Reproducibility of the centric relation bite registration technique

David P. Wood, DDS, MCID; Robert W. Elliott, DDS, MCID

The difference between centric relation (CR) and maximum intercuspation (MI) is commonly referred to as the "centric slide".[1] Orthodontists have traditionally paid little attention to CR and have used a bite registration coincident with maximum intercuspation to hand articulate unmounted casts. Today, however, many orthodontists are using casts mounted in CR on a semi-adjustable articulator as an important starting point for diagnosis.[2,3,4] This is because casts mounted in CR can reveal a completely different malocclusion than the same case viewed in MI.

A great deal of controversy exists regarding the concept of CR. Early gnathologists[5,6,7] used an acronym "RUM" for rearmost, uppermost and midmost, to describe the condyle's position when in CR. Over the years, rearmost position was inappropriately emphasized and led to a great deal of confusion. Dawson[8] has pointed out that 'rearmost' and 'uppermost' are misleading because the two positions are not compatible. He noted that the condyles are not in their rearmost position when they are in the uppermost position and vice versa.

Present knowledge strongly indicates that CR is

Abstract

Many orthodontists today are using diagnostic casts mounted in centric relation (CR) because they can reveal a completely different malocclusion than what is seen in maximum intercuspation (MI). The CR to MI slide can be measured at the condyles using a semi-adjustable articulator and a condylar position indicator device (CPI). However, before planning treatment from casts mounted in CR, the reliability of the method must be established. Therefore, the purposes of this investigation were: i) to determine the reproducibility, measured with the CPI, of the two-piece wax CR bite registration technique as described by Roth; ii) to determine the direction of the centric slide; iii) to determine differences in overjet measured from CR and MI and; iv) to evaluate the location of the initial tooth contacts in CR.

The condylar displacements for 39 subjects were measured in vertical and horizontal components from mounted models. A CR bite registration was taken five times (approximately every five days) and used to remount the lower cast and record the data five times.

Since there was not a significant difference between the five CPI readings ($p>.05$), the Roth CR bite registration is highly reproducible. The condyle moved inferiorly with a small distal component from CR to MI. A statistically significant difference ($p<.001$) was found in the overjet measurements between CR and MI. Thirty six out of 39 subjects had an initial tooth contact in CR on the most posterior tooth.

Key Words

Centric relation • Bite registration • Condylar displacement • Articulator

Submitted: May 1993 **Revised and accepted for publication:** August 1993 Angle Orthod 1994;64(3):211-221.

Table I
Error Study
Standard errors for each component of the CPI (in mm, n=39)

Component	Standard Error*	Limits of Error**
Δx	.39	± .76
Δz	.47	± .92

$$*S.E. = \sqrt{M.S.}$$

where M.S. = within subjects variance from 2 way ANOVA

** Limits of error = ± 1.96 X S.E.; (95% confidence level)

Table II
Reliability study
Interclass correlation coefficients* for each component of the CPI

Component	r_i
Δx	.73
Δz	.79

$$*r_i = \frac{s_b^2 - s_w^2}{s_b^2 + (n-1)s_w^2}$$

where s_b^2 = between subject variance
s_w^2 = within subject variance
n = number of values within a "set"

the most superior anterior position of the condyles against the posterior slope of the eminentia.[8-11] Moffett argued that this position is physiologically desirable and is an acceptable reference position for treatment.[12]

From an anatomical standpoint the condyle cannot move forward or backward from centric relation without moving downward, therefore any "centric slide" results in a downward displacement of the condyles. Most often there is also a distal component with the downward displacement of the condyle as the mandible fulcrums over the most posterior tooth and rotates the body of the mandible forward into MI. Such occlusal interferences are avoided by proprioceptive reflexes which guide the mandible repeatedly into maximum intercuspation and in the process distract the condyles downward and backward in posturing the mandible forward.

A variety of different clinical techniques are currently in use to obtain centric jaw relation records. They all involve some type of chairside manipulation of the mandible followed by placement of a medium (wax or cement) to capture cusp tip indexing from which to mount models. One of the most commonly used techniques is the 'one-handed push back technique' which comes from the aforementioned erroneous interpretation of CR as being the most retruded mandibular position. Such a technique consistently produces a downward and backward displacement of the condyles rather than seating them anteriorly and superiorly.

There are, however, several clinical techniques used to emphasize superior positioning of the condyle. The anterior jig advocated by Lucia[13] and the leaf gauge advocated by Long[14] are examples of anterior stops. If the anterior jig or leaf gauge are used improperly they too can drive the condyle distally. Use of an anterior stop separates the posterior teeth thereby allowing neuromuscular deprogramming and eliminating possible tooth interferences that would otherwise guide the mandible into maximum intercuspation. This has been referred to by Woelfel as a neuromuscular guided CR relationship.[15]

The chin-point guidance technique for superior positioning was first described by McCollum[16] and involves keeping the posterior teeth separated by downward chin-point pressure. It is believed this allows the elevator muscles to seat the condyles into CR. The McCollum method does not provide the level of verification that can be achieved by newer techniques.[4]

The method of bilateral manipulation[8] employs a specific superior guidance to the mandible at the same time the operator applies downward pressure with the thumbs attempting to seat the condyles in the most superior position. This method has been shown to have the most consistent reproducibility.[17,18] Bilateral manipulation methods require a combination of delicacy and timing when manipulating the mandible so that muscles that protrude the mandible are not triggered to contract by applying pressure at the wrong time or in the wrong direction.[8] It is

Table III
Reliability of laboratory technique
Standard errors of double measurement* for two separate CPI readings on the same set of mounted casts (in mm, n=39)

Component	Error
Δx	.27
Δz	.30

$$*S.E. = \sqrt{\frac{\sum d^2}{2n}}$$

therefore technique-sensitive.

The power centric registration, using a two-piece wax bite, is a technique advocated by Roth.[4] It incorporates the benefits of both mandibular manipulation and an anterior stop to register the most superior anterior position of the condyles. The anterior stop is fabricated in wax using a downward chin-point guidance with upward pressure at gonion to position the patient's condyles superiorly and anteriorly. The hardened anterior stop, once verified, is then used along with a softened posterior piece of wax to seat the condyles in the most superior position using the patient's own musculature. Lundeen[19] found that heavy muscular contraction by a patient with a rigid anterior stop seated the condyle in the most superior position when compared to two other methods.

The validity of information derived from the examination of casts mounted in a position believed to be CR on a semi-adjustable articulator depends upon both the precision in recording and the reproducibility of CR. The purposes of the study were: 1) to evaluate the reproducibility of the power centric registration as described by Roth; 2) to determine the direction of the centric slide; 3) to determine if there was a statistical significant difference in overjet between CR and MI; 4) to determine the sites of initial tooth contacts in CR.

Materials and methods

Subjects

Thirty-nine undergraduate dental students volunteered for the study and ethics approval was obtained. All participants were screened for any overt temporomandibular joint (TMJ) dysfunction through the completion of a questionnaire and a clinical examination of the TMJ.

Procedure

Maxillary and mandibular impressions were made using an irreversible hydrocolloid material (Type I - Fast set Alginate, Meer Dental Corp., Canton, MI.) in nonperforated rimlock stock trays. A maximum intercuspation (MI) bite registration was taken with two thicknesses of pink dental wax (10X wax, Moyco Industries Inc., Philadelphia, PA). Participants were instructed to bite completely through the warm water-softened wax into maximum intercuspation position.

A centric relation (CR) bite registration was then taken by the method described in Appendix I. This method is a repeatable "hands off" technique that allows the subject's own musculature to "seat the condyles". It is a slight modification of the Roth technique which advocates some mandibular manipulation. The "hands off" technique was employed to eliminate experimental bias. The entire procedure was repeated approximately every five days until five sets of CR bite registrations were collected. One operator performed all the CR bite registrations.

The maxillary and mandibular alginate impressions were poured up immediately using type IV high-strength dental stone (Vel-Mix, Kerr Manufacturing Co., Romulus, MI). Separation proceeded within one hour after initial set of the stone. The casts were inspected for detail and if any unwanted artifacts occurred on the teeth, the impression was retaken. The casts were trimmed for accuracy of mounting. Both sections of the CR bite registration were carefully trimmed with a scalpel blade so that only indentations for the cusp tips and incisal edges remained.

One Panadent articulator (Panadent Corporation, Grand Terrace, CA) was used for all mountings. The maxillary cast was mounted using the ear face-bow transfer provided to locate the estimated hinge axis. The face-bow was oriented on a line parallel to Frankfort horizontal plane by employing soft tissue nasion as the anterior reference point. All casts were mounted on the articulator using fast-set mounting stone (Snow White Plaster #2, Kerr Manufacturing Co., Romulus, MI).

The mandibular cast was remounted on the articulator five times for each subject; one for each

centric relation bite registration obtained. After each mounting, initial tooth contact in CR was marked on the mandibular cast with colored articulating paper (GHM Occlusion Test Foil, Hanel - GHM, Nurtingen, Germany) and overjets were measured with a Boley gauge in CR and MI. The same Boley gauge was used for all measurements.

For each of the subject's five mountings, centric slides were assessed in the sagittal plane at the articulator condyles using a condylar position indicator (CPI) (Panadent Corporation, Grand Terrace, CA). This device can measure the three-dimensional changes in the position of the articulator condyles between centric relation and maximum intercuspation. Only the sagittal plane was examined for this study. The horizontal and vertical changes in the sagittal plane at each articulator condyle correspond to the x and z changes respectively on the adhesive grids affixed to the sliding blocks on the CPI.

The x and z values at the left and right condylar mechanism were marked with articulator paper and then averaged to give Δx and Δz for each CPI taken. Δx and Δz values were recorded in multiples of 0.25 mm.

The five CPI readings obtained for each subject were analyzed by a two-factor analysis of variance (ANOVA). Overjet differences in CR and MI were compared by way of a paired t-test.

Reliability of laboratory technique

The first CR wax record obtained for each patient was mounted twice and CPI values for both mountings were obtained. The CPI values derived from the two mountings were compared by standard errors of double measurement. The standard error of double measurement was calculated according to the formula:

$$*S.E. = \sqrt{\frac{\sum d^2}{2n}}$$

where $\sum d^2$ is the sum of the squared differences between the two mountings, and n is the number of subjects.

Results

The reproducibility of the CR bite registration

The CPI readings taken for each subject are listed in Appendix II. A two-way analysis of variance was used for each component of the CPI, i.e., Δx and Δz. There was no statistical significance found for either of the components of the CPI for each of the five CR records obtained. ($p>.05$; $F_{4,38} = 1.62$ for horizontal direction and $F_{4,38} = 0.46$ for the vertical direction.

The mean of Δx and Δz of the five CR records for each patient is the best estimate of the true value and the deviations around the mean value define the error. The error for each component of the CPI are listed in Table I along with the likely limits of error.

A measure of the reliability using an interclass correlation coefficient (r_i) was determined for each component of the CPI and is listed in Table II (r_i = 0.73 and 0.79 for Δx and Δz respectively).

The direction of the "centric slide"

In over 90% of the 195 CPI readings obtained, the MI position of the articulator condyle was inferior to the CR position. In 177 out of 195 situations the condylar displacements were in a posterior-inferior (63%), anterior-inferior (20%), or straight inferior direction (8%). In 18 out of 195 situations the Δz of the condyles was negative denoting MI superior to CR. These 18 were scattered throughout the sample.

Overjet differences

Appendix III lists the different overjet readings in CR and MI for all 39 subjects. To test for statistical significance in overjet differences between CR and MI, a t-test was used. A statistically significant difference was found between overjet in CR and MI, ($p<0.001$, $t=9.97$,38 df). In 34 subjects overjets were larger in CR as compared to MI. In only four subjects were overjets the same in CR and MI. One subject had a smaller overjet in CR but exhibited a skeletal Class III occlusion, i.e., the overjet in CR was 0 mm and -1.1 mm in CO.

Site of first contact in CR

Examination of each subject's casts marked for initial contact in CR revealrd that in 36 out of 39 subjects there was an initial contact on the most posterior tooth.

Reliability of laboratory technique

An error study was performed using standard error of double measurement. Table III lists the standard errors for both components of the CPI. The values are 0.27 for Δx and 0.30 for Δz.

Discussion

Reproducibility of the CR bite registration

The analysis of variance showed no significant difference, at the 5% level, in the CPI values associated with five centric relation records obtained for each subject. The CR registration technique used in this study is a highly reliable method of recording centric relation. However, the CPI did not show the CR-MI difference for all five CR records as a pin point position. Rather, the CPI values obtained for each subject defines a small range of mandibular positions. Considering the error in mounting (0.27 mm to 0.30 mm) the dimensions of this range may be considered to be quite small. It is interesting to note that Wood and

Korne[20] found a similar error using slightly different instrumentation. For each subject, the average Δx and average Δz values corresponding to anterior-posterior and superior-inferior position of the condyles can be considered as a cluster of five markings on an adhesive grid. The tighter the cluster the more reproducible CR was for that subject. Precise or point centric[21] was not demonstrated for any of the subjects and this may be attributable to: 1) error in placing the grid paper precisely on the crosshairs on the sliding blocks, 2) inability of the MI wax to hold the models firmly in a reproducible position, 3) error in remounting the casts, 4) undetected TMJ dysfunction in the subject.

In patients with signs and symptoms of TMJ dysfunction a mandibular repositioning splint is recommended for up to 6 months prior to determining CR position.[9,22] The splint, it is believed, normalizes the neuromuscular pattern by deprogramming muscle splinting which allows for manipulation of the mandible on the retruded arc of closure.[22,23] Ideally in the present study it would have been better if all subjects had worn a mandibular repositioning splint for up to 6 months prior to obtaining CR records. We might expect the "cluster" of points for condylar position to be closer together if not superimposed on each other following splint therapy. In the future it would be of benefit to compare CR reproducibility in healthy individuals stabilized on a centric splint and exhibiting no overt TMJ dysfunction.

The direction of the "centric slide"

In 177 out of 195 CPI readings recorded, when the teeth were in MI the condyles were inferior to their position in CR. Our results are in agreement with Roth[4] and Dawson.[8] The method described seems to promote capturing of CR in a more superior position to MI since this was the case over 90% of the time. Along with the condyles displaced inferiorly when the teeth were in MI, the majority of the sample had a distal component as well. However, the magnitude of the vertical component was much greater than the horizontal component in the majority of cases.

Eighteen CPI recordings out of 195 showed the CR position to be inferior to MI. Therefore 18 centric relation bite registrations were incorrect. Either there was an error in the technique or sufficient muscle splinting occurred on these adult subjects that day to not allow condylar seating. The 18 incorrect CR bite recordings were scattered throughout the sample with no more than two to a subject.

Initial tooth contact in CR

In most situations the site of a subject's initial contact in CR was the same for each wax registration obtained. The markings of initial contacts recorded with colored articulating paper were superimposed on the casts so that differentiation was almost impossible under a tool maker's microscope with x30 magnification. For 36 out of 39 subjects, the site of initial contact was on the most posterior tooth. When it was not, it was because a molar more anterior was extruded or the most posterior tooth was tipped in such a fashion that initial contact in CR occurred on the first tooth anterior to it.

Nine subjects had variability in the site of initial contact in CR. In a few situations, the initial contact was on the most posterior tooth but alternated between right and left or both sides when the subject's five CR mountings were compared. In fewer situations still, markings on the casts in CR showed other initial contacts which ranged from premolars to molars. Seven of the nine subjects who had variability in the site of initial contact had a CPI recording of CR inferior to MI. According to Roth[4] and Dawson[8] CR was therefore recorded erroneously inferior to MI and explains why site of initial contact showed variability in these subjects. In one case a significant Class III skeletal pattern existed and initial contacts were the same for all mountings, that being between tooth numbers 12 and 42.

It has historically been considered[1] that the centric slide is an anterior shift of the condyles from CR to MI because in the mouth the mandibular teeth shift forward. The most prevalent type of centric slide observed in this investigation is a posterior and inferior shift of the condyles from CR to MI and supports the findings of Wood and Korne.[20] If the condyle is moving down and back then how can the mandibular teeth shift forward? Since the initial tooth contact is on the most posterior tooth the concept of a molar "fulcrum" as outlined by Roth[24] explains this. To understand the concept of molar fulcrum, imagine the condyles as being seated comfortably in CR. Now if there exists an occlusal prematurity on a posterior tooth, as was found in this study, the effects will produce one of two conditions. First, the condyles may remain seated in CR with occlusal contact only on the prematurity revealing a lateral and anterior open bite. Secondly, the condyle may be distracted inferiorly and posteriorly in the glenoid fossa to allow maximum intercuspation whereby the interfering tooth acts as a fulcrum and the mandibular teeth shift forward as is seen in the mouth clinically. The larger this molar fulcrum

the greater the condyle distraction from CR to MI. Obviously, for functional reasons, the molar fulcrum will prevail to obtain MI. However, a lateral and anterior open bite often occurs when patients have been stabilized on a mandibular repositioning splint.[9] The molar fulcrum is present but the splint normalizes muscles and ligaments such that finding maximum intercuspation becomes difficult.[9]

The orthodontist will not be aware of the presence of a molar fulcrum unless he or she is using mounted diagnostic casts. Traditional mechanics (cervical headgear and Class II elastics) that cause extrusion of molars will make the fulcrum worse. A greater condylar distraction from CR to MI will then occur. When the patient's musculature will not allow the condyles to distract enough to achieve MI, the condyles often seat. The authors believe this explains why clinicians often report an unexplained open bite, an increased overjet and possibly TMJ symptoms occurring a few months into treatment in some patients.

Overjet differences

In one case, overjet was larger in MI than in CR. This was expected as the patient had a significant Class III malocclusion associated with a prognathic mandible. For the remainder of subjects, CR-MI differences in overjets ranged from 0 (no difference) to 2.3 mm. Only three subjects had an overjet change of 2.0 mm or greater between CR and MI. The authors expected much greater differences, similar to what they have observed with mounting casts from several hundred adolescent patients. Although the overall differences were statistically significant the results found in this study appear not to be clinically significant. This, however, must be put in perspective. The sample consisted of adults, none of whom had been stabilized on a mandibular repositioning splint. Also, only six subjects had an overjet of 5 mm or greater suggesting the majority of the sample had a skeletal Class I relationship.

Even though the increase in overjets do not appear to be clinically significant, casts mounted in CR are different from those seen in MI and this serves to elucidate a very important point about using CR as a starting point for treatment. Many orthodontists are finding that a treatment plan derived from hand articulated casts will likely be quite different from one derived from casts mounted on an articular in centric relation.

Conclusions

1. The bite registration technique as described by Roth and used in this study is a reproducible method of obtaining centric relation.
2. The most prevalent type of centric slide results in a posterior and inferior distraction of the condyle from its position in centric relation to maximum intercuspation.
3. The increase in overjet from maximum intercuspation to centric relation was statistically significant.
4. Initial contacts in centric relation predominate on the most posterior tooth.

Author Address

Dr. David P. Wood
Chairman, Graduate Orthodontics
Faculty of Dentistry
University of Western Ontario
London, Ontario, Canada N6A 5C1

D.P. Wood is Chairman of the Division of Graduate Orthodontics, Faculty of Dentistry, University of Western Ontario, London, Ontario, Canada.

R.W. Elliott is in private practice in Prince George, British Columbia, Canada.

References

1. Hoffman PJ, Silverman SI, Garfinkel L. Comparison of condylar position in centric relation and in centric occlusion in dentulous subjects. J Prosthet Dent 1973; 30:582-588.
2. Slavicek R. J.C.O. Interviews - on clinical and instrumental functional analysis for diagnosis and treatment planning. Part I, J Clin Orthod 1988; 22:358-370.
3. Williamson EH. Occlusal concepts in orthodontic diagnosis and treatment. In Johnston L.I. ed. New Vistas in Orthodontics. Philadelphia: Lea and Febiger, 122-147, 1985.
4. Roth RH. Functional occlusion for the orthodontist. Part 1. J Clin Orthod 1981; 15(1):32-51.
5. McCollum BB. Fundamentals involved in prescribing restorative dentals remedies. Dental Items of Interest 1939, Vol 61, pages 522, 724, 852.
6. Stuart CE Articulations of Human teeth. Dental items of interest 1939, Vol 61, 1029.
7. Posselt V. Physiology of Occlusion and Rehabilitation, ed.2. Oxford Blackwell, 1968.
8. Dawson PE. Evaluation, diagnosis, and treatment of occlusal problems. St. Louis: C.V. Mosby, 28-55, 1989.
9. Roth RH, Rolfs DA. Functional occlusion for the orthodontist. Part II. J Clin Orthod 1981; 15(2): 100-123.
10. Williamson EH. Occlusion and TMJ Dysfunction. J Clin Orthod 1981; 15(3):333-410.
11. Celenza FV, Nasedkin JN. Occlusion, the state of the art. Quintessence Publishing Co., Inc. Chicago, 31-46, 1978.
12. Moffett B. A biologic consideration of centric relation based on skeletal and connective tissue responses. in:Occlusion, a state of the Art. Celenza, F.V. & Nasedkin, J.N. eds. Quintessence Publishing Co., Inc. Chicago, 13-18, 1978.
13. Lucia VO. A technique for recording centric relation. J Prosthet Dent 1964; 14:492-505.
14. Long JH. Locating centric relation with a leaf gauge. J Prosthet Dent 1973; 29:608-610.
15. Woelfel JB. Sliding and guiding the mandible into the retruded arc without pushing. Compendium, 1991; 12(9), 614-623.
16. McCollum BB. Function-factors that make mouth and teeth a vital organ. J Am Dent Assoc 1927; 14:1261-1271.
17. Kantor ME, Silverman SI, Garfinkel L. Centric relation recording techniques - A comparative investigation. J Prosthet Dent 1972; 28:593-600.
18. Hobo S, Iwata T. Reproducibility of mandibular centricity in three dimensions. J Prosthet Dent 1985; 53:649-654.
19. Lundeen HC. Centric relation records: The effect of muscle action. J Prosthet Dent 1974; 31(3):245-251.
20. Wood DP, Korne PH. Estimated and true hinge axis: a comparison of condylar displacements. Angle Orthod 1992; 62:167-175.
21. Celenza FV. The centric position - Replacement and character. J Prosthet Dent 1973; 30:591-598.
22. Williamson EH, Evans DL, Barton WA, Williams BH. The effect of the bite plane used on terminal hinge axis location. Angle Orthod 1977; 47:25-33.
23. Roth RH. Temporomandibular pain-dysfunction and occlusal relationships. Angle Orthod 1973; 43:136-153.
24. Roth, R.H. Functional occlusion for the orthodontist. Part III. J Clin Orthod 1981; 15(3):174-198.

Appendix I
The Roth Power Centric Technique

This bite registration is taken on the asymptomatic patient and/or the unresolved temporomandibular dysfunction patient as the best centric relation obtainable at the time. Because the patient may be unresolved and/or not deprogrammed from his or her occlusion, the power centric relation record is taken with anterior resistance. This resistance generates muscular activity to aid in seating the condyles.

The wax bite is taken with Delar Bite Registration Wax (Delar Corp., Lake Oswego, OR) and is made in two sections. The anterior section is made by folding the softened wax over to form four layers. The anterior posterior dimension is dictated by the overjet and the width should include both the upper and lower anterior teeth. The posterior section is two layers thick. The anterior posterior dimension is trimmed wide enough to include the first molar and second bicuspid teeth and does not extend too far buccally to be distorted by the cheeks.

Procedure

1. The patient should be reclined at a 45 degree angle to the floor.
2. Soften the anterior section of wax in a water bath at 135 degrees Fahrenheit then place and hold it against the maxillary anterior teeth. Instruct the patient to retrude his or her mandible as far back posteriorly as possible and to close until a space between 2 to 3 mm can be seen between the posterior teeth. Allow the patient to practice prior to placing the wax in the mouth. Then instruct the patient to close in this way into the anterior portion of the wax.
3. Remove the anterior wax when it has hardened sufficiently to allow removal without distortion and place it in ice water to further chill and harden it.
4. Heat the posterior section in the water bath until it is "dead soft". Now place the posterior section on the upper teeth and support it with your fingers on the buccal surfaces. While holding the posterior section in place, replace the chilled anterior section on the upper teeth. This can be supported with the same hand that is holding the posterior section.
5. Instruct the patient to index into the hard anterior bite registration holding his/her jaws together. Instruct the patient to "close firmly and hold it". This firm "closing" pressure will seat the condyles superiorly while the anterior wax stop will prevent deviation from CR. Remove the wax sections when they have hardened sufficiently to avoid distortion.
6. Trim the wax record with a scalpel blade to reveal only cusp tip indexing.

Appendix II
CPI Values for each subject

Subject	1st		2nd		3rd		4th		5th	
	ΔX	ΔZ	ΔX	ΔZ	ΔX	ΔZ	ΔX	ΔZ	ΔX	ΔZ
1	-0.3	1.0	0.3	0.4	0.8	-0.4	0.4	0.5	0.0	0.8
2	0.0	0.8	0.1	0.6	-0.5	0.4	-0.8	0.8	0.3	0.0
3	1.0	2.0	0.3	3.3	0.5	2.8	0.8	1.8	0.8	2.3
4	0.3	0.5	0.0	1.0	-0.4	1.8	0.3	0.8	0.5	0.3
5	-0.1	1.1	-0.8	1.5	-0.8	1.3	-0.9	1.5	-1.1	1.6
6	-0.3	1.1	1.0	1.0	-0.3	1.1	-0.3	1.1	-0.5	1.6
7	0.4	0.3	0.4	0.3	0.5	0.4	0.3	0.8	-0.3	1.1
8	-0.4	0.6	-0.1	1.6	-1.0	1.8	-1.1	1.9	-0.6	1.1
9	0.0	0.0	0.0	0.1	-0.1	0.4	-0.3	0.3	-0.5	0.5
10	-0.4	1.0	-1.1	1.3	-1.6	2.5	-1.2	1.5	-1.4	1.9
11	0.3	1.5	0.0	0.8	0.0	1.3	-0.5	1.9	-0.8	1.8
12	0.0	2.0	-0.3	1.5	-0.1	2.3	0.9	1.3	1.0	1.0
13	-0.8	1.5	-0.4	0.9	-0.5	1.0	-0.5	1.3	-0.5	1.1
14	-0.8	2.8	-1.0	2.4	-1.1	1.4	-1.3	1.3	-1.1	1.1
15	-0.4	3.9	-0.9	3.9	-0.8	4.0	-1.0	4.3	-1.1	4.0
16	-1.1	2.5	-0.9	2.5	-1.3	2.5	-1.1	2.8	-0.8	2.6
17	-0.8	1.5	-1.1	1.6	-0.8	1.5	-1.0	1.5	-1.0	1.5
18	0.5	-0.3	-0.5	0.5	0.0	0.3	0.5	0.0	0.1	0.0
19	0.4	1.0	0.0	1.4	0.0	1.8	-0.3	1.5	-0.8	2.4
20	0.5	-0.3	0.0	0.3	0.3	0.0	0.5	0.0	-0.3	0.4
21	1.0	-0.4	0.8	-0.4	1.6	-1.6	0.0	0.3	1.0	-0.4
22	0.6	0.1	1.4	-1.2	-0.5	1.0	-0.2	0.9	-0.4	1.0
23	0.0	0.8	-0.3	0.6	-0.3	0.6	-0.6	1.3	0.5	-0.3
24	-1.8	2.0	-1.0	1.8	-1.0	1.8	-1.0	1.5	-0.8	1.4
25	0.9	-0.4	0.8	0.5	1.6	-0.3	0.9	1.2	1.2	0.3
26	-0.4	1.1	-0.6	1.4	-1.0	1.8	-0.1	1.0	-0.3	1.0
27	0.5	-0.3	-0.8	0.8	0.0	0.8	-0.8	0.8	-0.8	0.8
28	0.5	0.0	1.0	-1.0	0.5	-0.5	1.0	-0.5	0.6	0.3
29	-1.3	2.5	-1.1	2.4	-1.3	1.8	-1.1	2.1	-1.5	2.3
30	-1.6	2.6	-1.0	1.6	-0.9	1.5	-0.6	1.4	-0.8	1.5
31	-1.5	2.5	-0.9	2.3	-0.8	2.1	-1.5	2.6	-1.5	2.6
32	-0.1	2.0	0.1	1.8	-0.8	2.4	-0.5	1.9	-0.3	2.0
33	1.0	0.0	0.9	0.3	1.8	-1.1	1.4	-0.4	0.9	0.1
34	-0.8	1.5	-1.3	1.6	-1.0	1.4	-0.4	0.5	-0.6	1.0
35	-1.0	2.8	-0.5	2.0	-1.3	2.8	-1.8	3.3	0.5	2.3
36	0.5	-0.5	-0.3	1.0	0.3	0.5	0.0	0.8	0.5	0.1
37	0.4	1.1	-0.4	1.9	-0.4	2.1	-0.1	1.5	-0.9	1.5
38	-0.3	1.4	-0.1	0.6	-0.3	1.1	-0.3	1.0	0.1	0.5
39	-0.4	1.3	-0.3	0.9	-0.9	1.8	-0.9	1.5	-0.8	1.4

Key: Δx = horizontal change
Δz = vertical change

For Δx: a '+' value means the MI position of the condyles is anterior to the CR position
a '-' value means the MI position of the condyles is posterior to the CR position

For Δz: a '+' value means the MI position of the condyles is inferior to the CR position
a '-' value means the MI position of the condyles is superior to the CR position

Appendix III
Overjets of subjects taken in CR and MI

Subject	Overjet in millimeters In CR	In MI
1	4.0	3.0
2	3.8	2.7
3	6.7	5.1
4	4.2	3.7
5	4.9	4.1
6	4.1	1.9
7	5.5	4.5
8	4.2	3.2
9	1.0	1.0
10	6.4	5.2
11	0	-1.1
12	8.4	6.1
13	3.3	2.1
14	4.0	4.0
15	6.2	4.2
16	7.1	5.3
17	2.6	2.6
18	4.0	3.5
19	4.5	2.6
20	2.0	1.9
21	6.5	6.1
22	3.4	3.4
23	6.9	5.9
24	2.7	2.3
25	5.0	4.4
26	3.2	2.8
27	4.3	3.4
28	3.6	3.1
29	2.7	1.5
30	4.8	3.6
31	6.4	5.3
32	4.3	2.7
33	3.9	3.2
34	4.2	2.8
35	4.8	3.0
36	4.9	3.2
37	4.6	3.5
38	4.4	3.7
39	4.2	2.8