (1975) Nocturnal EMG Evaluation of Bruxism Patients Undergoing Short Term Splint Therapy. *Journal of Oral Rehabili-*

tation, **2**, 215-223. https://doi.org/10.1111/j.1365-2842.1975.tb00915.x

[7] Howat, A.P., Capp, N.J. and Barrett, N.V.J. (1991) A Color Atlas of Occlusion and Malocclusion. CV Mosby, St. Louis.

[8] Huffman, R.W. and Regenos, J.W. (1978) Principles of Occlusion. Hand R Press, Columbus.

[9] Slavicek, R.J. (1988) Clinical and Instrumental Functional Analysis for Diagnosis and Treatment Planning, Part IV: Instrumental Analysis of Mandibular Casts Using the Mandibular Position Indicator. *Journal of Clinical Orthodontics*, **22**, 566-575.

[10] Roth, R.H. (1976) The Maintenance System and Occlusal Dynamics. *Dental Clinics of North America*, **20**, 761-788. https://doi.org/10.1016/S0011-8532(22)00917-X

[11] Wahlund, K., List, T. and Larsson, B. (2003) Treatment of Temporomandibular Disorders among Adolescents: A Comparison between Occlusal Appliance, Relaxation Training, and Brief Information. *Acta Odontologica Scandinavica*, **61**, 203-211. https://doi.org/10.1080/00016350310003891

[12] Capp, N.J. and Clayton, J.A. (1985) A Technic for Evaluation of Centric Relation Tooth Contacts: Part II: Following Use of an Occlusal Splint for Treatment of TMJ Dysfunction. *Journal of Prosthetic Dentistry*, **54**, 697-705. https://doi.org/10.1016/0022-3913(85)90254-9

[13] Koveleski, W.C. and DeBoever, J. (1975) Influence of Occlusal Splints on Jaw Position and Musculature in Patients with TMJ Dysfunction. *Journal of Prosthetic Dentistry*, **33**, 321-327. https://doi.org/10.1016/S0022-3913(75)80090-4

[14] Williamson, E.H., Evans, D.L., Barton, W.A. and Williams, B.H. (1977) The Effect of Biteplane Use on Terminal Hinge Axis Location. *The Angle Orthodontist*, **47**, 25-33.

[15] Karl, P.J. and Foley, T.F. (1999) The Use of a Deprogramming Appliance to Obtain Centric Relation Records. *The Angle Orthodontist*, **69**, 117-125.

[16] Dawson, P.E. (1996) A Classification System for Occlusions that Relates Maximal Intercuspation to the Position and Condition of the TM Joints. *JPD*, **75**, 60-68. https://doi.org/10.1016/S0022-3913(96)90419-9

[17] Lundeen, H. (1972) Centric Relation Records—The Effects of Muscle Action. *Journal of Prosthetic Dentistry*, **31**, 244-251. https://doi.org/10.1016/0022-3913(74)90191-7

[18] Lucia, V.O. (1983) Modern Gnathological Concepts-Updated. Quintessence Publishing, Chicago, 39-53.

[19] Throckmorton, G.S., Groshan, G.J. and Boyd, S.B. (1990) Muscle Activity Patterns and Control of TMJ Loads. *Journal of Prosthetic Dentistry*, **63**, 685-695. https://doi.org/10.1016/0022-3913(90)90327-9

[20] Lucia, V.O. (1964) A Technique for Recording Centric Relation. *Journal of Prosthetic Dentistry*, **14**, 492-505. https://doi.org/10.1016/S0022-3913(64)80017-2

[21] Long, J.H. (1973) Locating Centric Relation with a Leaf Gauge. *Journal of Prosthetic Dentistry*, **29**, 608-610. https://doi.org/10.1016/0022-3913(73)90267-9

[22] Kantor, M.E., Silverman, S.I. and Garfinkel, L. (1972) Centric Relation Recording Techniques: Comparative Investigation. *Journal of Prosthetic Dentistry*, **28**, 593-600. https://doi.org/10.1016/0022-3913(72)90107-2

[23] Fenlon, M.R. and Woeffel, J.B. (1993) Condylar Position Recorded Using Leaf Gauges and Specific Closure Forces. *The International Journal of Prosthodontics*, **6**, 402-408.

[24] Greco, P.M. and Vanarsdall, R.L. (1999) An Evaluation of Anterior Temporalis and Masseter Muscle Activity in Appliance Therapy. *The Angle Orthodontist*, **69**, 141-146.

[25] Ash, M.M. (1986) Current Concepts in the Etiology, Diagnosis, and Treatment of TMJ and Muscle Dysfunction. *Journal of Oral Rehabilitation*, **13**, 1-20. https://doi.org/10.1111/j.1365-2842.1986.tb01551.x

[26] Crispin, B.J., Myers, G.E. and Clayton, J.A. (1978) Effect of Occlusal Therapy on Pantographic Reproducibility of Mandibular Border Movements. *Journal of Prosthetic Dentistry*, **40**, 29-34. https://doi.org/10.1016/0022-3913(78)90154-3

[27] Williamson, E.H. and Lundquist, D.O. (1983) Anterior Guidance: Its Effect on EMG Activity of the Temporal and Masseter Muscles. *Journal of Prosthetic Dentistry*, **49**, 816-823. https://doi.org/10.1016/0022-3913(83)90356-6

[28] Wahlund, K. and List, T. (2003) Treatment of TM Disorders among Adolescents: A Comparison between Occlusal Appliance, Relaxation Training, and Brief Information. *Acta Odontologica Scandinavica*, **61**, 203-211. https://doi.org/10.1080/00016350310003891

[29] Okeson, J.P. (1993) Management of TM Disorders and Occlusion. 3rd Edition, CV Mosby, St. Louis, 113, 453-458.

[30] Hannam, A.D., *et al.* (1977) The Relationship between Dental Occlusion, Muscle Activity, and Associated Jaw Movement in Man. *Archives of Oral Biology*, **22**, 25-32. https://doi.org/10.1016/0003-9969(77)90135-2

[31] Pousselt, V. (1968) Physiology of Occlusion and Rehabilitation. 2nd Edition, Blackwell Scientific Publications, Oxford.

[32] Crawford, S.D. (1999) The Relationship between Condylar Axis Position as Determined by the Occlusion and Measured by the CPI Instrument and Signs and Symptoms of TM Joint Dysfunction. *The Angle Orthodontist*, **69**, 103-115.

[33] Hoffman, P.J., Silverman, S.I. and Garfinkel, L. (1973) Comparison of Condylar Position in Centric Relation and in Centric Occlusion in Dentulous Patients. *Journal of Prosthetic Dentistry*, **30**, 582-588.

[34] Rosner, D. (1982) Hinge Axis Translation from Retruded Contact Position to Intercuspal Position in Dentulous Subjects in Treatment. *Journal of Prosthetic Dentistry*, **48**, 713-718. https://doi.org/10.1016/S0022-3913(82)80035-8

[35] Rosner, D. and Goldberg, G.F. (1986) Condylar Retruded Contact Position and Intercuspal Position and Correlation in Dentulous Patients. Part 1: Three Dimensional Analysis of Condylar Registrations. *Journal of Prosthetic Dentistry*, **56**, 230-239. https://doi.org/10.1016/0022-3913(86)90481-6

[36] Girardot, R.A. (2001) Comparison of Condylar Position in Hyperdivergent and Hypodivergent Facial Skeletal Types. *The Angle Orthodontist*, **71**, 240-246.

[37] Wood, D.P., Floreani, K.J., Galil, K.A. and Teteruk, W.R. (1994) The Effect of Incisal Bite Force on Condylar Seating. *The Angle Orthodontist*, **64**, 53-61.

[38] Utt, T.W., Meyers, C.E., Wierzba, T.F. and Hondrum, S.O. (1995) A Three-Dimensional Comparison of Condylar Position Changes between Centric Relation and Centric Occlusion Using the Mandibular Position Indicator. *American Journal of Orthodontics*, **107**, 298-308. https://doi.org/10.1016/S0889-5406(95)70146-X

[39] Esmay, T.R. (1995) The Relationship of Condylar Position Changes between Centric Relation and Maximum Intercuspation in Orthodontic Treated and Non-Orthodontic Treated Individuals. Master's Thesis, New York University, New York.

[40] Hidaka, O., Adachi, S. and Takada, K. (2002) The Difference in Condylar Position

between Centric Relation and Centric Occlusion in Pretreatment Japanese Orthodontic Patients. *The Angle Orthodontist*, **72**, 295-301.

[41] Williamson, E.H. (1978) Laminagraphic Study of Mandibular Condyle Position When Recording Centric Relation. *Journal of Prosthetic Dentistry*, **39**, 561-564. https://doi.org/10.1016/S0022-3913(78)80194-2

[42] Williamson, E.H., Steinke, R.M., Morse, P.K. and Swift, T.R. (1980) Centric Relation: A Comparison of Muscle-Determined Position and Operator Guidance. *American Journal of Orthodontics*, **77**, 133-145. https://doi.org/10.1016/0002-9416(80)90002-0

[43] Alexander, S.R., Moore, R.N. and Dubois, L.M. (1993) Mandibular Condyle Position: Comparison of Articulator Mountings and Magnetic Resonance Imaging. *American Journal of Orthodontics*, **104**, 230-239. https://doi.org/10.1016/S0889-5406(05)81724-X

[44] Cordray, F.E. (2006) Three Dimensional Analysis of Models Articulatd in the Seated Condylar Position from a Deprogrammed Asymptomatic Population: A Prospective Study. Part I. *AJO-DO*, **129**, 619-630. https://doi.org/10.1016/j.ajodo.2004.10.015

[45] Cordray, F.E. (2016) Articulated Dental Cast Analysis of Asymptomatic and Symptomatic Populations. *International Journal of Oral Science*, **8**, 126-132. https://doi.org/10.1038/ijos.2015.44

[46] Clark, G.T. (1984) A Critical Evaluation of Orthopedic Interocclusal Appliance Therapy: Design, Theory, and Overall Effectiveness. *The Journal of the American Dental Association*, **108**, 359-364. https://doi.org/10.14219/jada.archive.1984.0010

[47] Clark, G.T. (1984) A Critical Evaluation of Orthopedic Appliance Therapy: Effectiveness for Specific Symptoms. *The Journal of the American Dental Association*, **108**, 364-368. https://doi.org/10.14219/jada.archive.1984.0002

[48] Greene, C.S. and Laskin, D.M. (1972) Splint Therapy for the MPD Syndrome: A Comparative Study. *The Journal of the American Dental Association*, **84**, 624-628. https://doi.org/10.14219/jada.archive.1972.0090

[49] Okeson, J.P., Kemper, J.T. and Moody, P.M. (1982) A Study of the Use of Occlusal Splints in the Treatment of Acute and Chronic Patients with Craniomandibular Disorders. *Journal of Prosthetic Dentistry*, **48**, 708-712. https://doi.org/10.1016/S0022-3913(82)80034-6

[50] Kemper, J.T. and Okeson, J.P. (1983) Craniomandibular Disorders and Headaches. *Journal of Prosthetic Dentistry*, **49**, 702-705. https://doi.org/10.1016/0022-3913(83)90400-6

[51] Lucia, V.O. (1983) Modern Gnathological Concepts-Updated. Quintessence Publishing, Chicago, 39-53.

[52] Lucia, V.O. (1964) A Technique for Recording Centric Relation. *Journal of Prosthetic Dentistry*, **14**, 492-505. https://doi.org/10.1016/S0022-3913(64)80017-2

[53] Ikeda, K. (2014) TMJ 1st Orthodontics. Topnotch Kikaku Ltd., Tokyo.

[54] Ikeda, K. (2021) Face Design and Orthodontics. Topnotch Kikaku Ltd., Tokyo.

[55] Ramfjord, S.P. and Ash, M.M. (1983) Occlusion. 3rd Edition, WB Saunders, Philadelphia.

[56] Heloe, B. and Heloe, L.A. (1975) Characteristics of a Group of Patients with TM Disorders. *Community Dentistry and Oral Epidemiology*, **3**, 72-79. https://doi.org/10.1111/j.1600-0528.1975.tb00284.x

[57] Shildkraut, M., Wood, D.P. and Hunter, W.S. (1994) The CR-CO Discrepancy and Its Effect on Cephalometric Measurements. *The Angle Orthodontist*, **64**, 333-342.

[58] Ingervall, B. (1972) Tooth Contacts on the Functional and Non-Functional Side in Children and Young Adults. *Archives of Oral Biology*, **17**, 191-200. https://doi.org/10.1016/0003-9969(72)90147-1

[59] Agerberg, G. and Sandstrom, R. (1988) Frequency of Occlusal Interferences: A Clinical Study in Teenagers and Young Adults. *Journal of Prosthetic Dentistry*, **59**, 212-217. https://doi.org/10.1016/0022-3913(88)90017-0

[60] deLaat, A. and Van Steenberghe, D. (1985) Occlusal Relationships and TM Joint Dysfunction Part I: Epidemiological Findings. *Journal of Prosthetic Dentistry*, **54**, 835-842. https://doi.org/10.1016/0022-3913(85)90483-4

[61] Lerman, M.D. (2011) The Muscle Engram: The Reflex That Limits Conventional Occlusal Treatment. *Cranio*, **29**, 297-303. https://doi.org/10.1179/crn.2011.044

[62] Roth, R.H. (1973) TM Pain-Dysfunction and Occlusal Relationships. *The Angle Orthodontist*, **43**, 136-153.

[63] Roth, R.H. (1981) Functional Occlusion for the Orthodontist Part I. *Journal of Clinical Oncology*, **15**, 32-40.

[64] Roth, R.H. (1981) Functional Occlusion for the Orthodontist Part 2. *Journal of Clinical Oncology*, **15**, 100-123.

[65] McMillen, L.B. (1972) Border Movements of the Human Mandible. *Journal of Prosthetic Dentistry*, **27**, 524-532. https://doi.org/10.1016/0022-3913(72)90265-X

[66] Johnston, L.E. and Huffman, R.W. (1988) Gnathologic Assessment of Centric Slides in Post-Retention Orthodontic Patients. *Journal of Prosthetic Dentistry*, **60**, 712-715. https://doi.org/10.1016/0022-3913(88)90405-2

[67] Teo, C.S. and Wise, M.D. (1981) Comparison of Retruded Axis Articular Mountings with and without Applied Muscular Force. *Journal of Oral Rehabilitation*, **8**, 363-376. https://doi.org/10.1111/j.1365-2842.1981.tb00510.x

[68] Roth, R.H. (1995) Point-Counterpoint. *AJO-DO*, **107**, 315-317. https://doi.org/10.1016/S0889-5406(95)90000-4

[69] Weffort, S.Y.K. and Fantini, S.M. (2010) Condylar Displacement between Centric Relation and Maximum Intercuspation in Symptomatic and Asymptomatic Individuals. *The Angle Orthodontist*, **80**, 835-842. https://doi.org/10.2319/090909-510.1

[70] He, S.S., Deng, X., Wamalwa, P. and Chen, S. (2010) Correlation between Centric Relation-Maximum Intercuspation Discrepancy and Temporomandibular Joint Dysfunction. *Acta Odontologica Scandinavica*, **68**, 368-376. https://doi.org/10.3109/00016357.2010.517552

[71] Padala, S., Padmanabhan, S. and Chithranjan, A.B. (2012) Comparative Evaluation of Condylar Position in Symptomatic (TMJ Dysfunction) and Asymptomatic Individuals. *Indian Journal of Dental Research*, **23**, 122-127. https://doi.org/10.4103/0970-9290.99060

[72] Ikeda, K. and Kawamura, A. (2011) Assessment of Optimal Condylar Position with Limited Cone-Beam Computerized Tomography. *Journal of Prosthodontics*, **20**, 432-438. https://doi.org/10.1111/j.1532-849X.2011.00730.x

[73] Ikeda, K. and Kawamura, A. (2009) Assessment of Optimal Condylar Position with Limited Cone-Beam Computerized Tomography. *AJO-DO*, **135**, 495-501. https://doi.org/10.1016/j.ajodo.2007.05.021