*Eur. J. Prosthodont. Rest. Dent.,* Vol.14, No. 1, pp 32-37
Printed in Great Britain


# Variability Of Centric Relation Position In TMD Patients

A.J.J. Zonnenberg* and J. Mulder†

**Abstract -** *Reproducibility of the centric relation position for patients with temporomandibular disorders (TMD) is not documented in the current literature. It was the objective of this study to assess clinical variability of the centric relation position for TMD patients with a muscle-determined technique by means of an anterior deprogramming device, the leaf gauge. A sample of 60 patients with signs of TMD was selected, 8 men (Mean age 28,6, SD 5,2) and 52 women (Mean age 30,5, SD 10,1). All patients were examined with the Research Diagnostic Criteria, including pain on movement and/or function, mouth opening, joint sounds and palpation of masticatory muscles. All 60 patients were allocated to one of the following diagnostic subgroups: myofascial pain, disk displacement with reduction, disk displacement without reduction, osteoarthritis, trauma. Twelve control subjects were taken from a previous study. Three sequential centric relation records were taken; the first one was used to mount a set of casts to an articulator. Criteria of precision were formulated beforehand: 2 out of 3 centric relation records had to be identical in a split-cast procedure. Variables XL and XR represented mandibular displacement in the sagittal plane, variables YL and YR in the transversal plane, and ZL and ZR in the vertical plane, on the left and right condylar level respectively. Variables XMIN, YMIN and ZMIN represented the minimal sagittal, transversal and vertical displacement left or right respectively. Likewise, variables XMAX, YMAX and ZMAX represented the maximal sagittal, transversal and vertical displacement left or right. XDIFF, YDIFF and ZDIFF represented the difference between the minimal and maximal values of X, Y and Z. The diagnostic subgroup trauma was excluded, because there was only one patient. The null-hypothesis of no between-group differences in within-subject and total variability was tested with an analysis of variance (ANOVA). The level of significance was set at 0.05. To minimize type I errors caused by multiple testing Scheffe's test was used to maintain an overall significance of 0.05. No significant difference between patients and control subjects could be found for variables XL, XR, YL, YR, ZR and ZL. Variables XMIN, YMIN, ZMIN, XMAX, YMAX, ZMAX, XDIFF, YDIFF and ZDIFF showed no significant differences. Scheffe's testing for the variables XL, XR, YL, YR, ZL and ZR, as well as the variables XMIN, YMIN, ZMIN, XMAX, YMAX, ZMAX, XDIFF, YDIFF and ZDIFF showed no significant differences. The results of this study suggest no variability in centric relation position between TMD-patients and control subjects by means of the leaf gauge.*

KEY WORDS: Centric Relation, TMD, Lea/gauge

## INTRODUCTION

"Centric relation is the maxillomandibular relationship in which the condyles articulate with the thinnest avascular portion of their respective disks with the complex in the anterior-superior position against the shapes of the articular eminencies. This position is independent of tooth contact. This position is clinically discernible when the mandible is directed superiorly and anteriorly. It is restricted to a purely rotary movement about a transverse horizontal axis " [1]. As this centric relation position presumably will be reached under strained muscular conditions, a purely rotary movement seems impossible. After all, centric relation as such cannot be assigned any movement. It simply denotes the condylar position with respect to the fossa, if the jaw is manipulated into this position or the elevator muscles stabilize the mandible into this position. Only if manipulated by an examiner into centric relation position, it is theoretically conceivable that any other movement than pure rotation may be prevented. Even this rotation seems questionable [2].

Centric relation is the mandibular position in which the condyles are in their most superoanterior position in the articular fossae against the articular eminencies and when their respective articular disks are properly interposed. Heavy elevator muscle action will stabilize the joint orthopedically. This is why the centric relation position is a musculoskeletal position that is considered to be a stable orthopedic position [3-5].

Centric relation is a maxillomandibular relationship, which is the basic reference position to evaluate occlusion and the treatment position for any comprehensive dental work, including occlusal, orthodontic, restorative, and orthognathic modalities [6-8]. In general a centric relation record is used to mount a set of casts to an articulator for diagnostic and treatment purposes.

Centric relation is also considered to be important in TMD-patients to clinically examine occlusion and to clinically finish a maxillary stabilization splint [4]. Several techniques to determine this centric relation position have been

* D.D.S
† Ing

proposed: some operator guided [3, 6-8], others muscle-determined [3, 4, 9-14] .

Bimanual manipulation is an effective operator guided technique to direct both condyles into centric relation position. However, if pain is produced in achieving centric relation, it is likely that an intracapsular disorder exists and the accurate reproducibility, and consequently, the stability of the centric relation position must be questioned [8] . Reproducibility of bimanual manipulation in healthy control subjects has been tested and established satisfactory within a 0.11 mm tolerance [6,12] . Compared to a maximum intercuspation position, control subjects showed better reproducibility with bimanual manipulation than with a chin-point guided technique, supported with an oblique jig with one antagonistic contact point [7].

Swallowing may be used to direct the mandible into its musculoskeletally stable position; unfortunately, this technique is not very reproducible [14]. When the swallowing technique is combined with a flat plane Lucia-jig [9] to prevent any occlusal contact, both the condyles are seated significantly more superoanteriorly compared to a chinpoint guided closure technique combined with the same jig. Yet, no difference in reproducibility of the found centric relation position, obtained with the chinpoint guidance technique as well as with this modified swallowing technique, could be detected [3].

Another example of a technique to locate centric relation position is a technique with an anterior deprogramming device, the leaf gauge [10, 11] . The purpose of the leaf gauge is to disengage the posterior teeth and to provide a fulcrum on the front teeth to facilitate seating of both condyles on their disks in their respective fossae. In this technique the elevator muscles will pull the condyles into their seated position. Reproducibility of centric relation, determined with a leaf gauge has been reported in the literature, but lacks statisticalevidence [15] . Reliability of a measuring procedure using a leaf gauge to determine the centric relation position has been assessed and proved to be satisfactory [16].

The use of an anterior deprogramming device has been proposed prior to taking a centric relation record in a patient whose mandible is hard to manipulate: a symptomatic patient [17]. A leaf gauge may deprogram the elevator muscles proprioceptively in order to seat thecondyles in its true skeletal position and preparing the patient for interocclusal centric relation records [13]. Even a favourable effect on cycling spasms of the lateral pterygoid muscle has been suggested [18, 19].

The use of an anterior deprogramming device seems a simple improvement of the technique to achieve a reliable centric relation position. However, a jig needs to be prepared in advance, the leaf gauge provides the clinician a straight-forward approach. Therefore, the purpose of this study is to assess the variability in centric relation position achieved in TMD-patients as well as control subjects with the leaf gauge.

## MATERIAL AND METHODS

A sample of 60 patients with signs of TMD was selected, 8 men (Mean age 28,6, SD 5,2) and 52 women (Mean age 30,5, SD 10,1). All patients presented themselves for treatment of their TMD at the Clinic of Special Dental Care in Amsterdam and at a private dental office in Santpoort-Noord. All patients were examined with the Research Diagnostic Criteria, Axis I [20] to diagnose their principal temporomandibular disorder. Diagnostic criteria included:

a) Myofascial pain: pain on movement and/or function, pain in response to palpation of three muscle sites, at least one on the side of the reported pain, normal or restricted mouthopening (< 40 mm), in the latter an assisted mouthopening with a passive stretch of 5 millimeters or more than the pain-free unassisted opening (MYO);

b) Myofascial pain as defined in a); plus disk displacement with reduction, reciprocal or reproducible (MYO/ID with reduction);

c) Disk displacement without reduction and limited opening: history of limited opening, maximum unassisted mouth opening less than 35 mm, passive stretch opens less than 5 mm (hard endfeel), contralateral excursion less than 7 mm and/or uncorrected deviation ipsilateral on mouth opening, or Disk displacement without reduction without limited opening: history of limited opening, maximum unassisted mouth opening more than 35 mm, passive stretch increases opening by 5 mm or more, contralateral excursion 7 or more millimeters, and presence of joint sounds, not meeting the criteria for disk displacement with reduction (ID without reduction);

d) Capsulitis (arthralgia): pain on palpation of the joint and the capsule, no joint sounds such as coarse crepitus, or Osteoarthritis: pain on palpation of the joint, coarse crepitus, radiographic confirmation of degeneration (OA) , or Osteoarthrosis: Absence of pain in the joint, (coarse) crepitus, radiographic confirmation of degenerative changes (OA).

The Research Diagnostic Criteria can lead to 5 diagnoses per patient: internal derangement and capsulitis/osteoarthritis/-osis per joint and myofascial pain. In general any patient will rarely exceed three diagnoses. Based upon their principle diagnosis/chief complaint patients were allocated to a diagnostic subgroup. Distribution of their TMD, number actually used for statistical assessment, and the amount of observations available is given in table 1.

For precision and convenience purposes a quickmount procedure was selected with a magnetic split-cast system and a face-bow (SAM-Company Munich, Germany) that accurately relates the mounted casts to the sagittal, transversal and vertical reference planes [21]. Three dimensional dislocation of the mandible as a result of the use of different interocclusal recording materials among which baseplate wax was tested in the Condymeter (Condymeter, SAM-Company Munich, Germany) [22] . Interocclusal waxrecords (Moyco Wax beauty Pink X-hard, Moyco Inc. Philadelphia PA, U.S.A.) had a small deviation, vertically as well as horizontally, if used after a short storage time up to 30 minutes [22, 23].

All patients were informed about the nature and purpose of the quickmount-procedure and the objective of the study. All gave their informed consent. The quickmount-

procedure in detail and the consequent measuring procedure has been discussed elsewhere [16] . MIVQUE variance components estimates for observers were 0, for subjects and error were small.

Consequently, the reliability of this measuring procedure has been established good [16]. Patient impressions of both maxillary and with irreversible hydrocolloid were made mandibular arch, and then poured in a Class IV stone (Fuji Rock, GC Europe Leuven, Belgium). An ear-bow was taken to mount the maxillary cast to an articulator with a magnetic split-cast system (Axiosplit, SAM-Company Munich, Germany) . Then three sets of interocclusal wax records were prepared (Moyco Wax beauty Pink X-hard, Moyco Inc. Philadelphia PA, U.S.A.) in a warm water bath and sequential centric relation records were taken using a leaf gauge to locate the centric relation position. The appropriate amount of leaves to separate the back teeth sufficiently are placed between the anterior teeth and the patient is asked to close on his or her back teeth. The number of leaves usually will be between 25 and 35. Next the patient is asked to slide the mandible forward, to go (all the way) back, bite (hard), and relax, not to open the mouth, but keep contact with the leaves. The first pair of centric relation records was used to mount the mandibular cast. Both maxillary and mandibular cast were mounted with magnetic split-cast mounting plates for convenience of handling in the measuring procedure (Fig. 1).

Next, the casts were transferred into the Condymeter III (Condymeter, version III, SAM-Company Munich, Germany) .

This instrument is a sophisticated articulator, in which the condylar housing has beenexchanged for a set of 6 measuring gauges with a 5 millimeter measuring range each (Fig. 2).

The instrument has been designed to measure any displacement of the mandible away from the centric relation position along the sagittal, the transversal and the vertical axis at the condylar level on both sides. Subsequently, the instrument gives the observer 6 dependent variables: XR, XL, YR, YL, ZR and ZL.

**Figure 1**. Mounted set of casts in an articulator

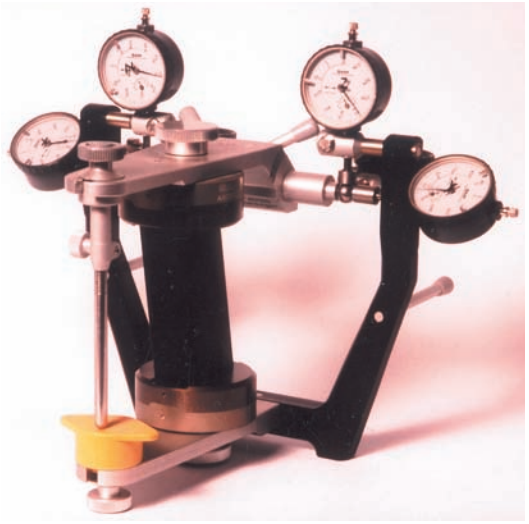

**Figure 2.** *The Condymeter III*

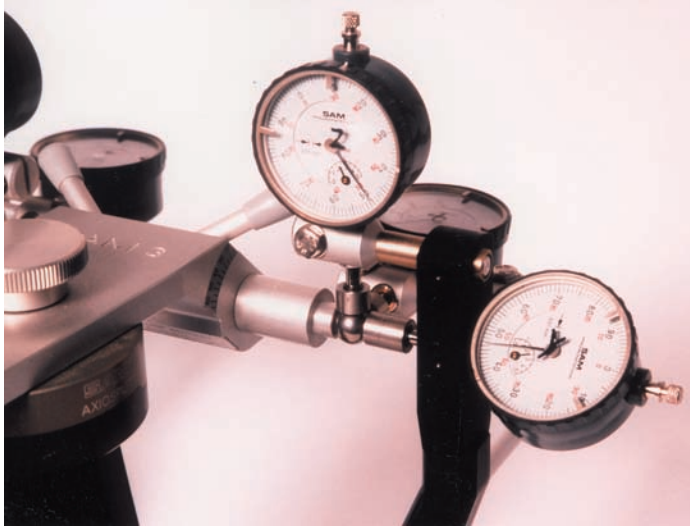

**Figure 3.** *The measuring gauges of the Condymeter III (detail)*

Variables XL and XR represent mandibular displacement in the sagittal plane, variables YL and YR in the transversal plane, and ZL and ZR in the vertical plane, at the left and right condylar level respectively. Variables XMIN, YMIN and ZMIN represented the minimal sagittal, transversal and vertical displacement left or right respectively. Likewise, variables XMAX, YMAX and ZMAX represented the maximal sagittal, transversal and vertical displacement left or right. XDIFF, YDIFF and ZDIFF represented the difference between the minimal and maximal values of X, Y and Z.

Calibration of the instrument beforehand sets all gauges at 2.50 millimeter, being the expected value, when sequential centric relation records are assessed in the Condymeter III (Fig. 3).

The study design of choice is a patient-control study. The control subjects were taken from a previous study [16]. The applied statistical method is an analysis of variance model (ANOVA) with one factor at 6 different levels, i.e. 5 patient groups and a control group, in total 60 patients and 12 controls. Mean values and standard deviations were computed for all variables. These values best represent the within-subject and the total variability for each of the variables.

The null hypothesis of no between-group differences in within-subject and total variability was tested with an analysis of variance (ANOVA). The level of significance $\alpha$ was set at 0.05. To minimize type I errors caused by multiple testing Scheffe's test was used to maintain an overall significance of 0.05.

## RESULTS

The data of 12 control subjects and of 60 patients were assessed in this study. Only data were used when at least two out of three sets of interocclusal wax records coincided in the split-cast procedure. The data of the diagnostic subgroup TRAUMA were excluded, because there was only one patient. From twelve control subjects, taken from a previous study, three observations were read and used. Out of the 59 patients three observations were available for 33 patients, two observations for 13 patients and of 13 patients no data could be used. The diagnostic subgroups MYO and MYO/D showed the greatest variability in the split-cast procedure: In the subgroup MYO for 3 patients the interocclusal records did not coincide, consequently could not be assessed. For 7 patients only 2 and for 3 patients all three interocclusal records could be analyzed. For the subgroup MYO/D the figures are 6, 2 and 15, for the subgroup ID 1, 2 and 6 and the subgroup OA 3, 2 and 9 respectively (Table 1). Consequently, the database consists of 161 observations. The data were tested and showed a normal distribution. To compensate for the different influence on the database of two and three observations per patient, first the mean values per patient were computed. Mean values and standard deviations for 5 diagnostic subgroups are given in table 2.

An analysis of variance of all 15 variables of interocclusal registrations is given in table 3. There was no significant difference between subjects for 6 variables: XL, XR, YL, YR, ZR and ZL. Next an analysis of variance was computed for the minimal values, the maximal values and the difference between minimal and maximal values of the variables, both left and right. Consequently, the minimal values of XL and XR, YL and YR and ZL and ZR are defined by XMIN, YMIN and ZMIN. The maximal values of XL and XR, YL and YR and ZL and ZR are defined by XMAX, YMAX and ZMAX. The difference between the minimal and the maximal values is defined by XDIFF, YDIFF and ZDIFF. There were no significant differences for all 9 variables.

Scheffe's testing for the variables XL, XR, YL, YR, ZL and ZR showed no significant differences. Scheffe's testing for the variables XMIN, YMIN, ZMIN, XMAX, YMAX, ZMAX, XDIFF, YDIFF and ZDIFF showed no significant differences.

To calculate the necessary number of subjects in a clinical trial to determine clinical reproducibility of the centric relation position, the following equation has been used for a power-analysis:

$$N = 2 \frac{(z_{\alpha} + z_{2\beta})^2 \sigma^2}{(\mu_x - \mu_y)^2}$$

The biggest difference was found in the variable XL between the MYO and the MYO/D group is 0.146. The accompanying value of the standard deviation 0.153. Consequently, the power analysis will be represented by $N = 2 ( z_{\alpha} + z_{2\beta})^2 \times (0.153)^2 / (0.146)^2$ in which $z_{\alpha}$ is 1.96 at $\alpha = 0{,}05$ en $z_{2\beta}$ is 1.65 at $\beta = 0{,}95$. Consequently, approximately 26 subjects are necessary per subdiagnosis of TMD or controls.

## DISCUSSION

Statistical analysis demonstrates no differences in an analysis of variance between the four diagnostic subgroups and the control subjects. Scheffe's testing confirms the result of the analysis of variance.

Values for mandibular displacement range from 0.00 for variables YL and YR until 0.137 for the variable XR in the diagnostic subgroup MYO. All other variables in the 5 different diagnostics subgroups range within this limit. Though the measuring technique is not comparable, these result are in line with the results of McKee [6], who found repeatability of the condylar position within 0.11 millimeter tolerance.

In conclusion, to demonstrate possible significant differences between variables of diagnostic subgroups, it is necessary to conduct a double-blind randomized clinical trial with at least 26 subjects per subdiagnosis, including the controls. The results of this study suggest no variability in centric relation position between TMD-patients and control patients by means of the leaf gauge.

The purpose of an anterior deprogramming device is disengage the back teeth and to deprogram the musculature of the masticatory system. In the literature of the last decade there is a tendency to use an anterior deprogramming device to improve precision in taking interocclusal centric relation records [3, 4, 7, 9-14, 24], even for chinpoint guidance [3, 7]. Traditional chinpoint guidance reflects the concept of the most posterior position, Posselt's ligamentous position or retruded contact position. Chinpoint guidance best fits

**Table 1.** Sample of 60 patients: Distribution of their TMD, number of patients actually used for statistical analysis, and the number of observations per patient available.

| | *N* | *N(used)* | *0 obs* | *2 obs.* | *3 obs* |
|---|---|---|---|---|---|
| MYO<br>Myofascial pain | 13 | 10 | 3 | 7 | 3 |
| MYO/D<br>Myofascial pain/Disk displacement with reduction | 23 | 17 | 6 | 2 | 15 |
| ID<br>Disk displacement without reduction | 9 | 8 | 1 | 2 | 6 |
| OA<br>Osteoarthritis | 14 | 11 | 3 | 2 | 9 |
| Trauma | 1 | 0 | 0 | - | - |

**Table 2.** Mean values and standard deviations of 5 diagnostic subgroups. MYO refers to myofascial pain, ID to disc displacement without reduction, MYO/D myofascial pain with disc displacement with reduction, and OA to osteoarthritis.

| *Group* | *N* | *XL* | | *XR* | | *YL* | | *YR* | | *ZL* | | *ZR* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | SD | M | SD | M | SD | M | SD | M | SD | M | SD |
| ID | 8 | -0.025 | 0.114 | -0.026 | 0.143 | 0.059 | 0.172 | -0.058 | 0.172 | 0.029 | 0.118 | -0.134 | 0.174 |
| MYO | 10 | -0.100 | 0.129 | -0.137 | 0.112 | -0.001 | 0.092 | 0.002 | 0.093 | 0.117 | 0.143 | 0.013 | 0.225 |
| MYO/D | 17 | 0.046 | 0.153 | -0.018 | 0.139 | 0.045 | 0.106 | -0.043 | 0.107 | -0.002 | 0.152 | -0.121 | 0.149 |
| OA | 11 | -0.029 | 0.146 | -0.107 | 0.175 | -0.011 | 0.129 | 0.011 | 0.129 | 0.058 | 0.144 | -0.118 | 0.181 |
| controls | 12 | -0.078 | 0.228 | -0.04 | 0.227 | 0.050 | 0.089 | -0.05 | 0.084 | 0.031 | 0.215 | 0.010 | 0.309 |

**Table 3.** Analysis of variance for the variables XL, XR, YL, YR, ZL, ZR, XMIN, YMIN, ZMIN, XMAX, YMAX, ZMAX, XDIFF, YDIFF and ZDIFF.

| | *XL* | *XR* | *YL* | *YR* | *ZL* | *ZR* | *XMIN* | *YMIN* | *ZMIN* | *XMAX* | *YMAX* | *ZMAX* | *XDIFF* | *YDIFF* | *ZDIFF* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | -0.03 | -0.06 | 0.03 | -0.03 | 0.05 | -0.07 | -0.13 | -0.11 | -0.11 | 0.04 | 0.11 | 0.09 | 0.17 | 0.23 | 0.20 |
| SD<br>(Root MSE) | 0.16 | 0.16 | 0.11 | 0.11 | 0.16 | 0.21 | 0.15 | 0.07 | 0.19 | 0.14 | 0.07 | 0.15 | 0.09 | 0.15 | 0.13 |
| P-value | 0.17 | 0.33 | 0.51 | 0.53 | 0.40 | 0.26 | 0.46 | 0.35 | 0.48 | 0.07 | 0.35 | 0.09 | 0.51 | 0.35 | 0.85 |

the technique to locate the retruded contact position. This position is not acceptable anymore from a functional, a physiological as well as an anatomic point of view [24]

Bimanual manipulation as an operator-guided technique has its limitations locating centric relation position in those TMD-patients, whose mandible is hard to manipulate as a result of their pathology [17] . The use of a jig maybe helpful to overcome this limitation; however, a jig must be prepared in advance. The concept of a stable orthopedic position sets its own requirements in terms of the technique to locate this specific centric relation position. A straight forward approach that provides some major advantages is offered by the leaf gauge:

1. the proper amount of leaves to disclude the back teeth needs no preparation in advance;

2. the two movements any TMD-patient with severe pathology almost without exception can make, is a protrusive and “bite hard” movement; and

3. this protrusive movement solicits a forward-backward movement, dominated by the lateral pterygoid muscle, that has a deprogramming effect on the lateral pterygoid muscle itself [11,2 6] on the elevator muscles as well as intracapsularly [11, 26].

Yet, another aspect has to be considered. The clinical opinion that the lateral pterygoid muscle is dysfunctional in patients with TMD is still widely accepted [25] . Current literature does not support an important role for the lateral pterygoid muscle in TMD-pathology [25] . However, there is sufficient evidence that the lateral pterygoid muscle generates and controls horizontal movement of the mandible. The lateral pterygoid muscle is not active at the postural jaw position [25] . In the backward movement of the mandible the activity of the inferior head of the lateral pterygoid muscle shows a lengthening contraction that has the effect of slowly letting out a rope to control the condyle as it travels back into the fossa [25] .

Disk displacement without reduction is a TM-diagnosis in which the lateral pterygoid muscle may shows myospasms. A partially contracted muscle or a myospasm cannot relax until contraction of the muscle is completed. True, the forward-backward movement of the mandible may account for pain, fatigue and intracapsular arousal, but it allows the lateral pterygoid muscle to complete its contraction.

Though the greatest variability may be expected in the subdiagnosis ID with its restricted condylar movement and its coexisting myospasm, in fact it does occur in the subdiagnosis MYO. Obviously, muscle fatigue and spasms in myofascial pain seem responsible for the bigger variability in the splitcast procedure.

Concluding, if the lateral pterygoid muscle is not dysfunctional in the majority of TMD-patients, second, if the muscle plays such a dominant role in the horizontal movements of the mandible, and third it serves as the stabilizer of the condyle and the disc, it should be used to properly align the condyles on their respective disks and to achieve a reliable and reproducible centric relation position. A definition of a stable orthopedic position subsequently would be the position at the end of the, by the lateral pterygoid muscle dominated, forward-backward movement of the mandible, and the position in which both condyles will be stabilized on their respective disks and in their fossae by the inferior lateral pterygoid muscle as well as by the elevator muscles in the direction of their composite vector, within the functional range of the dentition.

## ACKNOWLEDGEMENTS

The study was financially supported by The American Equilibration Society

## ADDRESS FOR CORRESPONDENCE

A.J.J. Zonnenberg, Velserhooftlaan 1, 2071 AJ Santpoort-Noord, The Netherlands, Tel: +3123 5378656, Fax: +3123 5490621, E-mail: a.j.j.zonnenberg@xs4all.nl

## REFERENCES

1. Glossary of Prosthodontic Terms, 7th ed. *J Prosthet Dent* 1999; **81**:58.
2. Ferrario VF, Sforza C, Miani A, Serrao G, Tartaglia G. Open-close movements in the human temporomandibular joint: does a pure rotation around the intercondylar hinge axis exist? *J Oral Rehabil* 1996;**23**:401-8.
3. Campos AA, Nathanson D, Rose L. Reproducibility and condylar position of a physiologic maxillomandibular centric relation in upright and supine body position. *J Prosthet Dent* 1996;**76**:282-7.
4. Okeson JP. Management of Temporomandibular Disorders and Occlusion. 5th ed. St. Louis: CV Mosby; 2003. p. 281-284, 510-512.
5. Wood DP, Floreani KJ, Galil KA, Teteruck WR. The effect of incisal bite force on condylar seating. *Angle Orthod* 1994;**64**:53-61.
6. McKee JR. Comparing condylar position repeatability for standardized versus nonstandardized methods of achieving centric relation. *J Prosthet Dent* 1997;**77**:280-4.
7. Keshvad A, Winstanley RB. Comparison of the Replicability of Routinely Used Centric Relation Registration Techniques. *J Prostbodont* 2003;**12**:90-101.
8. Dawson PE.Evaluation, diagnosis, and treatment of occlusal problems. 2nd ed. St. Louis: CV Mosby:1989. p. 28-54.
9. Celenza FV. The centric position: Replacement and character. *J Prosthet Dent* 1973;**30**:591-8.
10. Long JH. Locating centric relation with a leaf gauge. *J Prosthet Dent* 1973;**29**:608-10.
11. Carroll WJ, Woelfel JB, Huffman RW. Simple application of anterior jig or leaf gauge in routine clinical practice. *J Prosthet Dent* 1988;**59**: 611-617.
12. McKee JR. Comparing condylar positions achieved through bimanual manipulation to condylar positions achieved through masticatory muscle contraction against an anterior deprogrammer: a pilot study. *J Prosthet Dent* 2005;**94**:389-93.
13. Williamson EH, Steinke RM, Morse PK, Swift TR. Centric relation: A comparison of muscle determined position and operator guidance. *Am J Orthod* 1980;**77**: 133-145.
14. Celar AG, Kundi M, Piehslinger E, Führhauser R, Kohlmaier B. Mandibular position at chin-point guided closure, intercuspation and final deglutition in asymptomatic and temporomandibular dysfunction subjects. *J Oral Rehabil* 2000;**27**:70-78.
15. Downs DH, Albers MT, Boyle AG, Greer WT, Marker TJ, Parlet CR, Schulz KS, Wilson RL. Centric Relation for Diagnostic Mountings. *J Gnathology* 1997;**16**:7-14.
16. Zonnenberg AJJ, Mulder J, Sulkers HR, Cabri R. Reliability of a Measuring procedure to Locate a Muscle-Determined Centric Relation Position. Eur J Prosthodont Rest Dent 2004;3:125-128.
17. Karl PJ, Foley TF. The use of a deprogramming appliance to obtain centric relation records. Angle Orthod 1999;69:117-125.
18. Phillips RW, Hamilton IA, Jendresen MD, McHorris WH, Schallhorn RG. Report of the Committee on Investigation of the American Academy of Restorative Dentistry. *J Prosthet Dent* 1985;**53**:850.
19. Woelfel JB. New device for accurately recording centric relation. *J Prosthet Dent* 1986;**56**:716-727.
20. Dworkin SF, LeResche L. Research Diagnostic Criteria for Temporomandibular Disorders: Review, Criteria, Examinations, and Specifications, Critique. *J Craniomand Disord Facial Oral Pain* 1992;**6**:301-355.
21 Nagy WW, Smithy TJ, Wirth CG. Accuracy of a predetermined transverse horizontal mandibular axis point. *J Prosthet Dent* 2002;**87**:387-94.
22. Müller J, Götz G, Bruckner G, Kraft E. An experimental study of vertical deviation induced by different interocclusal recording materials. *J Prosthet Dent* 1991;**65**:43:50.
23. Dixon DL. Overview of articulation materials and methods for the prosthodontic patient. *J Prosthet Dent* 2000;**83**:235-47.
24. Keshvad A, Winstanley RB. An appraisal of the literature on centric relation. *J Oral Rehabil* 2001;**28**: 55-63.
25. Murray GM, Phanachet I, Uchida S, Whittle T. The Role of the Human Lateral Pterygoid Muscle in the Control of Horizontal Jaw Movements. *J Orofac Pain* 2001;**15**:279-305.
26. Phillips RW, Hamilton IA, Jendresen MD, McHorris WH, Schallhorn RG. Report of the Committee on Investigation of the American Academy of Restorative Dentistry. *J Prosthet Dent* 1985;**53**: 850.