A data-supported reference position of the intermaxillary relationship:

The stable orthopedic position for healthy individuals and for TMD patients

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Een met meetgegevens gedocumenteerde referentie positie van de intermaxillaire relatie:

De stabiele orthopedische positie voor gezonde proefpersonen en TMD patiënten

(met een samenvatting in het Nederlands)

Proefschrift

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door Adrianus Joannes Joseph Zonnenberg geboren op 28 juli 1951 te 's Gravenhage

Promotor: Prof. dr. R. Koole

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Paranimfen:
Drs. F. van Bunnik
Mr. Dr. G. Kerpestein

Colofon

Adrianus Joannes Joseph Zonnenberg

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Cover compilation of illustrations: Maartje Kunen

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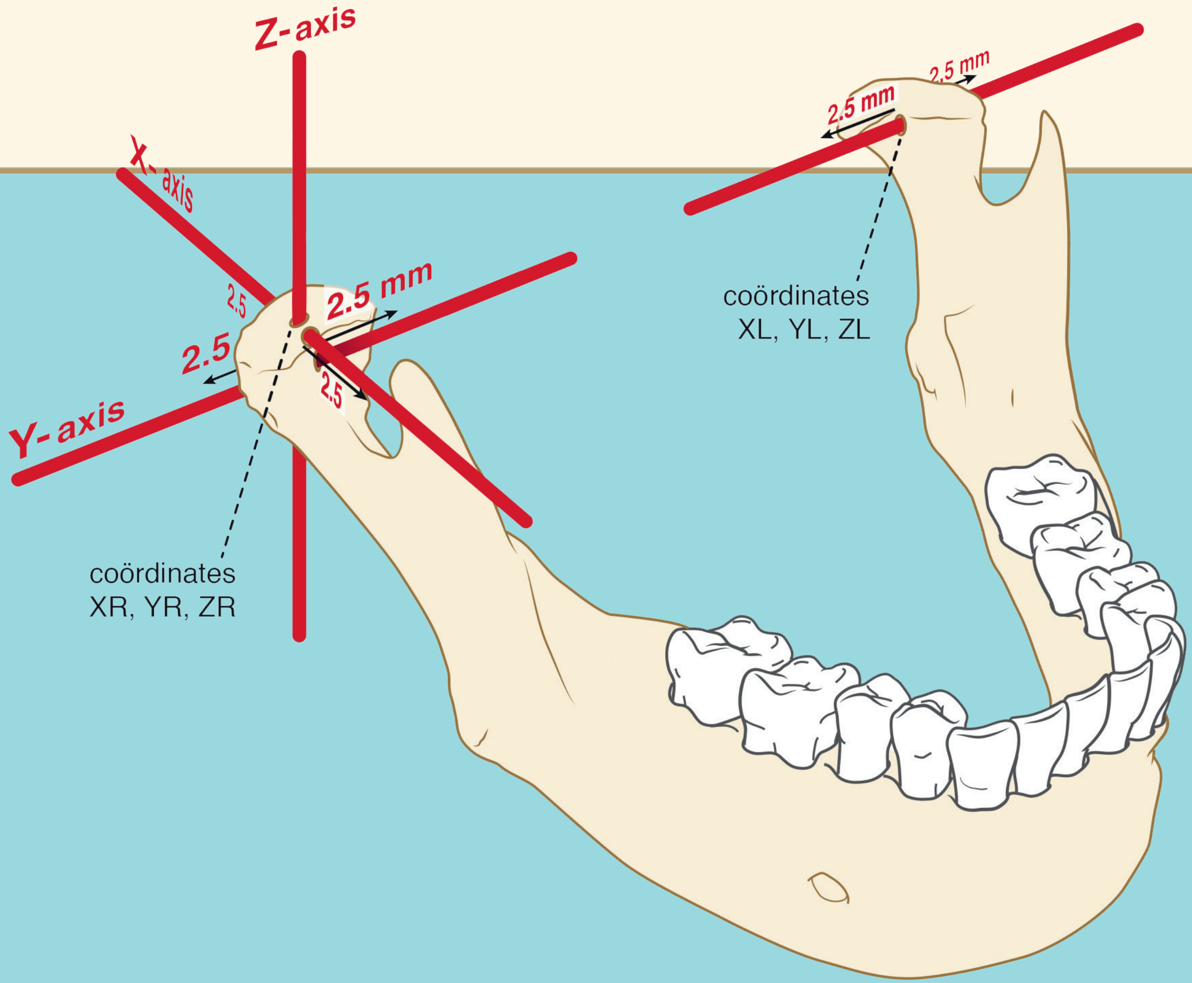
Table of contents

Preface

Starting point for this study was the assumption that centric slide could be an etiologic factor for a temporomandibular disorder (TMD). Centric slide must be considered as the mismatch between the ideal condylar alignment in the fossa (centric relation or CR) and the maximal intercuspal position, shortly, the trajectory from the first tooth contact in CR into maximum occlusion. Centric slide may be measured intraorally with a millimeter ruler or with plaster models mounted in an articulator. The former technique seems not very precise because the operator needs to make an interpretation of the increments in millimeters on the ruler and the measuring method is a 2-dimensional approach. The latter technique demands sophisticated articulator equipment to measure the centric slide 3-dimensionally. There is no validated reference position for mounted models in an articulator; the operator may choose one of 7 different definitions of centric relation as provided in the Glossary of Prosthodontic Terms, or the maximal intercuspal position. The Glossary's currently used definition of centric relation is the musculoskeletally stable or stable orthopedic position. The position can be achieved with 2 different methods: bimanual manipulation or with a leaf gauge. Reproducibility of bimanual manipulation has been tested, reproducibility of the method with a leaf gauge lacks in the current literature. Evidence of reproducibility is not sufficient to validate a reference position. A construct validity of a method to locate centric relation with a leaf gauge and the support of masticatory muscle contraction appears to be the most preferable choice to test reproducibility of this musculoskeletally stable centric relation position. Repetitive evidence of reproducibility makes the method to locate this stable orthopedic position eligible to be tested in a randomized clinical trial to prove validity of this potential treatment position of choice.

Chapter 1

Introduction



Introduction

Occlusion, including articulation, is the dentist's specific competence. Sound occlusal relationships and joint stability are the foundation of comprehensive dentistry. The maximal intercuspal position is such a sound occlusal relationship. The position is defined by the complete intercuspation of the opposing teeth independent of the condylar position. (Glossary of Prosthodontic Terms, GPT 8, 2005) Optimal joint stability will be achieved when the articular discs are properly interposed between the condyles and the articular fossae. (GPT 8, 2005) The condyles will assume this position when the elevator muscles are activated without any occlusal influence. (Okeson, 2013 p. 73-77) In many cases the maximal intercuspal position does not coincide with the optimal joint position. As mentioned above the coincidence of the maximal intercuspation with the optimal joint position is our actual objective for treatment. Centric relation is the intermaxillary reference position that takes the dental arches with the teeth as well as the temporomandibular joints into account.

In the 60s and 70s, the days of Stallard, Stuart, Lauritzen and others, occlusal disharmony was supposed to be the most important etiologic factor in TMD. Through the 1970s emotional stress became an important etiologic factor. (Dubner et al, in Greene & Laskin, 2012, p. 8-14) Through the 1980s physical therapy developed as a source of treatment in combination with dental means. (Kraus, 1988) Research of the last 20 years could not prove occlusal factors to influence the onset of TMD.

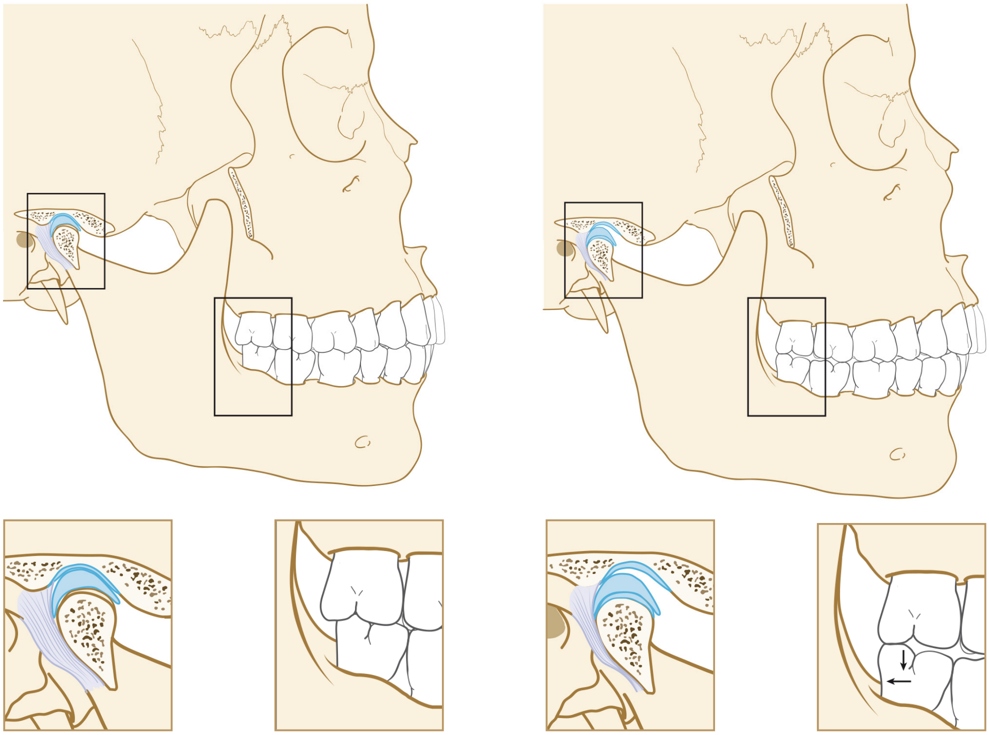
However, this thesis will focus on centric relation and the role of one occlusal factor in particular, centric slide. Centric slide is defined as the mandibular trajectory from the initial occlusal contact while the mandible is in centric relation, into maximal intercuspal position or maximum intercuspation (GPT 8, 2005), consequently being the measure of mandibular instability. Orthopedic stability of the mandible exists when the maximal intercuspal position of the teeth is in harmony with the musculoskeletally stable position of the condyles in the fossae. (Okeson, 2013 p. 117)

Static occlusal factors

Okeson remarkably discusses the occlusal condition rather than the occlusion. The occlusal condition as one of the etiologic factors for the onset of TMD should be considered statically and dynamically. (Okeson, 2013 p. 116 – 118) At first many occlusal studies have assessed the relative importance of static occlusal factors relative to TMD. In the course of the 1990s Kirveskari demonstrated a causal relationship in a univariate analysis between occlusal adjustment of occlusal interferences and clinical signs of TMD. (Kirveskari et al, 1992) In a double-blind study design 2 prospective cohorts of 5 and 10 year old school children were examined yearly for the development of clinical signs of TMD. Half of the children received occlusal adjustment and the other half mock occlusal adjustment at this yearly visit for a period of 6 consecutive years. The goal of the study was to prevent the children to develop signs of TMD by yearly adjusting premature occlusal contacts, consequently eliminating centric slide. Kirveskari utilized Dawson's bimanual manipulation to obtain centric relation. (Kirveskari et al, 1992)

From studies by Pullinger and colleagues (Pullinger et al, 1993, 2000) and Dworkin and colleagues (Dworkin and LeResche, 1992) it became clear that there was not a single causal relationship between occlusion and TMD. In a multiple logistic regression analysis odds ratios of the weighted influence of 11 static occlusal factors were computed in 5 randomly collected, but strictly defined temporomandibular disorder groups, and compared to asymptomatic controls. (Pullinger et al, 1993, Pullinger and Seligman, 2000) The odds ratio is a measure of association without etiologic implication, meaning no causal relationship between factors can be demonstrated. The authors found 5 initiating factors that increased significantly the risk for the development of a TMD: an anterior open bite, a Class II overjet > 4 millimeters, a unilateral crossbite, 5 or more missing occluding posterior teeth and a centric slide > 2 millimeters. (Pullinger et al, 1993) In a follow-up study the authors specified centric slide up to > 3.2 millimeters. (Pullinger and Seligman, 2000) The centric slide was measured on mounted casts. Each subject's centric relation was determined while seated in a slightly reclined position, moderate pressure on the chin was exerted, and passive manipulation of the mandible was used. (Solberg et al, 1979) In other words, a chinpoint guided centric relation was determined which the authors named retruded contact position. (fig. 1-1)

Figure 1-1. The retruded contact position: guided closure forces the mandible half a cusp backwards and impinges upon the orthopedic stability of the joints.



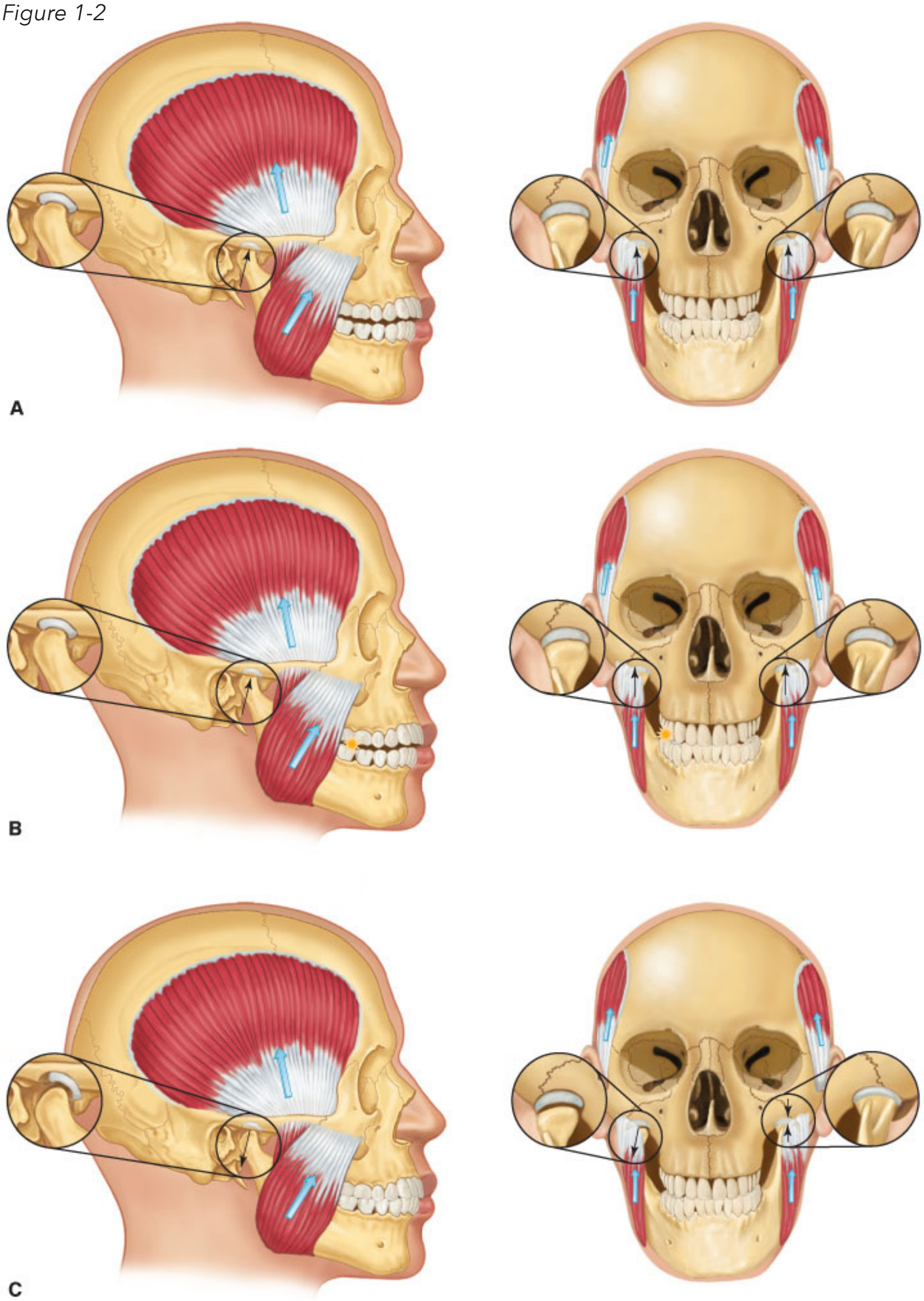
The authors concluded no single static occlusal factor could differentiate patients from asymptomatic controls. The 5 isolated factors occurred mainly in TMD patients and are rare in healthy individuals, but are rare in patient populations as well. This limits the diagnostic usefulness of these static occlusal factors. Pullinger and Seligman (Pullinger and Seligman, 2000) estimated the influence of occlusal factors between 4.8 and 27.1 % of the log likelihood. Static occlusal factors contribute little to none to TMD. Today 20 years later all questions regarding morphological and anatomical relationships between static occlusal factors remain as yet unanswered. (Pullinger, 2013) The chinpoint guided centric relation position was their reference position, probably defined as in the 5th edition of the Glossary (GPT5).

Dynamic occlusal factors

In dynamic occlusal conditions in which the mandible loads against the maxilla, the occlusal factor centric slide may be a critical factor. Centric slide must be considered the mismatch between the musculoskeletally stable joint position, the current definition of centric relation (CR), and the maximal intercuspal position. In general the magnitude of centric slide is between 0 and 1 to 1.5 millimeters. (Solberg et al, 1979, Keshvad and Winstanley, 2001) This trajectory will be well tolerated by the adaptive capacities of the masticatory system called the adaptation demand model, in healthy individuals. (Pullinger and Seligman, 2000) Centric slide may cause mandibular orthopedic instability. The combination of centric slide and overloading of the temporomandibular joint resulting from respectively trauma, microtraumata caused by parafunctional activities or deep pain input, play a critical role in the onset of a TMD. (fig. 1-2) Okeson states: The larger the slide, the bigger the risk that an intracapsular disorder will develop. (Okeson, 2013 p. 119) Okeson's maxillomandibular reference position is yet another position compared to Dawson's and Solbergs position: he refers to the musculoskeletally stable centric relation position. (Okeson, 2013 p. 117) Concluding, we find at least 3 different centric relation positions in the literature. Any derivative conclusion concerning centric slide may or may not be correct depending whether the used centric relation position will prove to be valid.

Figure 1-2. **A.** *With the teeth apart, the elevator muscles maintain the condyles in their musculoskeletally stable positions (superior-anterior positions resting against the posterior slopes of the articular eminences). In this situation there is joint stability.* **B.** *As the mouth is closed, a single tooth contact does not allow the entire dental arch to gain full intercuspation. At this point there is occlusal instability but still joint stability. Since the condyles and the teeth do not fit in a stable relationship at the same time, this is orthopedic instability.* **C.** *In order to gain the occlusal stability necessary for functional activities, the mandible is shifted forward and the intercuspal position is achieved. At this point the patient achieves occlusal stability, but the condyles may no longer be orthopedically stable. The orthopedic instability may not pose a problem unless unusual loading occurs. If loading begins, the condyles will seek out stability and the unusual movement can lead to strains on the condyle-disc complex, resulting in an intracapsular disorder.*

Figure 1-2



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Temporomandibular disorders

The term "Temporomandibular Disorders" (TMD) refers to a group of clinical conditions that involve the temporomandibular joints and associated tissues, which may manifest as pain in the temporomandibular region, limitations in jaw movements, and temporomandibular joint sounds such as clicking or crepitus during jaw movements. The dysfunction may include changes in the mandibular movement pattern and/or a limited mouth opening. In case of a disc displacement with reduction the mandible may show a deviating, occasionally restricted mouth opening. Disc displacement without reduction reveals mandibular deflection to the affected side, accompanied by a limited mouth opening. Besides these arthrogenous signs myogenous components may be observed.

Temporomandibular disorders have a prevalence of approximately 8% in the adult population. (Sessle, 2009) The prevalence of TMD will be, most commonly, found in women. (Orofacial Pain 5th Ed , 2013) Various epidemiological studies report a somewhat different outcome. One study reports a peak age from 25 until 44 years (Von Korff et al, 1988), another reports a peak age from 35 until 54 years. (Goulet et al, 1995) The temporomandibular dysfunction will present as pain in the temporomandibular joint and/or pain in the associated muscles of mastication. Clear gender differences exist: the prevalence in women is 9-10 % and 3-10 % in men, predominantly in a women-men ratio 3 to 1. (Orofacial Pain 5th Edition, 2013)

Today some clinicians prefer the term orofacial pain over temporomandibular disorders, a term that may gradually disappear in the near future, due to lack of specificity. (Laskin, 2008) In the vast majority orofacial pain includes odontogenous pain such as tooth ache, periodontal and periapical pain, followed by arthrogenous pain from the joints and myogenous pain from muscular origin. The prevalence of this non-odontogenous pain is in 10% of the cases arthrogenous, in 10% a combination of myogenous and arthrogenous, and the remaining 80% of the pain from myogenous origin. However, we will continue to use the term TMD, as was done in the historical order of the 5 publications in this thesis.

In a landmark paper Dworkin and LeResche proposed the Research Diagnostic Criteria, divided in Axis I and Axis II, to make an appropriate TMD diagnosis, comparable with the work of other researchers in the field. (Dworkin, LeResche, 1992) Originally proposed as comparative criteria for research purposes, RDC/TMD proved to be excellent criteria to a set a tentative clinical diagnosis. Within the framework of this thesis the Axis I criteria must be mentioned in order to compare these diagnoses with a control group of healthy individuals. The Axis I physical disorder diagnoses are muscle diagnoses (myofascial pain), disk displacements and a rest group consisting of arthralgia, to be divided in capsulitis, retrodiscitis, and synovitis, and osteoarthritis, finally developing towards osteoarthrosis.

The literature discusses predisposing, initiating and perpetuating (or aggravating) etiologic factors for TMD. (Xie et al, 2013) Okeson proposes 5 distinct etiologic factors: the occlusal condition, trauma, emotional stress, deep pain input, and parafunctional activities. (Okeson, 2013 p.108) Trauma can be divided into macrotrauma and microtrauma. Macrotrauma is any sudden force such as a blow in the face that causes structural alterations in the temporomandibular joint. Macrotrauma may lead to elongation of discal ligaments compromising normal temporomandibular joint mechanics. (Okeson, 2013 p. 144 - 146) Microtrauma refers to any small force repeatedly applied to the joint structures over a long period of time. Microtrauma may result from joint overloading associated with muscle hyperactivity leading to hypoxia, such as from bruxing or clenching. Mandibular instability, defined as a mismatch between the centric relation position of the condyle-disc assembly and the intercuspal position of the teeth, may as well cause microtrauma to the disc and the ligaments of the temporomandibular joints. Repetitive overloading causes nociceptive pain and structural changes in the fibrous surface of the cartilage lining of the fossa, the condyles and the disc.

Emotional centers in the brain such as the (hypo)thalamus, the reticular system and, partly, the limbic system influence muscle function. Emotional stress activates the hypothalamic-pituitary-adrenal axis (HPA-axis) which in turn increases the activity of the gamma efferent system that controls the contraction status of the muscle spindles. Muscle spindles will become conditioned and sensitized that even slight stretching of the muscle will elicit a reflex contraction. The overall effect will be an increase in muscle tonicity. (Dubner et al, in Greene & Laskin, 2012, p. 8-14) However, the lateral pterygoid muscles are an exception to this rule, since these muscles have hardly any muscle spindles as a result of their eccentric functioning. (Koole, 1998, Murray et al, 2001)

Deep and ongoing pain input can excite the trigeminal brain stem nuclear complex (VBSNC) to produce a muscular response known as 'protective co-contraction', also known as 'défense musculaire'. As the description suggests, it refers to a normal manner in which the body responds to potential or actual trauma. A good example represents the limited closure of the mouth opening (the protective contraction) in case of a toothache to avoid loading of the aching tooth. Any source of constant deep pain input may represent an etiologic factor that may cause muscular and/or joint problems. (Dubner et al, in Greene & Laskin, 2012, p. 8-14)

Parafunctional activity or muscular hyperactivity in various forms can be an initiating etiologic factor for a TMD. Parafunctional activity includes clenching, grinding, bruxing and several other oral habits, habits the patient is in general not aware of, and can be divided in diurnal and nocturnal activities. Similar to deep pain input and emotional stress parafunctional activity may increase muscle tonicity. (Okeson, 2013 p. 108 - 110) Certain medications, drugs abuse, alcohol and smoking also aggravate bruxing and/or clenching habits. (Lobbezoo et al, 2001)

Centric relation

The Glossary of Prosthodontic Terms (GPT 8, 2005) defines centric slide as the movement of the mandible while in centric relation from the initial occlusal contact into the maximal intercuspal position. Maximum intercuspation is a reliable and simply reproducible reference position of the mandible. (Beyron, 1973) As yet few authors use the maximal intercuspal position as their reference position for the maxillomandibular relationship. (Steenks et al, 2005) Contrary, centric relation has been universally accepted as the reference position of choice for any comprehensive, reconstructive procedure including orthodontics and orthognathic surgery to restore the maxillomandibular relationship. In full dentures it is actually the only reference position. However, from centric relation 7 different definitions are given in the Glossary. (GPT 8, 2005) Which of these CR positions is the correct one and is there a valid CR position for all individuals? Over 5 decades (fig. 1-3) the concept of centric relation has evolved from the most retruded, ligamentous position (Posselt, 1952), via the posterior, unstrained position (RUM-rule, Stuart, 1964), via the posterior, superior strained position (Williamson et al, 1980) and the uppermost apex of force (Dawson, 1995) to contemporary thinking, that it is the superior-anterior (McKee, 2005, Okeson, 2013 p. 74-76, Rinchuse and Kandasamy, 2006) strained position. This superior-anterior strained position equals the musculoskeletally stable or stable orthopedic position. (Okeson, 2013 p. 74-76)

Figure 1-3. The concept of centric relation over 6 decades.

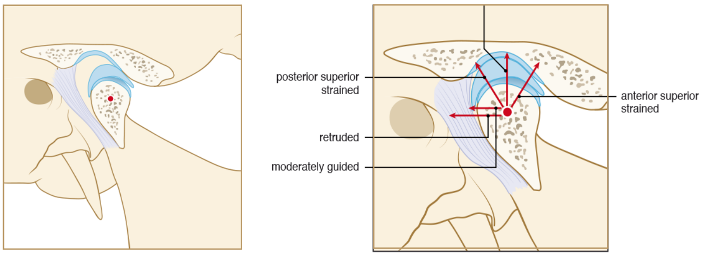
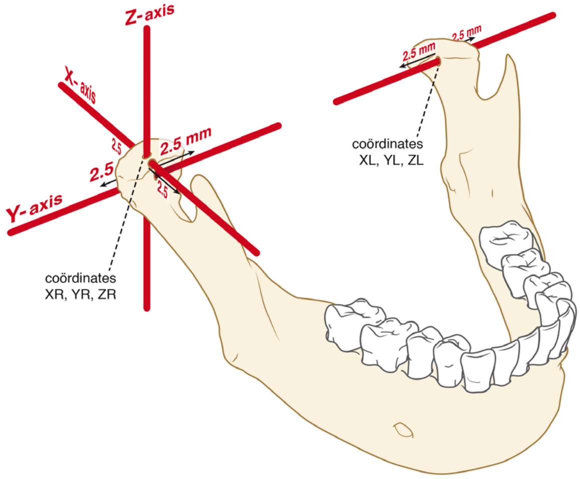


Figure 1 4. The condylar axis as a pars pro toto for the mandible.

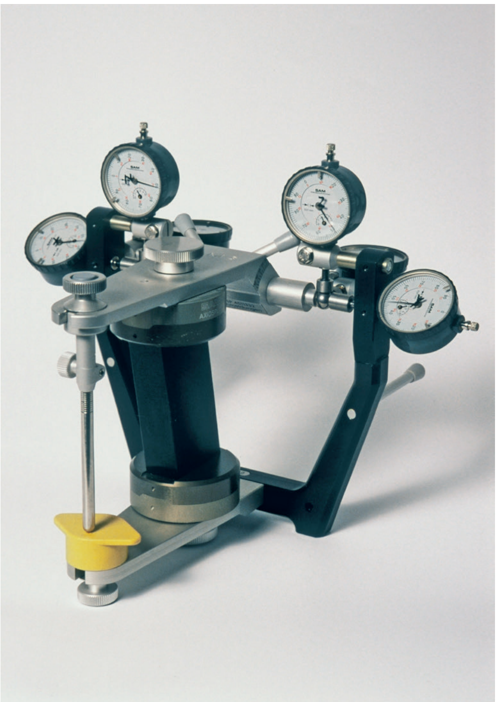


Instrumentation

To discuss any reference position of the masticatory system we need an articulator system that can assess the three-dimensional relationship from the mandible to the maxilla. Historically, dentists mount plaster models of the maxillary and the mandibular arches into an articulator to study and restore the occlusion. Several instruments were developed to achieve this goal. The occludator is the most simple design which does not permit any articulation. Semi-adjustable articulators have limited articulating features and hardly form a blueprint of the temporomandibular joint in replicating the motion within the temporomandibular joint. Fully adjustable articulators come nearest to this goal such as the Stuart and the Denar. Also SAM® Company offers such a complete system to evaluate the reproducibility of the maxillomandibular relationship. The system measures mandibular displacement using the intercondylar axis as a *pars pro toto* for the mandible. (fig. 1-4 and 1-5)

The plaster models of the dental arches, made beforehand, can be mounted with the face-bow to the centric reference instrument, the mounting jig of the system. With the face-bow the spatial relationship between the temporomandibular joints and the dentition in the maxilla is fixed using a reference plane e.g. the Frankfurter horizontal plane. The plaster models can be easily interchanged with the 2P articulator using the split-cast mounting plates. The actual measurement of the displacement of the intercondylar axis is performed in the Condymeter III.

Figure 1 5. The Condymeter, version III



In the current literature studies about a validated reference position of the intermaxillary relationship that can be considered a therapeutic or treatment position are not available. No conclusive evidence exists to either favour or reject any specific CR position as the optimally defined treatment position. Moreover a methodological issue is presented here: which method to locate centric relation must be used to possibly qualify and quantify the occlusal factor centric slide?

Development of a method to determine the musculoskeletally stable position
Available methods to locate centric relation

Centric relation can be determined operator guided, muscle-determined or in combination with an aid: a gothic arch tracer, TENS, a platform or a jig (Türp et al, 2006) or a leaf gauge. (Okeson, 2013 p. 195, 198) Methods to locate centric relation with aids such as a gothic arch tracer and TENS are not relevant for this study. The operator guided method utilizes meticulous mandibular manipulation, the muscle-determined techniques use an anterior deprogrammer and muscle contraction from the masticatory muscles, including the elevator and the lateral pterygoid muscles.

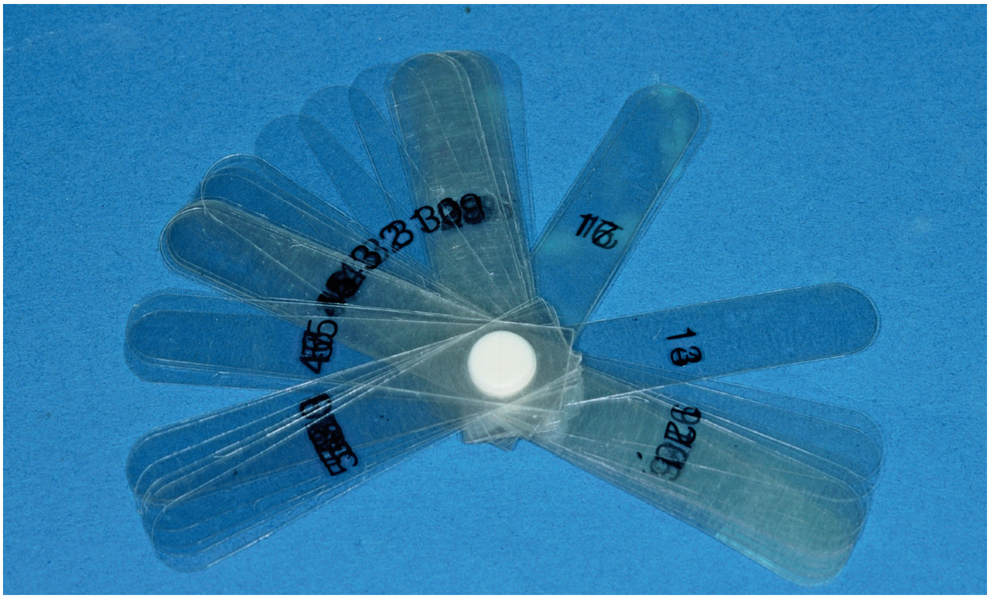
1 Operator guided:
- Chinpoint guidance: moderate guidance with sufficient dorsal pressure is exerted on the chin to overcome proprioceptive, protrusive displacement of the mandible, but not so much pressure that an antagonistic reflex is elicited (Kabcenell, 1964);
  - Chinpoint guidance in combination with passive positioning of the teeth on a jig (Campos et al, 1996);
- Bimanual manipulation: keeping the posterior teeth separated by downward chinpoint pressure of both thumbs, the 4 fingers of each hand supporting the mandible and seating the condyles with firm pressure on the discs in their respective fossa, i.e. into centric relation (Dawson, 1989);

2 Muscle-determined
- Bimanual manipulation with an anterior deprogrammer (a jig) keeping the posterior teeth separated, allowing elevator muscle contraction to actively seat the condyles into centric relation (McKee, 2005);
- A technique keeping the posterior teeth separated with a leaf gauge, (moderate) dorsal pressure on the chin and elevator muscle contraction to actively position the condyles into centric relation. (Long, 1973, Woelfel, 1986, Carroll et al, 1988)

Other considerations

An anterior deprogrammer is a tool to deprogram neuromuscular engrams of the mandibular closing patterns. The tool is applied as an aid to locate centric relation.
An anterior deprogrammer may present as a platform, a jig or a leaf gauge. (fig. 1-6)
The former ones need to be fabricated in the dental laboratory and, occasionally, adapted chair side. The latter is best comparable to a feeler gauge to set engine valves.
A leaf gauge consists of a number of plastic leaves with a rivet-type connection.

Figure 1 6. The leaf gauge.



An original Huffmann's leaf gauge contains 56 blades and gives the operator a straight forward approach to determine centric relation.

Any manipulation of the mandible, for example pressure on the mandibular front teeth and/or lip with a leaf gauge, will elicit reactive activity, displacing the mandible anteriorly. (Kabcenell, 1964) The lateral pterygoid muscles accompany, i.e. dominate any mandibular motion including a forward backward movement (Koole, 1998, Murray et al, 2001) and can prevent anterior displacement of the mandible. A jig is less flexible and therefore less suitable to accompany a forward backward movement. Another reason to prefer the use of a leaf gauge over a jig or platform as a deprogrammer.

As mentioned before, Okeson (Okeson, 2013 p. 74-76) states that the musculoskeletally stable position is synonymous to the most recent definition of the CR position as defined in the Glossary. (GPT 8 , 2005) The best approach to describe a technique to locate the musculoskeletally stable position demands a construct validity. Construct validity refers to the validity of inferences that observations or measurement tools actually represent or measure the construct being investigated, as the definition states. In lay terms, construct validity examines the question: Does the measure behave like the theory says a measure of that construct should behave? Concluding one may state that determining the musculoskeletally stable position is best feasible with a leaf gauge, a forward backward mandibular movement and masticatory muscle contraction, all 3 factors necessary to achieve this muscle-determined stable orthopedic position.

Elevator muscle contraction positions the condyles in a superior anterior direction into their respective fossae, consequently in the direction of the vector of the elevator muscles. (Keshvad, 2001) The tonus in the inferior head of the lateral pterygoid muscles position the condyles anteriorly against the posterior slopes of the articular eminencies. (Okeson, 2013 p. 74) To be certain the elevator muscles and the inferior heads do position the condyles at the highest point of the slope of the eminentiae, they best do so at the end of a forward backward movement of the mandible. As stated above this movement is dominated by the reciprocal interaction of the lateral pterygoid muscles. In mandibular movement lateral pterygoid muscles react by instant and reflex action before any other muscle groups come into action. (Koole, 1998) At the end of the backward movement, at the highest point of the slope of the eminentiae the inferior heads of the lateral pterygoid muscles will be at their full resting length. (Koole, 1998, Murray, 2001) As a general rule hyper tonicity or rather relative hyperactivity of the lower head of the lateral pterygoid muscles are observed in the locking phase of a disc displacement without reduction. This hyperactivity more likely is the result of a temporomandibular disorder rather than part of the temporomandibular disorder causing the locking condition. (Stegenga, 2001, Murray et al, 2001, Okeson, 2013)

Aims of the study

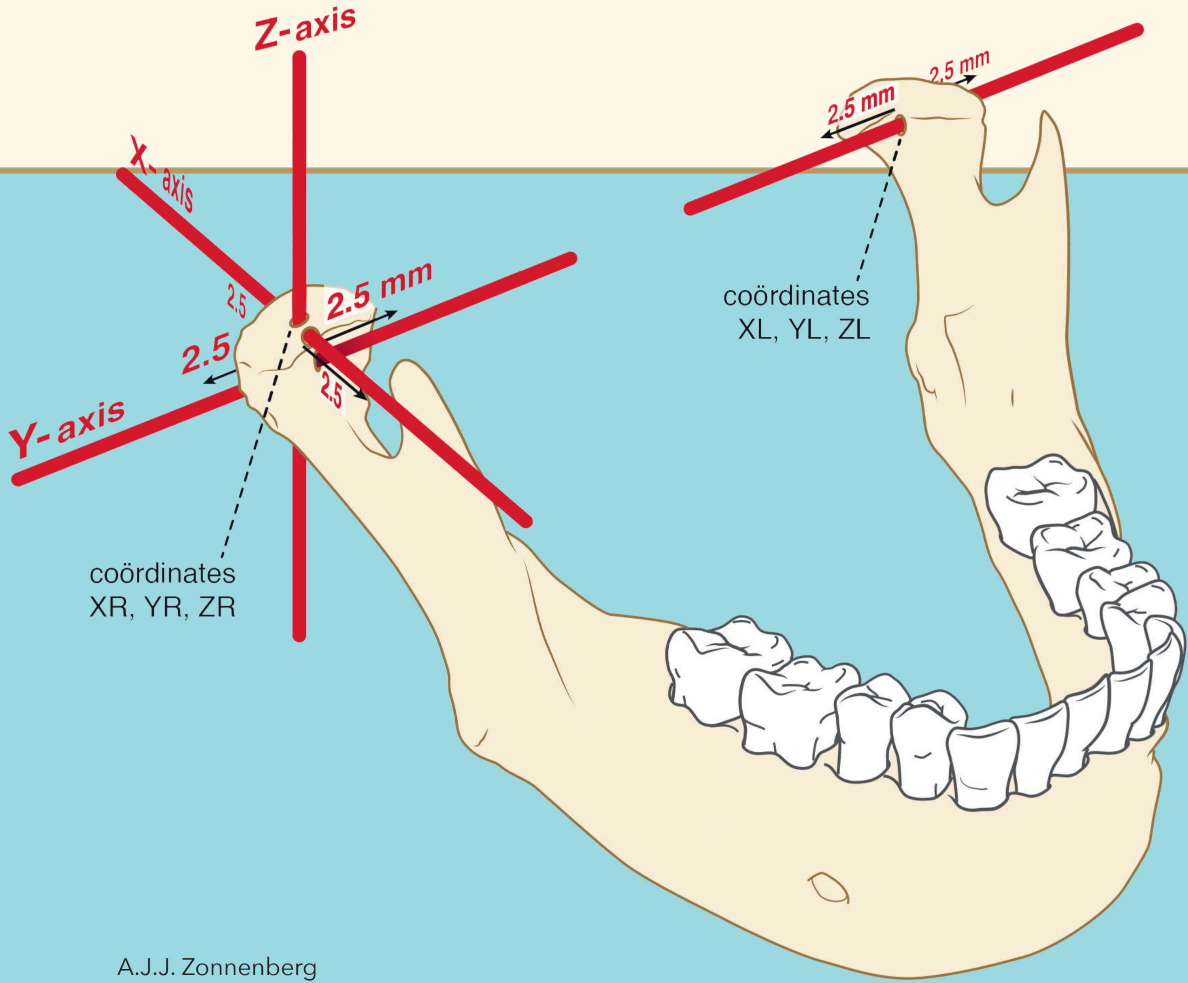
A methodologically sound study about reproducibility and validity of this method to locate the musculoskeletally stable centric relation position is lacking in the literature. A reproducibility study is necessary before in a follow-up RCT the found position can be validated. This study is necessary as well to quantify centric slide. In addition to this is qualifying the etiologic aspect of centric slide for TMD a second purpose of this study.

1 The development of a reproducible method to locate, verify, record and transfer centric relation into an articulator for healthy individuals is described in Chapter 2
2 The found data of centric relation in Chapter 2 were tested upon variability among 4 specific TMD diagnoses in Chapter 3. The study provided a power analysis to compose the controlled clinical trial of Chapter 4.
3 Chapter 4 reports a double-blind controlled clinical trial to test reproducibility of 2 methods to locate centric relation. Chinpoint guided centric relation was compared to the musculoskeletally stable centric relation position on mounted plaster models in an articulator. Location of both methods to locate CR were twice performed in the TMD patient groups, prior to and after stabilization splint treatment; location of both methods in the control group was performed only once.
4 As a spin-off of Chapter 4, Chapter 5 reports the magnitude of centric slide. Centric slide was measured intraorally with a millimeter ruler. The found data were compared to the measured centric slide in both articulator mountings. The study also reveals evidence that the static/dynamic occlusal factor centric slide may or may not be an etiologic factor for a temporomandibular disorder.

5 **Chapter 6** documents the non-controlled clinical observations and data from stabilization splint treatment. The patient group with disc displacement without reduction received a stabilization splint, fabricated in the musculoskeletally stable centric relation position..

Chapter 2

Reliability of a measuring-procedure to locate a muscle-determined centric relation position.



A.J.J. Zonnenberg
J. Mulder
H.R. Sulkers
R. Cabri

Eur J Prosthod Rest Dent 2004;12(3):125-128

Abstract

Although reproducibility of centric relation position, determined with an anterior deprogramming device, a leaf gauge, is widely accepted among clinicians, data confirming statistical evidence are lacking in the current literature. It is the objective of this study to prove clinical reliability of a measuring-procedure to locate the centric relation position, determined with the leaf gauge. A sample of 15 subjects (6 men, 9 women, age 22 to 46), assessed with the Research Diagnostic Criteria to rule out any TMD-signs, was selected. Three observers each took three sequential interocclusal records with the leaf gauge, to mount a set of casts into the centric relation position in an articulator. Out of 15 subjects, 12 (5 men, 7 women) fitted criteria of precision - three out of three interocclusal records for each of the three observers - in a split- cast procedure. The applied statistical method is an analysis of variance model (ANOVA) with two factors for 3 observers and 12 subjects. The variance components estimation procedure is MIVQUE (0). The level of significance was set at 0.05. No significant difference between observers for the measured variables sagittally (XL, XR), transversally (YL, YR), and vertically (ZL, ZR) could be found. MIVQUE variance components estimates for observers is < 0, varies for subjects from 0.04 to 0.20 and varies for error from 0.12 to 0.25 mm. Reliability of a measuring-procedure to locate a muscle-determined centric relation position could be established satisfactory.

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] Centric relation is a maxillomandibular relationship, which is the basic reference position to diagnostically evaluate occlusion. Centric relation position is the treatment position for comprehensive dental work with occlusal, orthodontic, restorative, and orthognathic modalities. [2]

Centric relation position is the starting point to accommodate functional harmony for teeth, muscles, bone, ligaments and temporomandibular joints. [3] Centric relation position is considered musculoskeletally to be the most stable position of the condyles in their respective fossae, in other words a stable orthopedic position. [4] Centric relation position is reached under strained muscular conditions [5], though the latest definition suggests otherwise. [1]Centric relation in the superoanterior position can be achieved with several techniques: 1. bimanual manipulation [6]; 2. anterior deprogramming devices with a jig [7] or a leaf gauge [8], and 3. a sagittal recording device; i.e. axiography. [9]

Reproducibility of bimanual manipulation has been tested and established satisfactory within a 0.11 mm tolerance. [2] Reproducibility of centric relation, determined with a leaf gauge has been reported, but the study does not reveal statistical evidence. [10] No significant differences in condylar position superoinferiorly were found between three different interocclusal records, i.e. two registrations with the leaf gauge and the third with bimanual manipulation. [11] Comparison of repeatability of condylar position between a control group and a group with the TMD diagnosis of internal derangement showed no difference in the vertical position of the axis point. However, in the horizontal plane the control group showed more variability of the axis point than the internal derangement (ID) group at three different time replicates, though no statistical significant differences were reported. [9] It is the objective of this study to investigate the clinical reliability of a measuring-procedure to locate the centric relation position, determined with the leaf gauge.

Material and Methods

A sample of 15 healthy subjects was selected, 7 men (age 36.4, SD 7.2) and 8 women (age 27, SD 4.9), range 22 to 46 years. All subjects were examined with the Research Diagnostic Criteria [12] to rule out any biophysical signs of temporomandibular disorders. All subjects were informed about the nature of a quick mount procedure and the objective of the study. All gave their informed consent.

Four irreversible hydrocolloid impressions were made of each subject and then poured in Class IV die stone, one of the maxillary and three of the mandibular arch. Next, an ear-bow was taken to mount the maxillary cast into an articulator with a magnetic split-cast system. The leaf gauge is used to adjust the occlusion and to locate centric relation. [8, 13, 14] A number of leaves are placed between the anterior teeth and the patient is asked to retrude the mandible and close firmly on the leaves. Both condyles are expected to be seated on their discs against their respective eminences. Reducing the number of leaves identifies the first contact between the teeth, increasing the number facilitates locating centric relation.

Over the years the technique has got somewhat modified. The appropriate amount of leaves to separate the back teeth sufficiently are placed between the anterior teeth and the patient is asked to slide the mandible forward, to go back, bite (hard) and relax. The procedure is repeated several times to deprogram the muscles in order to locate centric relation. [15] Three examiners, all dentists with a long time experience in the use of dental articulators, each recorded centric relation with a leaf gauge in one visit.

The following approach was selected. The patient was seated upright in a dental chair and asked to bite on a pair of cotton rolls to deprogram the neuromuscular closing pattern and facilitate retrusion of the mandible. [16] The first examiner determined the appropriate amount of leaves to separate the back teeth of the subject sufficiently.

In general, the amount of leaves necessary was between 30 and 40. The patient was instructed to close on his back teeth and bite with both central incisors on the leaf gauge to seat their condyles against their respective eminences. After a few minutes the patient was asked to protrude the mandible, retrude, bite and relax. The procedure was repeated several times to make the patient familiar with it. Then three sets of interocclusal wax records per examiner were prepared. A plate of wax was softened in a hot water bath at 52 degrees Celsius. The plate was folded and interocclusal records of an appropriate size, from cuspid to second molar, were cut with scissors. Three sequential interocclusal records were taken by each examiner (Fig. 2-1 a, b, c). Next, each examiner mounted one lower cast with the first pair of interocclusal records, resulting in three sets of mounted casts with the same upper and for each rater their own individual lower cast. Both upper and lower cast were mounted with magnetic split-cast mounting plates for convenience of handling in the measuring-procedure (Fig. 2-2).

Figure 2-1. (a) Huffmann's leaf gauge; (b) Three sets of interocclusal wax records; (c) The leaf gauge and the wax records in situ in the patients mouth.

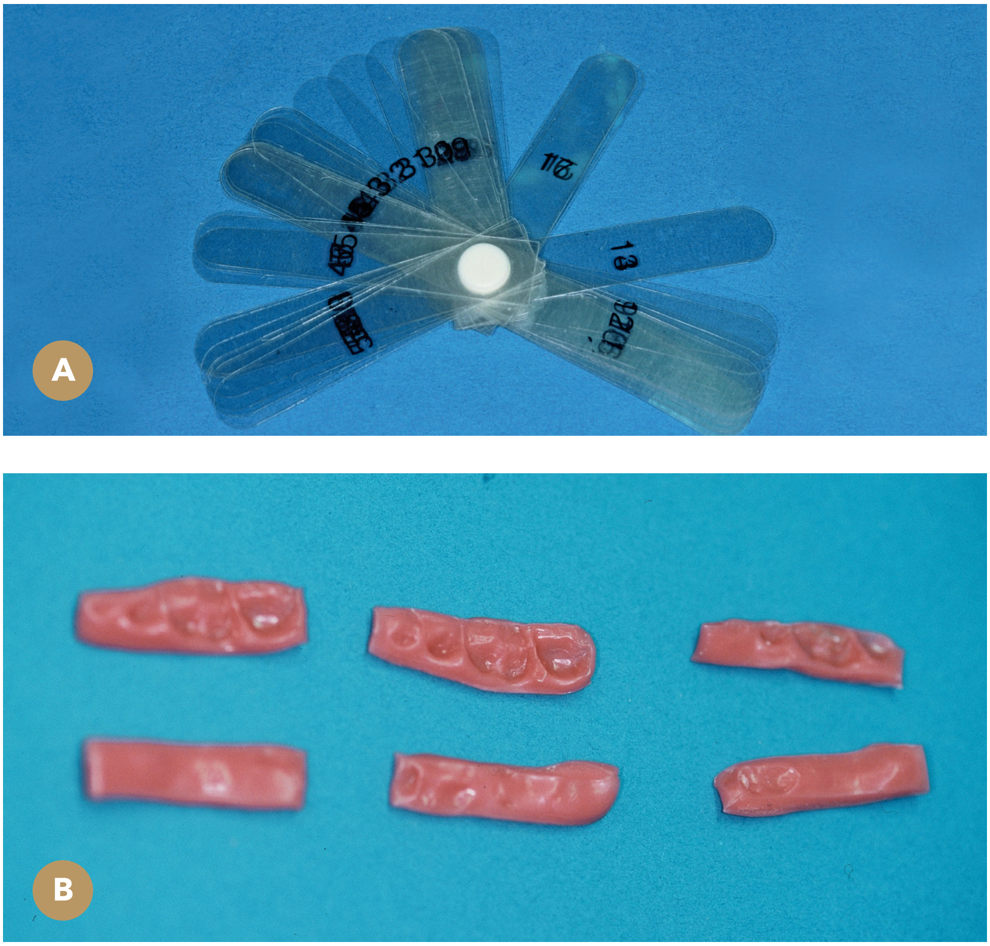


Figure 2-2. Mounted set of casts in an articulator

Next, the casts were transferred into the Condymeter III. This instrument is a sophisticated articulator in which the condylar housing is exchanged for a set of 6 measuring gauges with a 5 millimeter measuring range each (Fig. 2-3). 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 (Cartesian system).

Figure 2-3. The Condymeter, version III

Figure 2-4. The measuring gauges of the Condymeter III (detail)

The x-values represent the sagittal, the y-values the transversal, and the z-values the vertical component. Subsequently, the instrument gives the observer 6 dependent variables: XR, XL, YR, YL, ZR and ZL. Calibration of the instrument beforehand sets all gauges at 2.50 millimeter, being the expected value, when sequential wax records are assessed (Fig. 2-4) In total 9 sets of interocclusal records per patient have been measured with the Condymeter III and the outcome was written on the subject's individual data chart.

To conclude the procedure, clinical precision of the interocclusal records was tested with the split-cast method. When all three interocclusal records coincided, the data of the Condymeter III were accepted as being correct. When three sets of interocclusal records coincided for all three observers, data were used for statistical analysis. The examiners recorded the centric relation reference position of the same patient in various order. The applied statistical method is an analysis of variance model (ANOVA) with two factors for 3 observers and 12 subjects. The variance components estimation procedure is MIVQUE (0). The level of significance was set at 0.05.

Results

From the 15 subjects that were assessed in this study, 12 fitted the criteria regarding clinical precision with the split-cast check that were formulated beforehand. Only data were used when three sets of interocclusal records for all three observers coincided. The database consists of the dependent variables: XR, XL, YR, YL, ZR en ZL to a total of 108 observations. The data were tested and showed a normal distribution. Mean values and standard deviations for three observers are given in table 1.

Table 1. Mean values and standard deviations in millimeters of the variables XL,XR, YL, YR, ZL and ZR for three observers and 12 subjects

	XL		XR		YL		YR		ZL		ZR	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Observer 1	2.42	0.27	2.45	0.28	2.55	0.11	2.45	0.11	2.58	0.28	2.50	0.33
Observer 2	2.41	0.20	2.46	0.26	2.56	0.13	2.43	0.13	2.50	0.27	2.57	0.32
Observer 3	2.42	0.23	2.52	0.24	2.54	0.14	2.45	0.13	2.55	0.28	2.57	0.27

An analysis of variance of all 6 variables for three observers is given in table 2. Calibration of the Condymeter III instrument sets the expected value at 2.50 millimeter. There is no significant difference between observers for all 6 variables .

Table 2. Analysis of variance (ANOVA) of the variables XL. XR. YL. YR. ZL and ZR for testing differences between 3 observers

	XL	XR	YL	YR	ZL	ZR
Mean	2.42	2.48	2.55	2.44	2.56	2.55
SD	0.21	0.23	0.12	0.12	0.25	0.24
P-value	0.95	0.38	0.73	0.76	0.44	0.40

The various variance (σ^2) components are represented in the following equation: $\sigma^2_{total} = \sigma^2_{observers} + \sigma^2_{subjects} + \sigma^2_{error}$ The total variance of the measuring procedure consists of the variance of the observers, the variance of the subjects and the variance of the measuring technique. The latter consists of the error of the instrumentation. The estimates of the variance for all variables is given in Table 3. As table 3 shows, the estimates of variance for the three observers is negative, indicating that the variance is too small for an appropriate estimate and consequently must be set at 0.

Table 3. The MIVQUE (0) estimates for the variables XL. XR. YL. YR. ZL and ZR

Variance Component (SD)	XL	XR	YL	YR	ZL	ZR
Observers	< 0.000	< 0.000	< 0.000	< 0.000	< 0.000	< 0.000
Subjects	0.01138 (0.10)	0.01577 (0.12)	0.0020922 (0.045)	0.002136 (0.046)	0.01527 (0.12)	0.04169 (0.20)
Error	0.04711 (0.21)	0.05478 (0.23)	0.01570 (0.12)	0.01489 (0.12)	0.06442 (0.25)	0.06103 (0.24)

Discussion

Since the variance between observers is negligible, the variance is caused by the subjects and the measuring technique. The between subjects variance is smaller than the error in the measuring technique and varies between 0.04 and 0.20 for the various variables. The latter varies between 0.12 and 0.25 millimeter and determines the reliability of the measuring-procedure predominantly.

The variance components for the variables YL and YR have the smallest values, as a result of the fixed intercondylar distance in the Condymeter III. The total variance that was found in this study, was relatively small.

In this study it was the choice to measure the interocclusal records in the Condymeter III first before checking clinical precision in a split-cast procedure. For future study it seems obvious to check clinical precision of the sequential wax-records first before measuring in the Condymeter III, since it is of no use to assess clinical inaccuracy.

Since the Glossary of Prosthodontic Terms [1] provides the dental community with no less than seven different definitions of the centric relation position, it must be clear that the discussion on the topic of the centric relation position has not been concluded yet. The difficulty to manipulate the mandible in patients with temporomandibular disorders is in favor of a muscle-determined rather than an operator guided technique. It is therefore an argument to further investigate a measuring-procedure to accomplish a muscle-determined centric relation position as a reference position for occlusal analysis and a treatment position for the benefit of patients with a variety of temporomandibular disorders.

The results of this study indicate a satisfactory reliability of the measuring-procedure with no ifferences between observers and acceptable variance between subjects and technical error. This means that the measuring-procedure is a reliable procedure to determine the centric relation position with a leaf gauge.

A second pilot study will be done to compare the results of this study with a sample of TMD-patients who will be diagnosed with the Research Diagnostic Criteria, as proposed by Dworkin. [12] The results of both studies will be used as pilot data to formulate a correct research hypothesis for a clinical trial. In this clinical trial centric relation will be assessed with the leaf gauge and compared to the chin point guidance technique, being the most commonly used technique to achieve centric relation.

References

1 Glossary of Prosthodontic Terms, Edition 7, J Prosthet Dent 1999;81:58.

2 McKee JR. Comparing condylar position repeatability for standardized versus non-standardized methods of achieving centric relation. J Prosthet Dent 1997;77:280-284.

3 Atwood DA. A critique of research of the posterior limit of the mandibular position. J Prosthet Dent1968;20;21-36.

4 Okeson JP. Management of Temporomandibular Disorders and Occlusion. 4th ed. St. Louis: CV Mosby; 2003. p. 512..

5 Koole P. Masticatory muscle function: a multi-channel electromyographic investigation. PhD-dissertation Rijksuniversiteit Groningen, The Netherlands, 1998:333-4.

6 Dawson PE. Evaluation, diagnosis, and treatment of occlusal problems. 2nd ed. St. Louis: CV Mosby; 1989. p. 28 -54

7 Lucia VO. A technique for recording centric relation. J Prosthet Dent 1964;13:492-505.

8 Long JH. Locating centric relation with a leaf gauge. J Prosthet Dent 1973;29:608-610.

9 Harper RP, Schneiderman E. Condylar movement and centric relation in patients with internal derangement of the temporomandibular joint. J Prosthet Dent 1996;75:67-71

10 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.

11 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.

12 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.

13 McHorris WH. Centric Relation: Defined. J Gnathology 1985;5:4-21.

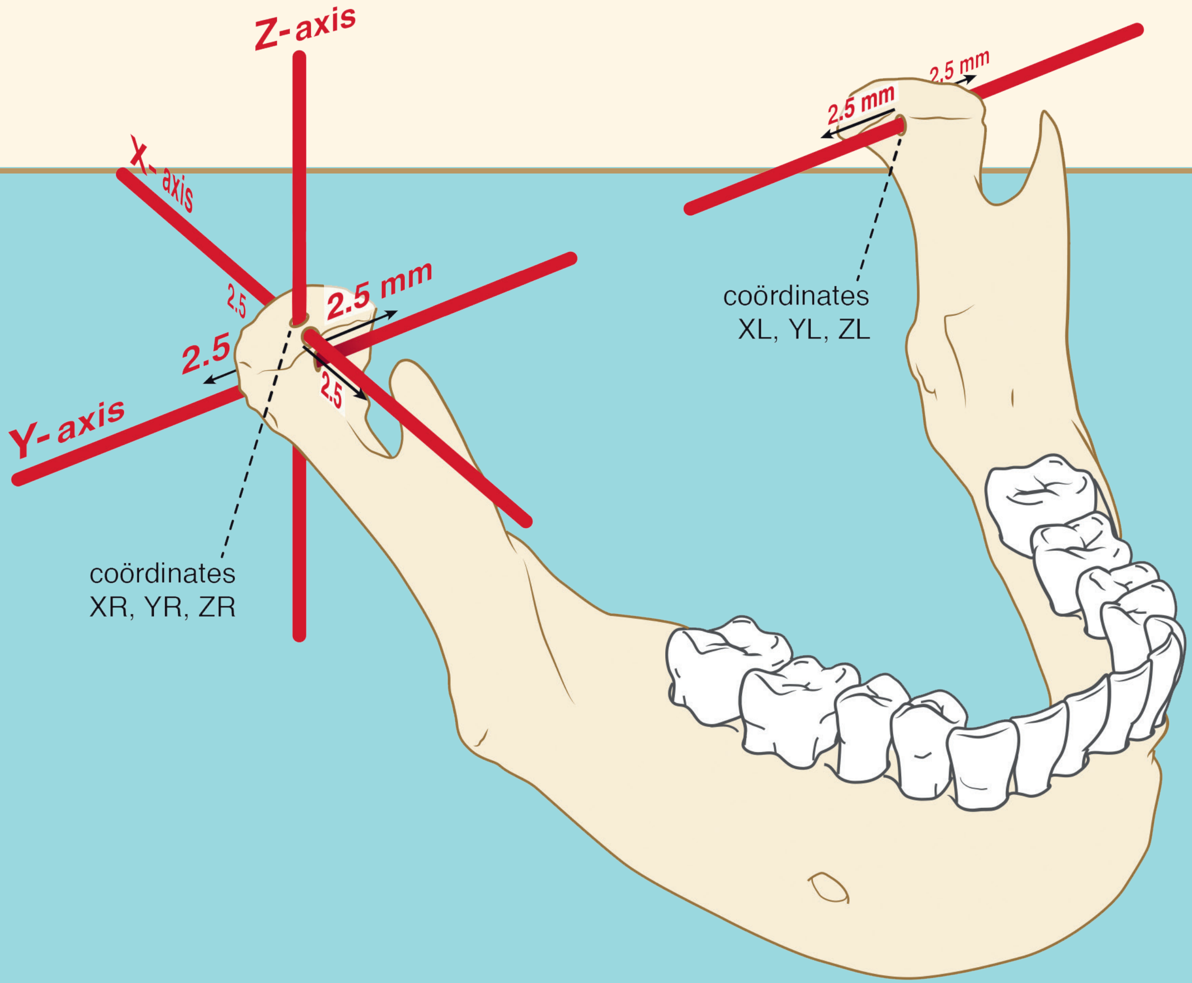
14 Carroll WJ, Woelfel JB, Huffman RW. Simple application of anterior jig or leaf gauge in routine clinical practice. J Prosthet Dent 1988;59:611-617.

15 McHorris WH. Occlusal Adjustment via Selective Cutting of Natural Teeth. J Gnathology 1997;16:37-51.

16 Kabcenell JL. Effect of clinical procedures on mandibular position. J Prosthet Dent 1964;14:266-278.

Chapter 3

Variability of centric relation position in TMD patients.



A.J.J. Zonnenberg
J. Mulder

Eur J Prosthod Rest Dent 2006;14(1):32-37.

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, jaw 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, 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, ZL and ZR.

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 patients by means of the leaf 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 finish a maxillary stabilization splint. [4] Several techniques to determine this centric relation position have been proposed: some operator guided [3, 6-8], other muscle-determined [3,4, 9-14].

Bimanual manipulation [4] 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. [4, 8] Reproducibility of bimanual manipulation 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, deter-mined with a leaf gauge has been reported in the literature, but lacks statistical evidence. [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 the condyles in its true skeletal position and preparing the patient for interocclusal centric relation records. [13] Even a favorable 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 subjects 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 to diagnose their principal temporomandibular disorder. [20] 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);

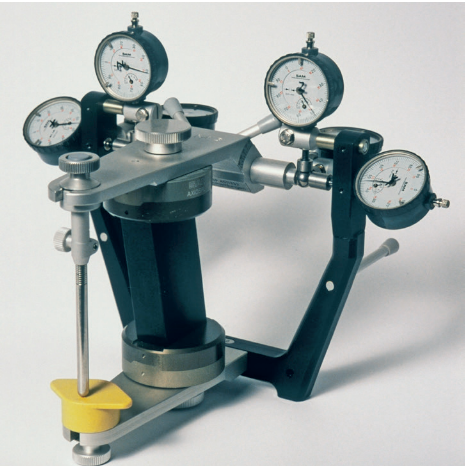
d Capsulitis (arthralgia): pain on palpation of the joint and the capsule, no joint sounds such as coarse crepitus, or
Osteoarthritis: pain on palpation of the joint, coarse crepitus, radiographic confirmation of degeneration (OA) , or
Osteoarthrosis: Absence of pain in the joint, (coarse) crepitus,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

The Research Diagnostic Criteria can, in potential, 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-diagnoses is given in table 1.

For precision and convenience purposes a quick mount 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 base plate wax was tested in the Condymeter (Condymeter, SAM-Company Munich, Germany) 22 . Interocclusal wax records (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 a quick mount procedure and the objective of the study. All gave their informed consent. The quick mount 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. 3-1). Next, the casts were transferred into the Condymeter III (Condymeter, version III, SAM-Company Munich, Germany) .

Figure 3-1. Mounted set of casts in an articulator

Figure 3-2. The Condymeter, version III

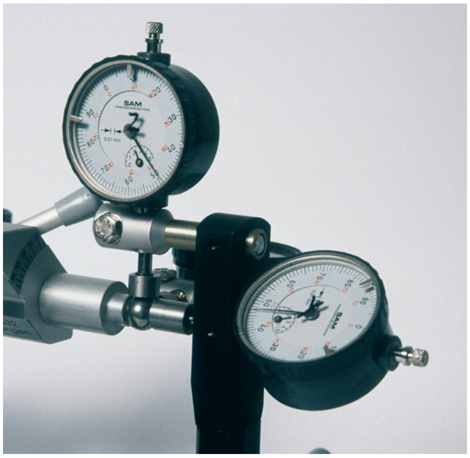


This instrument is a sophisticated articulator, in which the condylar housing has been exchanged for a set of 6 measuring gauges with a 5 millimeter measuring range each (Fig. 3-2). The instrument has been designed to measure any displacement of the mandible away from the centric relation position along the sagittal, the transversal and the vertical condylar level on both sides. Subsequently, the instrument gives the observer 6 dependent variables: XR, XL, YR, YL, ZR and ZL.

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 Condimeter III (Fig. 3-3) 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 6 dependent variables XR, XL, YR, YL, ZR and ZL. 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 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.

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



Results

The data of 12 control subjects and 60 patients were assessed in this study. Only data were used when 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 I. 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
MYO	13
MYO/ID with Reduction	23
ID without reduction	9
OA	14
TRAUMA	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.

Table II. 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	9	2.539	0.177	2.573	0.171	2.399	0.208	2.591	0.210	2.261	0.152	2.457	0.253
MYO	13	2.436	0.136	2.422	0.186	2.422	0.150	2.613	0.221	2.485	0.287	2.626	0.241
MYO/D	23	2.437	0.173	2.516	0.196	2.485	0.213	2.494	0.229	2.355	0.260	2.561	0.216
OA	14	2.425	0.153	2.483	0.221	2.469	0.152	2.545	0.149	2.375	0.225	2.578	0.153
controls	12	2.422	0.228	2.460	0.227	2.550	0.089	2.450	0.084	2.581	0.215	2.510	0.309

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, ZL and ZR. 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, ZR, XMIN, YMIN, ZMIN, XMAX, YMAX, ZMAX, XDIFF, YDIFF and ZDIFF showed no significant differences.

Table III. Analysis of variance (ANOVA) of the variables XL, XR, YL, YR, ZL and ZR.

	XL	XR	YL	YR	ZL	ZR
Mean	2.44	2.48	2.47	2.53	2.40	2.55
SD	0.26	0.33	0.34	0.41	0.72	0.37
P-value	0.54	0.46	0.27	0.19	0.02*	0.50

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 α + z 2β) 2 x (0.153)2 / (0.146)2 in which z α is 1.96 at α = 0,05 en z 2β is 1.65 at β = 0,95. Consequently, approximately 26 subjects are necessary per subdiagnosis of TMD or controls.

Table IV. Analysis of variance for the variables XMIN, YMIN, ZMIN, XMAX, YMAX, ZMAX, XDIFF, YDIFF and ZDIFF.

	XMIN	YMIN	ZMIN	XMAX	YMAX	ZMAX	XDIFF	YDIFF	ZDIFF
Mean	2.36	2.34	2.34	2.56	2.65	2.62	0.20	0.31	0.28
SD	0.31	0.26	0.46	0.29	0.23	0.45	0.23	0.47	0.20
P-value	0.40	0.22	0.27	0.35	0.40	0.14	0.30	0.31	0.85

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 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 on the elevator muscles as well as intracapsularly. [11, 18]

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 o 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 split-cast 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.

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;23:401-408.

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;76:282-287.

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 non-standardized methods of achieving centric relation. J Prosthet Dent 1997;77:280-284.

7 Keshvad A, Winstanley RB. Comparison of the replicability of routinely used centric relation registration techniques. J Prosthodont 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;30:591-598.

10 Long JH. Locating centric relation with a leaf gauge. J Prosthet Dent 1973;29:608-610.

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;94:389-393.

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;87:387-394.

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;83:235-247.

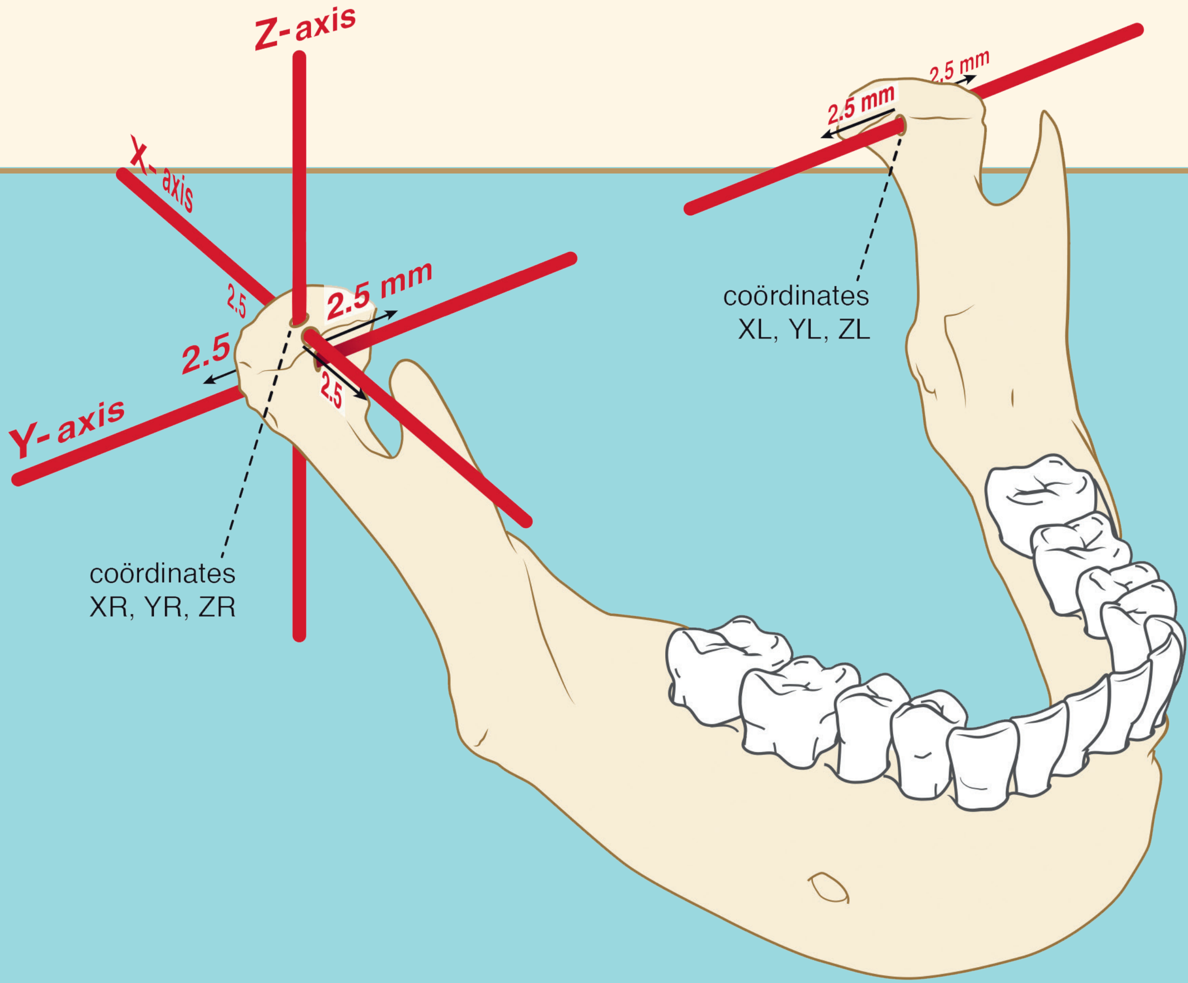
24 Keshvad A, Winstanley RB. An appraisal of the literature on centric relation. J Oral Rehabil 2001;28: 55-63.

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.

Chapter 4

Reproducibility of 2 methods to locate centric relation in healthy individuals and TMD patients.



A.J.J. Zonnenberg
J. Mulder

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Abstract

No conclusive evidence exists for any maxillomandibular relationship as the preferable treatment position. Measurement reliability of 2 different methods to attempt to locate centric relation in control and TMD patients was assessed to determine if both methods lead to the same position. A group of 27 controls and 91 TMD patients were examined using the Research Diagnostic Criteria for TMD (RDC/TMD). Three patient groups were recruited: 27 patients with myofascial pain (MYO), 34 patients with disc displacement without reduction (ID), and 30 patients with osteoarthritis (OA). For each study participant centric relation was located with chinpoint guidance and a technique with a leaf gauge, for the controls once, for all TMD patients before and after stabilization splint treatment. A paired t-test and a number of mixed models were applied to the collected data and Fisher's exact tests were performed to test changes in the number of TMD patients having a coincident split-cast result before and after splint treatment. The mixed model procedure revealed no significant differences between the methods, the patient groups and the time interval. However, the patient groups at baseline and conclusion of treatment differed significantly from the controls. The percentage of patients (15.9%) having a coincident split-cast result for both methods was significantly smaller ($P<.001$) than the corresponding percentage (85.2%) of controls. After splint treatment, the percentage of coincident split-casts increased from 15.9% to 76.8% ($P=.42$; Fisher's exact test). Both methods are reproducible techniques to locate centric relation for control and TMD patients. However, the leaf gauge provides the clinician a different centric relation position in TMD patients than chinpoint guidance does.

Introduction

Determining the maxillomandibular relationship is a routine procedure in dental practice. Among the decisive factors are first, that the chosen mandibular position must be reproducible for both the operator and the patient, and secondly that this therapeutic position must be physiologically acceptable and comfortable for the patient. [1]

The maximal intercuspal position is a stable and clinically readily reproducible treatment position. However, centric relation is universally accepted as the reference position of choice for extensive restorative dentistry. [2, 3] Multiple techniques to determine and transfer centric relation have been studied and proposed, all for healthy individuals [4-19], some for TMD patients. [20-22] Chinpoint guided computerized axiography [22] shows a high intra-/interrater measurement reliability of the condylar reference position in asymptomatic and symptomatic patients. However, transfer of the maxillomandibular relationship with zinc oxide-eugenol impression paste remains troublesome. [22] Pantography claims to be a diagnostic test for temporomandibular dysfunction rather than a method to locate centric relation. [20, 21] No single approach appears to be superior over another, nor for all clinical circumstances. Among these, bimanual manipulation [8, 10, 12, 18] and chinpoint guidance appear to be often used. Variability of chinpoint guidance has been documented extensively in healthy individuals. [23, 24] Chinpoint guidance allows the operator to determine the most retruded relation of the mandible to the maxilla, when the condyles are in the most posterior, unstrained position in the glenoid fossae from which lateral movements can be made at any given degree of jaw separation. [25] Centric relation has most recently been defined as 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. [25]

Over 5 decades the concept of centric relation has evolved from the most retruded, ligamentous position [5], via the posterior, unstrained position [7] and the uppermost apex of force [8,10] to contemporary thinking, that it is the superior-anterior [3,18] strained position. It is considered impossible to achieve centric relation in TMD patients, since one or more of the criteria of centric relation [10] cannot be fulfilled. However, in many patients an adapted centric posture [10, 18] can be accomplished.

In the presence of musculoskeletal facial pain, the reproducibility of centric relation registrations appears to be questionable. [10, 26, 27] In one study an artificial masticatory muscle disorder was induced by placing 5% hypertonic saline solution into the central portion of the superficial masseter muscle of 5 volunteers. The resulting experimental muscle pain affected the mandibular border movements and the apex of the tracing in both anterior-posterior and transverse directions from 0.0 to 0.6 mm with a mean value of 0.22 mm. [27] All pain-induced effects proved to be reversible.

In the most recent Glossary of Prosthodontic Terms [25], the centric relation position is considered identical to the musculoskeletally stable or stable orthopaedic position of the mandible [3]. Clinically this musculoskeletally stable position can be obtained with bimanual manipulation [12, 18], with a jig [18] or, similarly, with a leaf gauge. [3, 28-32] The musculoskeletally stable position with a leaf gauge is located by instructing the patient to "close on the back teeth" and then to protrude the mandible while the incisors maintain contact with the leaf gauge, followed by retruding the mandible, biting on the leaf gauge and relaxing the elevator muscles. [29, 32] Bimanual manipulation in particular is a well-documented and reproducible method [12, 18] to achieve this position. However, the method has been documented for healthy individuals. One of the studies just discussed [12] would suggest that in the presence of pain an accurate location of centric relation may prove difficult.

Any comprehensive treatment of the occlusion, including treatment with a stabilization splint [33], demands a physiologically and functionally acceptable reference position. [1-19, 22] Many clinicians have suggested that treatment goals should include the concept of having the centric relation position of the condyles coincide with the maximal intercuspal position of the teeth. [2-18] Yet, no conclusive evidence exists to either favour or reject any specific centric relation position as the optimally defined treatment position. [3] The purpose of this study was to assess measurement reliability of 2 different methods to locate centric relation, an operator-guided and a muscle-determined technique, to determine if with either method the same centric relation position can be obtained. The null hypothesis was that there would be no differences between the obtained centric relation positions, in healthy individuals and in TMD patients prior to and after stabilization splint treatment.

Material and methods

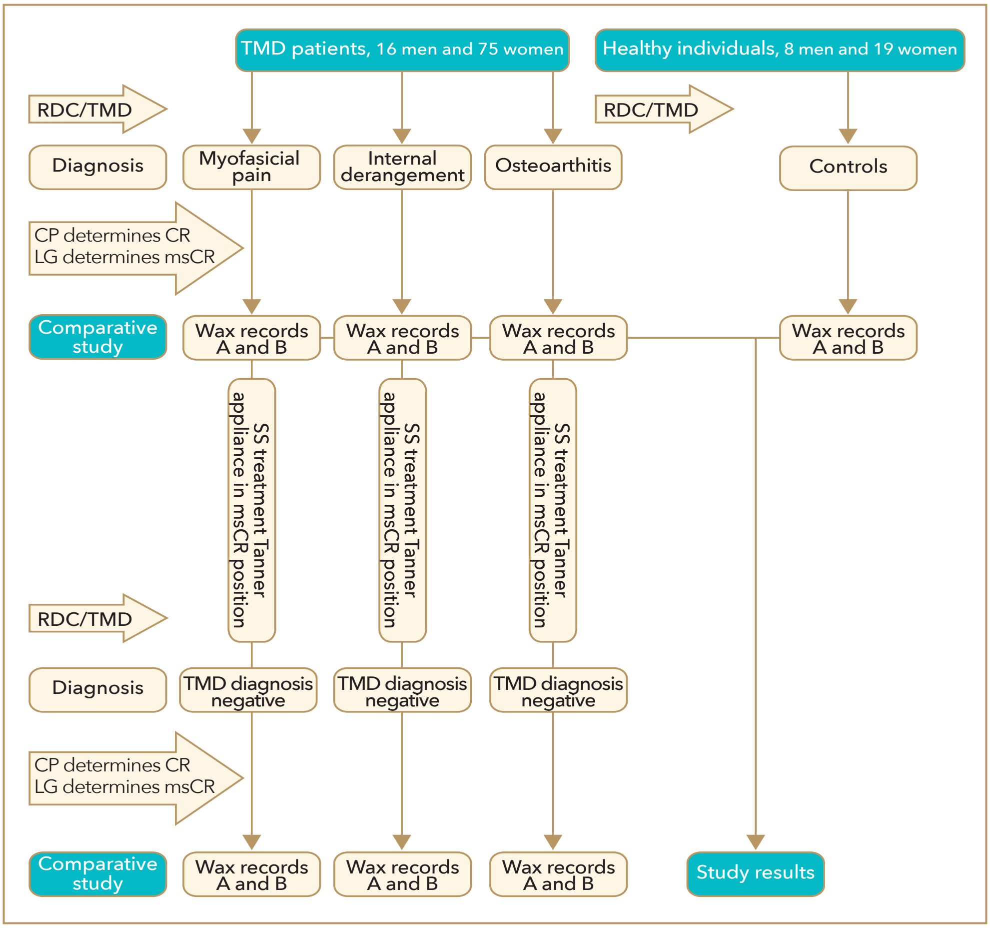
In a controlled clinical study measurement reliability was assessed of chinpoint-guided and the musculoskeletally stable centric relation position, in control and in TMD patients. Potential differences between both centric relation positions were tested in the controls and in the TMD patients, at baseline and conclusion of stabilization splint treatment.

The study enrolled a group of healthy individuals and 3 patient groups. One hundred and eighteen individuals participated in this study: 27 control subjects, 8 men and 19 women, recruited at a private dental office, and a group of 91 TMD patients, 16 men and 75 women. The TMD patients presented themselves for treatment at the Clinic of Special Dental Care, Amsterdam, the Netherlands with pain. [34] All subjects were examined with the Research Diagnostic Criteria for TMD (RDC/TMD) [35], Axis I, to diagnose the chief temporomandibular disorder of the patients and to exclude a TMD diagnosis for the control subjects. [36] The data of the RDC/TMD, Axis II of 91 patients were collected as well, however, they will not be discussed within the framework of this manuscript.

TMD patients were allocated to diagnostic subgroups based on one of the following diagnoses from Axis I: 27 patients were diagnosed with a masticatory muscle disorder (n=27), 17 with limited and 10 with unlimited mouth opening, LO and UO respectively; 34 patients were diagnosed with disc displacement without reduction (n=34), 23 of whom had limited opening (L) and 11 without limited mouth opening (O); and 30 patients were diagnosed with osteoarthritis (OA). The study design is presented in Figure 4-1.

In a power analysis conducted in a previous study [28], the minimally required number of participants was calculated to be 26 subjects per group. From this pilot study the biggest difference [28] was found in variable XL = 0.146 with the corresponding standard deviation SD = 0.153. Variable XL represents one of the 6 variables that determine the condylar axis. Consequently, the power analysis [28] will be represented by $N = 2\,(z_\alpha + z_{2\beta})^2 \times (0.153)^2 / (0.146)^2$ in which z_α is 1.96 at $\alpha = 0.05$ and $z_{2\beta} = 1.65$ at $\beta = 0.95$. All subjects were informed about the nature and objective of a quick-mount procedure and the purpose of this study to compare 2 different methods to record their maxillomandibular relationship. Written informed consent was obtained from all

Fig. 4-1. *Flowchart of the study design. CP = chinpoint guidance, CR = centric relation, LG = leaf gauge, msCR = musculoskeletally stable centric relation.*



participants in this study. For the comparison of both methods to locate centric relation an IRB approval was obtained from the Medical Ethical Committee of the University of Utrecht, Netherlands.

The study design was double-blinded and controlled using a principal investigator and 2 examiners. The investigator was blinded for the order and method to take consecutive wax records and the examiners for the patient's diagnosis. The principal investigator examined all patients and control subjects and allocated them to the appropriate diagnostic group. At the same appointment 3 impressions were made with irreversible hydrocolloid (CA 37, Cavex), 1 maxillary and 2 mandibular to conduct a quick-mount procedure. These were poured in type IV stone (Fuji Rock; GC). An arbitrary face-bow (Axioquick; SAM-Co) transfer was used to orient the maxillary cast to an articulator (SAM 2P, SAM-Co). Magnetic split-cast mounting plates (Axiosplit, SAM-Co) were used to facilitate the exchange of individual casts from the articulator for the split-cast and measuring procedures. Split-cast mounting is a method of mounting casts wherein the dental cast's base is sharply grooved and magnetically keyed to the mounting ring's base. The procedure allows verifying the accuracy of the mounting by coincidence of the dental cast's base and the mounting ring's base.

At a second visit 1 out of 2 calibrated examiners, X or Y, prepared 2 identical sets of 3 interocclusal wax records (Fig. 4-2) that were labelled A and B for blinding purposes (Moyco Wax, Pink X-hard). Next, the available examiner made sequential centric relation records, starting with chinpoint guidance or with the leaf gauge (Huffmann's leaf gauge) technique. A 1-3 and B 1-3 (Fig. 4-2) wax records were made, representing chinpoint guidance or the technique with the leaf gauge in that particular patient. The sequential wax records were cooled in cold water with ice. The order in which both techniques were recorded, was noted on the patient chart, including the number of leaves used. All wax records consisted of 2 layers of wax, cut to size with scissors.

Fig. 4-2. Interocclusal wax record series A and B.

Wax record sets A and B were returned to the principal investigator for mounting and further instrumental analysis. Wax record A1 and B1 were used to mount a mandibular cast A and B respectively in the articulator. A split-cast procedure was performed to check the accuracy of the 2 mountings. For a correct mounting of the mandibular cast, at least 2 out of 3 wax records A 1-3 and B 1-3 had to show visual coincidence of the dental cast's base and the mounting ring's base. Next wax record B1 was tested on mandibular cast A to determine if the mounting of the mandibular cast A and B were coincident.

The casts were then transferred into the condymeter (Condymeter III; SAM-Co) to quantify the accuracy at the level of the condylar axis. This articulator in lieue of the condylar housing has 2 sets of 3 measuring gauges, each with a measuring range from 0 to 5 mm, subdivided in 0.1 mm increments (Fig. 4-3 and 4-4). The instrument has been designed to measure any displacement of the condylar axis along the x, y and z-axes bilaterally. Instrument calibration of the condymeter with a specific calibration tool (Master check P, SAM-Co) was conducted before the assessment of the wax record sets of each individual.

Fig. 4-3. Condymeter, version III.

Fig. 4-4. Detail of Condymeter III.

This tool sets all gauges at 2.50 mm, being the reference value, when sequential centric relation wax records are assessed (Fig. 4-4). Of each wax record the instrument provides a dataset of 6 variables: XR, XL, YR, YL, ZR and ZL, representing the displacement at the level of the condylar axis. R refers to the right, L to the left condyle. Only the values of the coincident wax records, A 1-3 and B 1-3, in the split-cast analysis were accepted and recorded. The data of the 6 variables consisted of 2 or 3 values after the split-cast analysis, since at least 2 out of 3 wax records had to be coincident. The mean value of these 2 or 3 values was considered in the statistical analysis.

After instrumental analysis a Tanner type stabilization splint was fabricated on the leaf gauge articulation for each of the TMD patients. [37,38] A Tanner appliance is a mandibular full-coverage, heat-cured acrylic splint with cuspid-to-cuspid anterior guidance and the lingual, maxillary cusps in contact with the appliance. [39] Splint treatment was continued until resolution of symptoms and the patient reported to be pain-free in a follow-up visit. Next, all patients were re-examined with RDC/TMD, to confirm the absence of the patient’s initial TMD diagnosis. The mean time elapsed from the initial TMD diagnosis until the active monitoring of the appliance stopped, was 7.5 months (range 3-12) for the masticatory muscle group, 8.2 months (range 5-12) for the disc displacement without reduction group, and 7.4 months (range 4-12) for the osteoarthritis group respectively. The mean time the splint treatment was monitored, was 5 months (range 2-9) for the masticatory muscle disorder group, 6.8 months (range 3-12) for the disc displacement without reduction group and 5.4 months (range 2-12) for the osteoarthritis group. Next a second quick-mount procedure was initiated. The RDC/TMD, the location of centric relation and the written informed consent of the controls required a single visit.

For the analysis of the variables XL, XR, YL, YR, ZL and ZR a paired t-test and a number of mixed models were applied (SAS/STAT, version 9, SAS Institute. Cary NC, USA). The mixed model is a specific ANOVA model with fixed and random factors. The fixed factors methods, diagnostic group and point in time (at baseline and at conclusion of splint treatment) were tested for differences. Subjects were the random factor in each model. The Bonferroni correction was chosen for multiple comparison of the 3 diagnostic groups. Three extra models were applied to test each of the variables age (continuous), gender (class), and the duration of treatment (continuous) by adding these variables to the first mixed model. To test the duration of treatment between baseline and conclusion of treatment one-way ANOVA was performed. To assess accuracy of the 2 methods a F-test was performed. Fisher's exact tests were performed to test changes in the number of patients having a coincident split-cast result for both methods (CP=LG). A P-value of less than .05 was considered significant.

Results

Age and gender distribution of the control and the 3 patient groups is listed in Table I. The subdivision of the TMD diagnoses is listed in Table II. Over the duration of the study, attrition was as follows: Of 91 patients, 1 woman dropped out of 27 (3.7%) from the masticatory muscle disorder group (MYO), there were 5 dropouts from the disc displacement without reduction group (ID), 1 man and 4 women (14.7%), and 2 women of 30 (6.7%) dropped out from the osteoarthritis (OA) group. Dropouts occurred for various reasons. Three patients relocated, 3 quit treatment without notice. One patient developed another diagnosis during treatment and 1 patient discontinued treatment as a result of her comprehensive Axis II disorder. Consequently, the data of the condymeter (SAM, Co) from 83 successfully treated patients at baseline and at conclusion of treatment were assessed.In a paired t-test no significant differences were found in the control group for the 2 methods to locate centric relation (Table III). The variance of either method was tested for differences, however, the performed F-test showed no statistical significance for any of the 6 variables (P>.2).

Table I. Distribution of TMD diagnosis and control subjects. MYO = masticatory muscle disorder, ID = disc displacement without reduction, OA = osteoarthritis

Group	Age		Number	Gender	
	Mean	SD	N	Male	Female
Control	37	14	27	8	19
MYO	32	9	27	7	20
ID	35	15	34	5	29
OA	40	13	30	5	25
All	36	13	118	25	93

Table II. Subdivision of participants in study diagnosed with RDC/TMD Axis 1. LO = restricted mouth opening < 40 mm, UO = unrestricted mouth opening, L = without reduction with limited opening < 36 mm, O = without reduction without limited opening

Diagnosis	Subdiagnosis	n
Control subjects		27
MYO	LO	16
	UO	10
	Dropout	1
ID	L	21
	O	8
	Dropout	5
OA		28
	Dropout	2

Table III. Student's paired t-test of the factor method to locate centric relation in the dataset of the control subjects. CP = chinpoint guidance, LG = leaf gauge

Variable	Mean difference CP – LG in millimetre	Standard Deviation	P
XL	0.006	0.175	.84
XR	-0.027	0.140	.32
YL	0.010	0.107	.62
YR	-0.010	0.107	.62
ZL	-0.016	0.164	.60
ZR	0.015	0.136	.56

A mixed model was applied to test the random factor (patients) with the fixed factors (3 patient groups, method to locate centric relation and point in time before and after splint treatment). The applied model did not show any significant difference for the factor patient group, method and point in time except for variable ZR in point in time (Estimate of ZR = 0.035, St. Error = .012, P=.004). Age, gender and duration of treatment were included in the analysis and did not significantly influence any of the results.

In the next analysis, controls were compared to the patient groups in 2 separate mixed models, at baseline and conclusion of treatment. The variables in half of the comparisons from the patients at baseline (Table IV and V) as well as after treatment (Table VI and VII) significantly differed from those obtained from the control subjects. The differences (in mm) were the largest for variable ZR between the ID and the control group at baseline (Estimate of ZR = -.101, St. Error = .018, P<.001).

In a frequency procedure the percentage of patients at baseline who had their chinpoint guided mounting coinciding with their leaf gauge mounting (15.9%) in the TMD groups was significantly smaller than the corresponding percentage (85.2%) of the controls (P<.001; Fisher's Exact Test). At conclusion of treatment the percentage of patients that had their chinpoint guided mounting identical to the leaf gauge mounting had increased from 15.9% to 76.8% and no longer differed from the percentage of the control subjects 85.2% (P =.42; Fisher's exact test).

Table IV. Mean values in millimetres in a mixed model of variables XL, XR, YL, YR, ZL and ZR in comparison of various diagnostic groups at baseline of treatment. Superscripted small characters refer to significant differences between variables of diagnostic groups.

Group		XL	XR	YL	YR	ZL	ZR
a	ID	2.55^{d}	$2.44^{c,d}$	$2.53^{c,d}$	$2.47^{c,d}$	2.52	2.47^{d}
b	MYO	2.54	2.46^{d}	2.54^{d}	2.46^{d}	2.50^{d}	2.47^{d}
c	OA	2.53	$2.48^{a,d}$	$2.56^{a,d}$	$2.44^{a,d}$	2.49^{d}	2.47^{d}
d	Control	2.51^{a}	$2.52^{a,b,c}$	$2.49^{a,b,c}$	$2.51^{a,b,c}$	$2.55^{b,c}$	$2.57^{a,b,c}$

Table V. P values in the mixed model for various diagnostic groups at baseline of treatment.

Group	XL	XR	YL	YR	ZL	ZR
ID - MYO	.71	.26	.39	.36	.52	.99
ID - OA	.27	.02	.01	.01	.16	.80
ID - Control	.04	<.001*	<.001*	<.001*	.14	<.001*
MYO - OA	.47	.24	.14	.14	.47	.81
MYO - Control	.11	<.001*	<.001*	<.001*	.04	<.001*
OA - Control	.37	.03	<.001*	<.001*	<.001*	<.001*

* denotes significant difference after Bonferroni correction

Table VI. Mean values in millimetres in a mixed model of variables XL, XR, YL, YR, ZL and ZR in comparison of various diagnostic groups at conclusion of treatment. Superscripted small characters refer to significant differences between variables of diagnostic groups.

Group		XL	XR	YL	YR	ZL	ZR
a	ID	2.57 ^{c,d}	2.45 ^{d}	2.53 ^{d}	2.47 ^{d}	2.49 ^{b,c,d}	2.52 ^{d}
b	MYO	2.55 ^{d}	2.48 ^{d}	2.54 ^{d}	2.46 ^{d}	2.55 ^{a}	2.51 ^{d}
c	OA	2.52 ^{a}	2.45 ^{d}	2.54 ^{d}	2.46 ^{d}	2.54 ^{a}	2.49 ^{d}
d	Control	2.51 ^{a,b}	2.52 ^{a,b,c}	2.49 ^{a,b,c}	2.51 ^{a,b,c}	2.55 ^{a}	2.57 ^{a,b,c}

Table VII. P values in the mixed model for various diagnostic groups at conclusion of treatment.

Group	XL	XR	YL	YR	ZL	ZR
ID - MYO	.19	.09	.73	.68	<.001*	.47
ID - OA	.02	.98	.38	.32	.03	.20
ID - Control	<.001*	<.001*	<.001*	<.001*	<.001*	<.001*
MYO - OA	.22	.18	.55	.52	.70	.49
MYO - Control	.02	.02	<.001*	<.001*	.90	<.001*
OA - Control	.54	<.001*	<.001*	<.001*	.77	<.001*

* denotes significant difference after Bonferroni correction

Discussion

The 6 variables XL, XR, YL, YR, ZL and ZR reflect the coordinates of the condylar axis, representing the mandibular position in the articulator (SAM 2P; SAM-Co). The t-test indicated that no significant differences were found in the control group between the 2 methods to locate centric relation (Table III). The mean measured difference between the 2 condylar axes ranged from .006 ± .175 mm in variable XL to -.027 ± .140 mm in variable XR. The non-significant P-values (Table III) make obvious that both axes practically coincide. The coincidence of both lines confirms the assumption in the literature that various methods to locate centric relation result in the same mandibular position and confirms the null hypothesis, at least in healthy control subjects.[3]

Potential error of vertical dimension exists when making sequential wax records. This problem appears more likely with the chinpoint guidance technique in which no vertical stop is used. The variance of chinpoint guidance is larger than the variance of the leaf gauge technique in the three patient groups. although no significant differences were found (P>.2). To a certain extent, chinpoint guidance will be influenced by the operator and by the thickness of the wax record; however, the leaf gauge technique has a fixed occlusal stop , relies almost completely upon the dominant influence of the lateral pterygoid muscle [27] and the limitation imposed by the temporomandibular ligament [3]. The difference in variance between the two methods may be attributed to the operator's manipulation. However, such was not significantly different, suggesting that an experienced operator may use either technique according to personal preference. This appears to confirm that the operator's role in the reproducibility of centric relation records is negligible [17,22, 32].

In the TMD patients no significant differences were found between the 2 methods to locate centric relation, the patient group and the point in time of splint treatment, confirming comparable accuracy of both methods. Age, gender and duration of treatment added to the model did not influence the outcome. However, by adding the control group to the patient groups, the null hypothesis had to be rejected. The 2 methods, at baseline and at conclusion of SS treatment, showed a significant difference in half of the variables (Table IV – VII). The largest difference was found in variable ZR = .10 ± .01 mm between the ID and control group at the baseline of SS treatment. In general, the estimates for the difference between the ID and the control group were the largest. Nevertheless, all differences are well within the error of measurement that was documented previously, variable XR in MYO: -.137±.112. [28] Though extremely small, the significant differences between controls and TMD patients could indicate a causal relationship of an unknown factor in TMD patients. Splint treatment does not influence the differences. It is unknown if these differences existed before the TMD developed. However, their magnitude appears to be of limited clinical impact.

As TMD patients often complain that their teeth do not fit together properly, the presumption exists that orofacial pain influences the maxillomandibular relationship and the mandibular excursions. Both relationship and range of motion can be observed by recording a gothic arch tracing. Artificially induced musculoskeletally facial pain was caused by infusion of a hypertonic saline solution [27] and had a significant effect on the protrusive and laterotrusive mandibular excursions and the orientation in degrees of these excursions. Consequently, masseter muscle pain will probably influence the range of mandibular motion as also can be demonstrated with the pantographic reliability index. [21, 22] However, the effect of the masseter muscle pain on the anterior-posterior and the transverse position of the apex of the centric relation tracing ranged from 0.0 to 0.6 millimetre, a mean of 0.22 millimetre. As there were only 5 subjects [27] in that study and a power analysis is lacking, the suggested influence on centric relation seems to be more in line with the normal distribution in the reproducibility of a gothic arch tracing, which is less consistent than both chinpoint guidance or bimanual manipulation with a jig. [17] The normal distribution of the apex of a gothic arch tracing proved to be 0.94 millimetre anterior-posteriorly and 1.0 millimetre laterally in a sit-ting patient and 0.25 millimetre anterior-posteriorly and 0.48 millimetre in a supine patient. [4]

Another, rather conspicuous result was found in the split-cast analysis of wax record sets A and B. In patients with a TMD diagnosis, the split-cast mounting of chinpoint guidance did not coincide with the leaf gauge position before treatment in the majority of the patients. Contrary to the control group, the null hypothesis for TMD patients must be rejected. The 2 methods to locate centric relation lead to a different position. However, after splint treatment both positions were coincident in most patients, which suggests that the TMD patients start to behave as control subjects. This finding again confirms the general opinion that the various techniques to locate centric relation result in the same position [3] in healthy individuals.

The fact that in some recent studies a stabilization splint is considered to be the most effective means [37,38] in the reduction of symptoms of musculoskeletal facial pain suggests that the significance of centric relation, at least as one determining factor, is more important than thus far believed and challenged. In clinical practice, reproducibility is a valuable tool to assess the validity of a centric relation [16] record. Validation of one of both reference positions in this study as the therapeutic position of choice for extensive restorative dentistry in general and for the fabrication of a stabilization splint in particular remains to be demonstrated in a future, randomized controlled clinical trial.

Conclusions

1. Chinpoint guidance and the muscle-determined technique with the leaf gauge are reliable methods to determine the maxillomandibular reference position centric relation in healthy individuals and in TMD patients.
2. In patients with a TMD diagnosis the chinpoint guided position differs from the stable orthopaedic centric relation position at baseline of splint treatment, compared to their coincidence at conclusion of treatment.
3. Since no difference exists in the accuracy of both methods to locate CR, the difference in the CR position in TMD patients before splint treatment must be attributed to the used bite force in the technique with the leaf gauge.

References

1. Woda A, Pionchon P, Palla S. Regulation of mandibular postures: Mechanisms and clinical implications. Crit Rev Oral Biol Med, 2001;12:166-178.

2. Rosenstiel SF, Land MF, Fujimoto J. Contemporary fixed prosthodontics. 4th edn. St Louis: Elsevier, 2006; 42, 55-59.

3. Okeson JP. Management of temporomandibular disorders and occlusion. 6th edn. St. Louis: Elsevier, 2008; 12, 13, 96-98, 250-251, 473, 515-516.

4. Watanabe Y. Use of personal computers for gothic arch tracing: Analysis and evaluation of horizontal mandibular positions with edentulous prosthesis. J Prosthet Dent 1999;82:562-572.

5. Posselt U. Studies in the mobility of the human mandible. Acta Odont Scand 1952;10:19-160.

6. Lucia VO. A technique for recording A. J Prosthet Dent 1964;14:492-505.

7. Williamson EH, Steinke RM, Morse PK, Swift TR. A: A comparison of muscle-determined position and operator guidance. Am J Orthod 1980;77:133-145.

8. Dawson PE. Evaluation, diagnosis and treatment of occlusal problems. 2nd ed. St Louis: CV Mosby Co, 1989; 28-39.

9. Wood DP, Elliott RW. Reproducibility of the centric relation bite registration technique. Angle Orthod 1994;64:211-220.

10. Dawson PE. New definition for relating occlusion to varying conditions of the temporomandibular joint. J Prosthet Dent 1995:74:619-627.
11. 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;76:282-287.

12. McKee JR. Comparing condylar position repeatability for standardized versus non-standardized methods of achieving centric relation. J Prosthet Dent 1997;77:280-284.

13. Karl PJ, Foley TF. The use of a deprogramming appliance to obtain centric relation records. Angle Orthod 1999;69:117-125.

14. Keshvad A, Winstanley RB. An appraisal of the literature on A. Part I. J Oral Rehabil 2000;27:823-833.

15. Keshvad A, Winstanley RB. An appraisal of the literature on A. Part II. J Oral Rehabil 2000;27:1013-1023.

16. Keshvad A, Winstanley RB. An appraisal of the literature on A. Part III. J Oral Rehabil 2001;28:55-63.

17. Keshvad A, Winstanley RB. Comparison of the replicability of routinely used A registration techniques. J Prosthodont 2003;12:90-101.

18. 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;94:389-393.

19. Zonnenberg AJJ, Engels PA, Valk JWP, van Wonderen UGT. The intermaxillary relationship with the aid of a modified axiography. J Craniomand Pract 1989;7:305-311.

20. Clayton JA. A pantographic reproducibility index for use in diagnosing temporomandibular joint dysfunction: A report on research. J Prosthet Dent 1985;54:827-831.

21. Clayton JA, Beard CC. An electronic computerized pantographic reproducibility index for diagnosing temporomandibular joint dysfunction. J Prosthet Dent 1986;55:500-505.

22. Piehslinger E, Celar A, Celar R, Jäger W, Slavicek R. Reproducibility of the condylar reference position. J Orofac Pain 1993;7:68-75.

23. Ingervall B, Helkimo M, Carlsson GE. Recording of the retruded position of the mandible with application of varying external pressure to the lower jaw in man. Archs Oral Biol 1971;16:1165-1171.

24. Helkimo M, Ingervall B, Carlsson GE. Comparison of different methods in active and passive recording of the retruded position of the mandible. Scand J Dent Res 1973;81:265-271.

25. Glossary of Prosthodontic Terms. 8th ed. J Prosthet Dent 2005;94:22.

26. Obrez A, Türp JC. The effect of musculoskeletal facial pain on registration of maxillomandibular relationships and treatment planning: A synthesis of the literature. J Prosthet Dent 1998;79:439-445.

27. Obrez A, Stohler CS. Jaw muscle pain and its effect on gothic arch tracings. J Prosthet Dent 1996;75:393-398.

28. Zonnenberg AJJ, Mulder J. Variability of A Position in TMD Patients. Eur J Prosthodont Rest Dent 2006;14:32-37.

29. Long JH. Locating A with a leaf gauge. J Prosthet Dent 1973;29:608-610.

30. Woelfel JB. New device for accurately recording A. J Prosthet Dent 1986;56:716-727.

31. 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.

32. Zonnenberg AJJ, Mulder J, Sulkers HR, Cabri R. Reliability of a measuring procedure to locate a muscle-determined A position. Eur J Prosthodont Rest Dent 2004;3:125-128.

33. Al-Ani MZ, Gray RJM, Davies SJ, Sloan P, Glenny AM. Stabilization splint therapy for the treatment of temporomandibular myofascial pain: a systematic review. J Dent Educ 2005;69:1242-1250.

34. Gatchel RJ, Stowell AW, Buschang P. The relationships among depression, pain, and masticatory functioning in temporomandibular disorder patients. J Orofac Pain 2006;20:288-296.

35. 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.

36. Rantala MA, Ahlberg J, Suvinen TI, Savolainen A, Könönen M. Symptoms, signs, and clinical diagnoses according to the research diagnostic criteria for temporomandibular disorders among Finnish multi-professional media personnel. J Orofac Pain 2003;17:311-316.

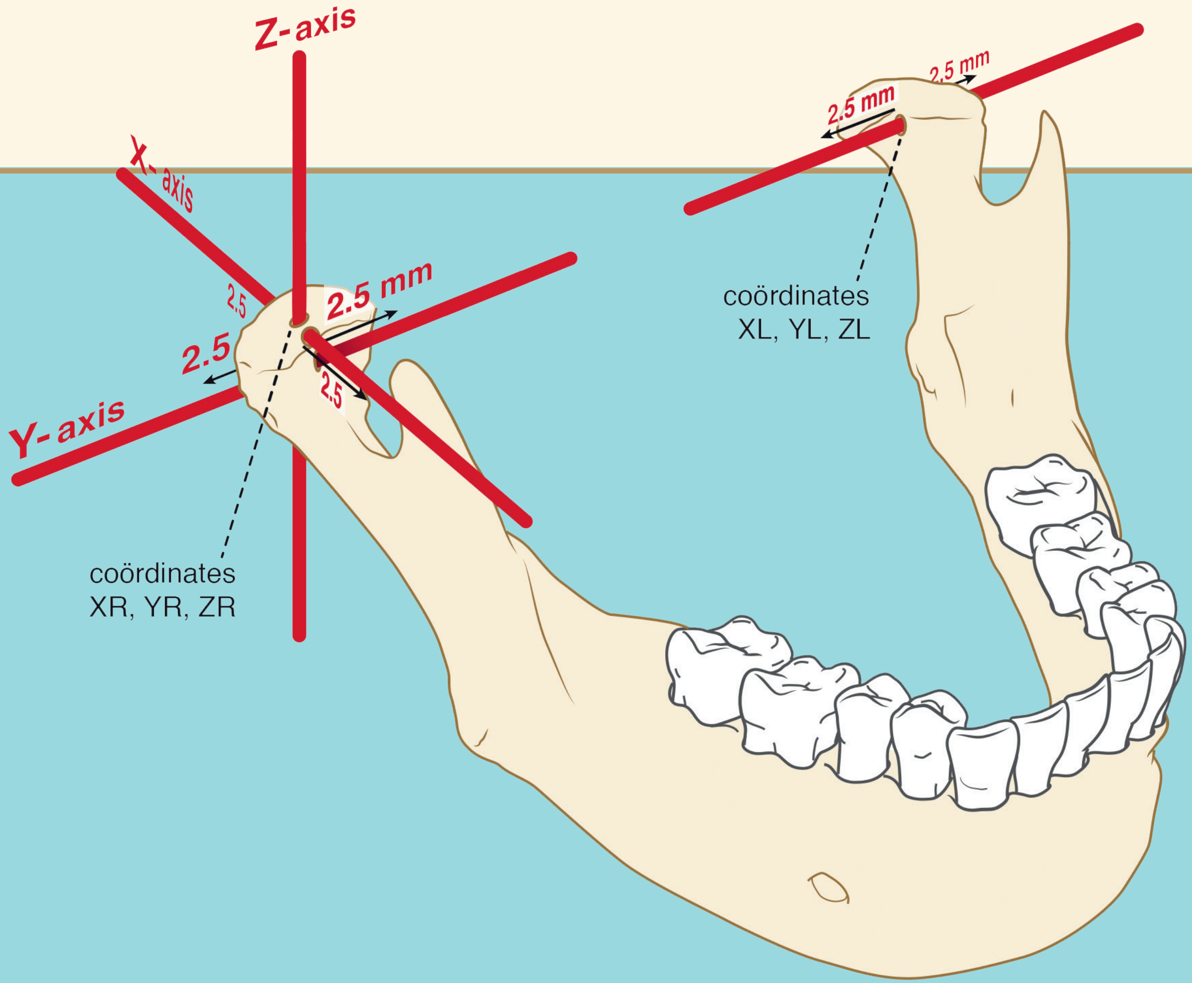
37. Schmitter M, Zahran M, Phu Duc JM, Henschel V, Rammelsberg P. Conservative therapy in patients with anterior disc displacement without reduction using two common splints: a randomized clinical trial. J Oral Maxillofac Surg 2005;63:1295-1303.

38. Al Quran FAM, Kamal MS. Anterior midline point stop device (AMPS) in the treatment of myogenous TMDs: Comparison with the stabilization splint and control group. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:741-747.

39. Tanner HM. The Tanner mandibular appliance. J Colo Dent Assoc 1996;75:14-18.

Chapter 5

The incidence of centric slides in healthy individuals and TMD patients.



A.J.J. Zonnenberg
J. Mulder

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Abstract

Controversy exists as to whether centric slide is an etiological factor for temporomandibular disorders. In this cross-sectional study the magnitude of centric slides, obtained with 2 different articulations and one with a millimetre ruler was compared. The study enrolled a group of 27 healthy individuals and 83 TMD patients, the latter divided in 3 groups of 26, 28 and 29 subjects with the RDC/TMD diagnoses of myofascial pain, osteoarthritis and disc displacement without reduction, respectively. Measurement reliability of a chinpoint guided articulation was compared with a musculoskeletally stable articulation, obtained using a leaf gauge. Next, centric slide was measured, if any, intraorally with a millimetre ruler and in both articulations measuring the difference between centric relation and the maximal intercuspal position. A mandibular full-arch Tanner type stabilisation splint was fabricated for each of the TMD patients. After splint treatment, new casts were obtained and mounted using both methods to locate centric relation. The magnitude of centric slide intraorally and in both articulations was reassessed. For the analysis of the variables a mixed-model procedure was applied (α=.05). At baseline and upon conclusion of splint treatment all groups exhibited centric slides with large standard deviations (ranging from 1.03 ± 0.83 to 1.97 ± 1.3 millimetre). In the mixed-model procedure a significant difference in magnitude existed between the millimetre ruler and both the chinpoint guidance as well as the leaf gauge articulation ($P<0.001$). No correlation between centric slide and TMD could be demonstrated.

Introduction

Centric slide has been defined in the eighth edition of Glossary of Prosthodontic Terms (GPT-8), as the movement of the mandible while in centric relation, from the initial occlusal contact into maximum intercuspation [1], the maximal intercuspal position (ICP). This initial occlusal contact is referred to as the retruded contact position (RCP) and considered synonymous to the first contact in centric relation. [1] Therefore, centric slide may be designated as an RCP-ICP slide. The term RCP may be confusing since in the beginning the retruded position was defined as that guided occlusal relationship occurring at the most retruded position of the condyles in the joint cavities, synonymous to the ligamentous position [2] and possibly more retruded than centric relation (GPT-4). [1] Some consider the terms 'retruded' and 'most posterior' obsolete. [3] More recently, the term centric relation contact position has been introduced. [3]

The presence of RCP-ICP slides can be detected when moderate posterior pressure is exerted on the chin and the mandible is manipulated around a virtual axis to the initial tooth contact. [4] If a slide is present, the mandible moves from this first contact in RCP anteriorly and/or laterally to ICP. Centric slide is also the anterior-posterior discrepancy manipulating the mandible into the musculoskeletally stable centric relation position and bringing, with a hinge-type movement, the teeth into light contact.[5]

Okeson suggested that the musculoskeletally stable centric relation position can only be determined with bimanual manipulation, with a jig or a leaf gauge. [5] Centric slide may result from the occlusion, the joints, or both. [5] Joint instability may be related to alterations in the normal anatomic form, such as in a disc displacement or an arthritic condition. [5] Prolonged clenching may lead to disc displacement, possibly as a result of splinting of the lateral pterygoid muscle. [6] Harmful occlusal interferences or premature contacts may prevent the condyle being seated on the disc, lead to centric slide and some considered them the cause of bruxism and/or temporomandibular disorders. [7] Occlusal adjustment has been recommended as treatment to eliminate the RCP-ICP slide as a preventive and/or a treatment means. [7]

In a descriptive survey of a large student population, asymmetrical slides larger than 1 millimetre were found to be related to dysfunction, characterized by temporomandibular joint (TMJ) tenderness and dull occlusal sounds. [4] In an epidemiological survey among healthy individuals ranging in age from 20 to 40 years, 90% of the slides were 0 (21%) or less than 1 millimetre (69%). [8] The remaining 10% were larger than 1 millimetre. Asymmetrical RCP-ICP slides > 1 millimetre showed the most TMJ tenderness. In a clinical controlled study, centric slide, as a univariate occlusal factor, was demonstrated to be an etiological factor [9], largely expressed as muscle signs of TMD, although not correlated with any specific TMD diagnosis. From a contemporary study [10] it has been demonstrated that slides larger than 2 millimetre were observed in patient groups with disc displacement and osteoarthritis/-osis. In a multiple logistic regression model occlusal variables explained at most 4.8 to 27.1% of the various TMD diagnoses.

At first, occlusal adjustment was proposed to eliminate deflective occlusal contacts, consequently the centric slide, in particular by Clark and colleagues. [11] Occlusal adjustment [7, 11] was supposed to prevent the development of TMD. However, a systematic review [12] concluded that there is no evidence of efficacy of occlusal adjustment and that occlusal adjustment should not be recommended for either treatment or prevention of TMD. It is not possible to draw any etiological conclusions from prevalence based models; occlusal variation, specifically, the presence of a centric slide, may be a consequence rather than a cause of TMD. [10]

Centric slides occurs in 90% of all dentitions, measuring 1.25 millimetre on average [3] and are considered to be a normal distribution of functional adaptation. The presence of a centric slide is relatively easy to observe clinically [3], can be measured with a millimetre ruler [4], but for a more accurate evaluation of its magnitude occlusal analysis on articulator-mounted casts is necessary [3]. The purpose of this study was to compare centric slide, measured intraorally with a millimetre ruler with the centric slide in articulator mounted casts. Four groups were evaluated: healthy individuals, and patients with 3 different TMD diagnoses: myofascial pain, disc displacement without reduction and osteoarthritis. Simultaneously, the magnitude of centric slides measured after chinpoint guided centric relation articulation were compared with those measured using a musculoskeletally stable centric relation articulation, obtained using a leaf gauge technique. The null hypothesis was formulated that there are no differences between the magnitude of the slides, obtained with the millimetre ruler and both CR articulations, in healthy individuals and in TMD patients before and after stabilization splint treatment.

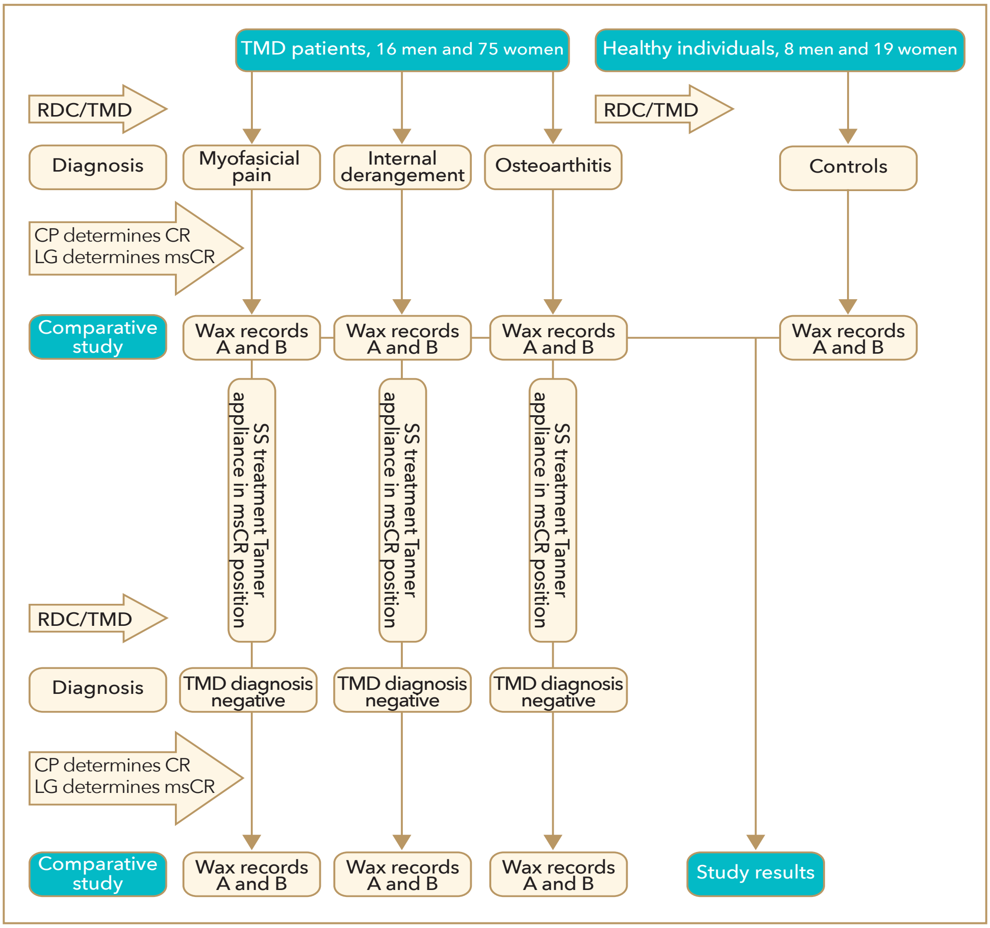
Material and methods

The original study [13] was conducted to test reproducibility of 2 methods to locate centric relation: chinpoint guided centric relation and musculoskeletally stable centric relation, obtained with a leaf gauge, in 27 control and 91 TMD patients. Attrition of this study was 8 TMD patients. Consequently, the current study enrolled a group of 27 healthy individuals and 83 TMD patients, divided in 3 groups of 26, 28 and 29 subjects with the RDC/TMD [14] diagnosis myofascial pain (MYO), osteoarthritis (OA), and disc displacement without reduction (ID) respectively. The study design is presented in figure 1. Based on a power analysis conducted in a previous study [15], the minimally required number of participants was calculated to be at least 26 subjects per group to determine statistical significance for a 95% confidence interval. All subjects were informed about the nature and objective of a quick-mount procedure and the purpose of this study to compare 2 different methods to record their maxillomandibular relationship. A quick-mount procedure consists of impressions of the mandibular and the maxillary arch, poured in Class IV stone, mounted to an articulator with a face bow registration and a centric relation record. Written informed consent was obtained from all participants in this study. For the comparison of both methods to locate centric relation an IRB approval was obtained from the Medical Ethical Committee of the University of Utrecht, Netherlands. [13]

The study was blinded and controlled using 1 investigator and 2 independent examiners. The principal investigator examined all patients and control subjects and allocated them to the appropriate diagnostic group. Two calibrated examiners, X and Y, prepared 2 identical sets of 3 interocclusal wax records that were labelled A 1 - 3 and B 1 – 3 (Moyco Wax, Pink X-hard). The examiners made sequential centric relation records for a mounting procedure. Wax record A1 and B1 were used to mount mandibular casts A and B respectively to a maxillary cast that was oriented by means of a face-bow transfer (Axioquick; SAM-Co) to the articulator (SAM 2P; SAM-Co). Next centric slide was measured intraorally with a millimetre ruler [4] and noted in the patient record. The principal investigator performed an instrumental analysis with a split-cast procedure and subsequent measurements in a Condymeter (Condymeter III; SAM-Co). The results of the reproducibility study have been previously reported. [13] Next, the magnitude of the centric slide was measured on both articulations and recorded.

Subsequent to these measurements a Tanner type stabilization splint was fabricated for each of the TMD patients, using the leaf gauge articulations. A Tanner appliance is a mandibular complete arch, full-coverage, heat-cured acrylic splint with cuspid-to-cuspid anterior

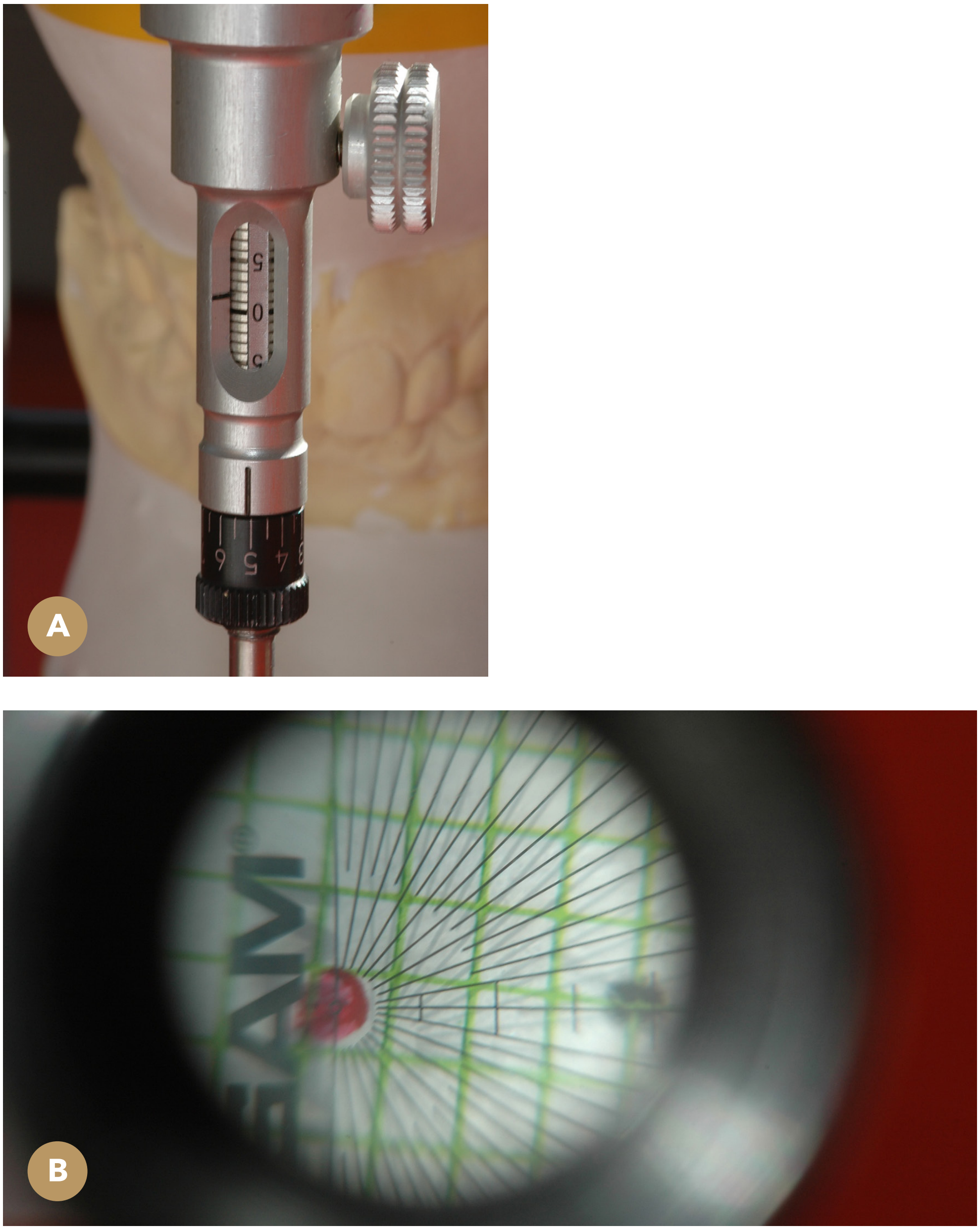
Fig. 5-1. *Flowchart of the study design. CP = chinpoint guidance, CR = centric relation, LG = leaf gauge, msCR = musculoskeletally stable centric relation.*



guidance and the maxillary, lingual cusps in contact with the appliance. [13] Splint treatment was continued until resolution of symptoms and the patient reported to be pain-free in a follow-up visit. Next, all patients were re-examined with RDC/TMD, to confirm the absence of the patient's initial TMD diagnosis. The mean time elapsed from the initial TMD diagnosis until the active monitoring of the appliance stopped, was 7.5 months (range 3-12) for the masticatory muscle disorder group, 8.2 months (range 5-12) for the disc displacement without reduction group, and 7.4 months (range 4-12) for the osteoarthritis group respectively. The mean time the splint treatment was monitored, was 5 months (range 2-9) for the masticatory muscle disorder group, 6.8 months (range 3-12) for the disc displacement without reduction group and 5.4 months (range 2-12) for the osteoarthritis group. [13] Next, a second mounting procedure was initiated to test reproducibility of the 2 methods to locate centric relation and to reassess the magnitude of any residual centric slide after splint treatment.

On an articulator, the centric slide can be measured by taking Pythagoras' hypotenuse from the horizontal displacement on the incisal table and the vertical displacement along the incisal pin. The SAM articulator system (SAM-Co) provides a millimetre loupe and an incisal pin, each with a measuring range of 10 millimetres, the latter subdivided in increments of 0.1 millimetre (Fig. 2 A and B.). For the analysis of the variables a mixed-model procedure was used (SAS/STAT, version 9, SAS Institute. Cary, NC).

Figure 2A and 2B. Incisal pin and millimeter loupe with increments of 0.1 millimeter.



Results

In the ID group of the current study centric slide of 1 patient was not measurable accurately as a result of her extreme Class II division 2 maxillomandibular relationship. Estimates for pooled mean values and standard deviations of centric slide in the patient groups, before and after SS treatment and in the control group are presented in table I. Centric slide ranged from 1.04 millimetre in the OA group of the chinpoint guidance articulation to 1.76 millimetre in the ID group of the leaf gauge articulation (Table I). All mean values of centric slides of the control and the 3 patient groups, before as well as after splint treatment, showed a relatively large range and standard deviation (Table I). The mean centric slide in healthy controls, the MYO and the OA group was similar. Splint treatment did not influence the magnitude of the slide in the MYO and OA groups. Splint treatment increased the magnitude of the slide in the ID group but both articulations, before and after splint treatment, reveal a large standard deviation (Table I). However, the increase in magnitude was not statistically significant (Table II, P=.053).

Table I. Pooled mean values, standard deviation and range of the distribution of centric slide pre and post SS treatment in 3 patient groups with a TMD diagnosis and single values in healthy control subjects. ID = disc displacement without reduction, MYO = masticatory muscle disorder, OA = osteoarthritis.

In mm	Method											
Group	Millimetre ruler				CP articulation				LG articulation			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Control	0.17	0.41	0.00	1.50	1.21	1.26	0.00	4.64	1.34	0.93	0.00	3.04
ID	0.50	0.64	0.00	2.50	1.54	1.21	0.00	5.06	1.76	1.27	0.03	5.32
MYO	0.40	0.64	0.00	2.25	1.19	0.93	0.10	3.58	1.28	0.96	0.11	3.14
OA	0.25	0.50	0.00	1.75	1.04	0.70	0.00	2.84	1.27	0.88	0.08	3.26

A mixed model was applied to test the random factor patients with the fixed factors method, patient group, point in time, before and after SS treatment. The applied model revealed no significant differences in point in time (Table II), before and after splint treatment (P=.48). In a next analysis control subjects were added to the mixed model. Testing for differences between the control group, 3 patient groups and 3 methods (Table III) only revealed a significant difference in the methods (P<.001). This significant difference in the magnitude of centric slide existed between the millimetre ruler and chinpoint guidance, as well as with the leaf gauge articulation (Table IV).

Table II. Mixed model procedure with the fixed factors method, patient group, point in time, before and after SS treatment and the random factor patients. ID = disc displacement without reduction, MYO = masticatory muscle disorder, OA = osteoarthritis.

Source of variation	method	diagnosis	time	Mean	P
method	chinpoint guidance			1.24	<.001
method	millimetre ruler			0.38	
method	leaf gauge			1.43	
point in time			1	0.99	0.48
point in time			2	1.05	
diagnosis		ID		1.26	0.053
diagnosis		MYO		0.95	
diagnosis		OA		0.85	

Table III. Mixed model procedure with the fixed factors method and patient group and the random factor patients. CON = control, ID = disc displacement without reduction, MYO = masticatory muscle disorder, OA = osteoarthritis.

Source of variation	method	diagnosis	Mean	P
method	chinpoint guidance		1.22	<.001
method	millimetre ruler		037	
method	leaf gauge		1.33	
diagnosis		CON	0.90	0.41
diagnosis		ID	1.18	
diagnosis		MYO	0.93	
diagnosis		OA	0.87	

Table IV. Mixed model procedure with the fixed factor method and the random factor patients.

Effect	method		Mean	SE	df	t Value	P
method	chinpoint guidance	millimetre ruler	0.85	0.11	216	7.73	<.001
method	chinpoint guidance	leaf gauge	-0.10	0.11	216	-0.96	0.33
method	leaf gauge	millimetre ruler	0.95	0.11	216	8.96	<.001

Discussion

As reported previously [3] a significant difference in magnitude existed between the millimetre ruler and the articulations (P<.001). No significant difference was demonstrated between the 2 methods of articulation. A millimetre ruler was less accurate than either of the articulations. Therefore, the null hypothesis must be rejected. The millimetre ruler is a one-dimensional measurement in the sagittal plane between the first contact in centric relation and the maximal intercuspal position; the articulator provides a measurable 3-dimensional mandibular displacement. The ruler is divided in millimetre increments, the loupe provides magnified millimetre increments and the incisal pin has increments of 0.1 millimetre (Fig. 2 A and B). These results are in line with a previously reported study. [3]

There is a large range in the magnitude of centric slide within healthy control subjects and TMD patients. The distribution of centric slide within the pain diagnoses myofascial pain and osteoarthritis, at baseline and at conclusion of splint treatment, and the control group is similar. However, splint treatment increased the magnitude of centric slide in the ID group, though not statistically different (P=.41, Table III). This is the result of the large standard deviations and, consequently, of the substantial overlap of the data between the other groups and the ID group. Centric slides in the OA group were the smallest (1.04 mm) and in the ID the largest (1.76 mm). Some authors suggest that patients with osteoarthritis/-osis remodelling of the temporomandibular joint may develop a larger slide. [10] However, in the current study, disc displacement without reduction revealed the largest slide, possibly a matter of definition and presumably as a result from splinting of the lateral pterygoid muscle. [5, 6] Clenching may lead to disc displacement [6], activating the lateral pterygoid muscle to pull the disc out of the friction area and prevent damage. The prolonged contraction of the lateral pterygoid muscle may lead to a spasm, a phenomenon usually observed in disc displacement without reduction. [5] The magnitude of the centric slides exhibited by the healthy control subjects is well within the range of the slides found in the TMD patients. Therefore, the problem in modelling occlusal variables to differentiate TMD patients from healthy control subjects remains the overlap between most TMD patients and healthy individuals [10], as demonstrated by the large ranges and standard deviations in the present study. In the current study centric slide is not associated with a specific temporomandibular disorder, suggesting that centric slide and TMD are separate entities and probably unrelated.

Disc displacement without reduction may be partly accountable for the 4.8 to 27.1% [10] where occlusal factors are an etiological factor for this specific TMD diagnosis. In the present study the variable 'centric slide' does not necessarily have the same power [15] as the variable 'reproducibility of centric relation' does. [13] Recruiting a higher number of patients may lead to a significant difference in the centric slides between the disc displacement group compared to the control and the 2 other groups (Table II, P=.0538). The ID group shows the largest centric slide in the present study and its increase in magnitude may explain the ID group patients' symptom 'my bite is off".

In conclusion this study supports the theory of the adaptation demand model [10] of the temporomandibular joint. This model explains that more extreme biological variation, for example extreme occlusal factors may impose a greater adaptation demand upon a multifactorial system as the temporomandibular joint to maintain its normal function [10]. Centric slide probably is a consequence rather than a cause of TMD. Therefore, occlusal adjustment to eliminate the slide [11] is not an option for treatment of a temporomandibular disorder. This outcome is confirmed in recent literature [12].

Conclusions

Within the limitations of this study the following conclusions were drawn:

1. No relationship was demonstrated between centric slide and temporomandibular disorders in this study.
2. Centric slides were equally distributed between healthy control subjects and patients with selected TMD diagnoses.
3. The millimetre ruler appeared to be an unreliable instrument to measure centric slide intraorally.

References

1. Glossary of Prosthodontic Terms. 8th ed. J Prosthet Dent 2005;94:22.

2. Posselt U. Studies in the mobility of the human mandible. Acta Odont Scand 1952;10:19-160, suppl.10.

3. Keshvad A, Winstanley RB. Comparison of the replicability of routinely used centric relation registration techniques. J Prosthodont 2003;12:90-101.

4. Solberg WK, Woo MW, Houston JB. Prevalence of mandibular dysfunction in young adults. J Am Dent Assoc 1979;98:25-34.

5. Okeson JP. Management of temporomandibular disorders and occlusion. 7th ed. St. Louis: Elsevier Mosby; 2013. p.117-122, 193-198, 443.

6. Tanaka E, Hirose M, Koolstra JH, van Eijden TMGJ, Iwabuchi Y, Fujita R et al. Modeling of the effect of friction in the temporomandibular joint on displacement of its disc during prolonged clenching. J Oral Maxillofac Surg 2008;66:462-8.

7. Ramfjord SP, Ash MM. Occlusion. 4th ed., Philadelphia: WB Saunders; 1995. p.111, 151, 161.

8. Pullinger AG, Seligman DA, Solberg WK. Temporomandibular disorders. Part I: Functional status, dentomorphologic features, and sex differences in a nonpatient population. J Prosthet Dent 1988;59:228-35.

9. Kirveskari P. The role of occlusal adjustment in the management of tempo-ro-mandibular disorders. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1997;83:87-90.

10. Pullinger AG, Seligman DA. Quantification and validation of predictive values of occlusal variables in temporomandibular disorders using a multifactorial analysis. J Prosthet Dent 2000;83:66-75.

11. Clark GT, Mohl ND, Riggs RR. Occlusal adjustment therapy. In Mohl ND, Zarg GA, Carlsson GE, Rugh JD. (Eds): A textbook of occlusion. Chicago: Quintessence Publ Co, 1988; 285-303.

12. Koh H, Robinson PG. Occlusal adjustment for treating and preventing temporomandibular joint disorders: a systematic review. The Cochrane Collaboration. Wiley's Publ., 2006, p.1-13.

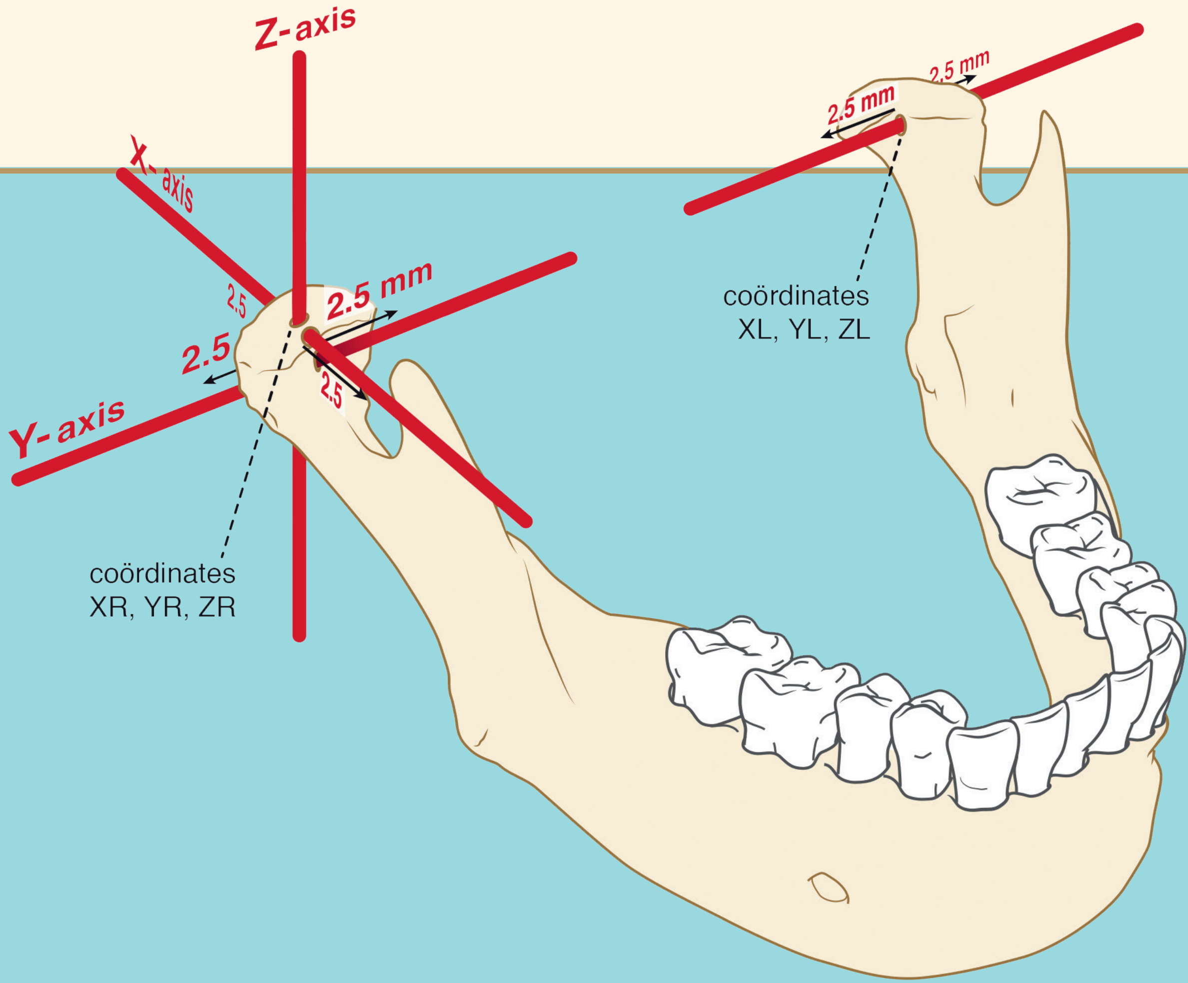
13. Zonnenberg AJJ, Mulder J. Reproducibility of 2 methods to locate centric relation in healthy individuals and TMD patients. Eur J Prosthodont Rest Dent 2012:20:151-158.

14. 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.

15. Zonnenberg AJJ, Mulder J. Variability of Centric Relation Position in TMD Patients. Eur J Prosthodont Rest Dent 2006;14:32-37.

Chapter 6

The efficacy of a specific stabilization splint.



A.J.J. Zonnenberg
J. Mulder

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Abstract

Background; The use of a Tanner type stabilization splint, fabricated on a leaf gauge articulation for the treatment of patients with disk displacement without reduction, is lacking in the literature.

Objectives: The purpose of the study is to collect non-controlled, therapy-related observations, in other words to demonstrate the efficacy of this appliance for the treatment of patients with disk displacement without reduction.

Methods: The study enrolled 55 patients, 5 men and 50 women, with the clinical diagnosis disk displacement without reduction, 42 with and 13 without limited mouth opening. All patients received a splint in the musculoskeletally stable CR position. Mouth opening, clinical performance and the timeframe of splint treatment were assessed.

Results: For 37 patients with a disk displacement without reduction with limited opening the largest increase in mouth opening (9.5 ± 5.6 millimeter) occurred in the first week (7.9 ± 2.5 days). No occlusal adjustment of the splint was needed during the treatment sequence. For 3 patients treatment took up to 3 months (8.1%), for 13 patients between 3 and 6 months (35.1%) and for 17 patients within a year (45.9%), making a total of 89.1% successfully treated patients. Out of 50 patients 29 had a total resolution of signs and symptoms, whereas 21 patients still suffered from solitary TMD signs.

Conclusion: A Tanner type stabilization splint, fabricated in the musculoskeletally stable CR position appears to be an effective and efficient means for the treatment of patients with disk displacement without reduction. Its efficacy makes it eligible to be tested in a randomized controlled trial.

Clinical implications: The efficacy of this specific splint, fabricated in the musculoskeletally stable CR position makes it a promising tool to treat TMD patients with disk displacement without reduction.

Introduction

Disk displacement without reduction is a temporomandibular disorder (TMD), characterized by pain and limited mandibular movement. [1] Clinical examination of disk displacement without reduction reveals a restricted mandibular opening of 25 – 35 millimeter with a hard end feel, a normal eccentric range of movement to the ipsilateral side and a restricted movement to the contralateral side, often with severe pain. [1,2] Disk displacement without reduction is considered an advanced stage of internal derangement and the diagnosis can be confirmed with dynamic MRI. [1,3] However, imaging is not required for a correct diagnosis. [3] Clinical examination with the Research Diagnostic Criteria [4] (RDC/TMD, Axis I) is a good alternative to obtain a correct diagnosis. The RDC/TMD have been found reliable and clinically useful for adults. [5-8]

Disk displacement without reduction was diagnosed clinically by CDC/TMD, similar to the RDC/TMD and compared to MRI. The positive predictive value for a correct clinical diagnosis disk displacement without reduction, based upon CDC/TMD, was 86%. [9] The overall diagnostic agreement between MRI and clinician was 78.3%. [9] Measuring mouth opening as the interincisal distance not including the vertical overlap is highly reproducible for healthy individuals [10] as well as for TMD patients. [7,8] The smallest detectable difference in mouth opening is 4 to 5 millimeter in healthy individuals [10] and 6 to 9 millimeter in TMD patients with a restricted mouth opening, reflecting the effect of a treatment intervention. [11]

To date the etiology of internal derangement is considered to be multifactorial, consequently, different therapies have been advocated such as physical therapy [12], manual therapy, relaxation and biofeedback [13] and a combination of physical therapy and a number of different treatment options. For the treatment of disk displacement without reduction physical therapy in combination with an anterior (re)positioning splint [2], a stabilization splint [14], a distraction or a stabilization splint [1], a stabilization splint and surgical intervention [15], with injection of sodium hyaluronate [16], and even no treatment [17, 18] at all have been recommended. None of these interventions appears to have superior results.

Recently, a numerical model of static clenching suggested to cause [19] the onset of disk displacement without reduction. Splint treatment could increase cognitive awareness. [20] A negative outcome of splint therapy can be decisive for the planning of a surgical intervention. An effective splint design may reduce the number of surgical interventions considerably. [1]

Centric relation is still the reference position of choice in prosthodontics in general, although its definition has changed several times over the years and is expected to change again. [21] The currently advocated description defines CR as 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. [22] The centric relation position has been defined for healthy individuals [23], not for TMD patients, in particular TMD patients with an intracapsular disorder such as disk displacement without reduction. Nevertheless, a splint fabricated in a chinpoint guided centric relation position proved effective for the treatment of the TMD diagnosis disk displacement without reduction. [1]

The definition of the centric relation position in the most recent Glossary of Prosthodontics is considered to be the same position as the musculoskeletally stable CR of the mandible. [2] Okeson suggested that the musculoskeletally stable CR position can only be determined with bimanual manipulation, with a jig or a leaf gauge. [2] The musculoskeletally stable CR position proved not to be coincident with the chinpoint guided CR position in TMD patients. [24]

A maxillary stabilization splint fabricated in chinpoint guided CR is currently the most extensively described and used occlusal appliance for the treatment of various types of TMD. The overall clinical effectiveness of splint treatment is not in question. [2, 25, 26] However, several systematic reviews, based upon controversial research, question its efficacy. [27-29] Maxillary and mandibular splints seem to be equally beneficial to reduce signs and symptoms. [30] Although similarly working splints have been introduced for the treatment of mainly masticatory muscle disorders [31-33], the splint in the current study is missing in the literature. The purpose of this study is to collect non-controlled, therapy-related observations [34] and assess the efficacy of a full-arch stabilization splint for the mandible, fabricated on a musculoskeletally stable CR articulation of type IV stone casts.

Material and methods

This study enrolled 55 subjects with the specific TMD diagnosis of disk displacement without reduction, 5 men and 50 women, among whom 29 patients participated in a concurrent study, testing measurement reliability of CR in a group of healthy controls and 3 different patient groups, all with a specific TM diagnosis. [24] All patients had a complete, natural dentition, except wisdom teeth and/or teeth removed for orthodontic reasons, usually bicuspids. Disk displacement without reduction can be confirmed with MRI. [1,3,9] Since the outcome of this study was not clear in advance, MRI to confirm a displaced disk was not an option for this study. Although MRI is the method of choice for imaging the disk, a systematic review found the evidence grade for the diagnostic efficacy of MRI to be insufficient. [35]

The diagnosis had to be confirmed clinically, using the RDC/TMD, Axis 1. [4] The diagnosis of 42 patients with and 13 patients without limited mouth opening could be confirmed. [4] Distribution of age and gender is listed in table I.

Table I. Distribution of age, gender and residual signs of the TMD diagnosis disk displacement without reduction and a control group. (W)LO = (without) limited mouth opening and residual TMD signs at conclusion of treatment.

		Total	LO	WLO	Controls
N		55	37	13	27
Attrition		5			
Gender	M	5	3	2	8
	F	45	34	11	19
Age	Mean	36	36.9	33.4	37.4
	SD	14.4	15.1	12.2	13.9
Residual TMD signs		21	15	6	

All 55 patients received a full-arch mandibular stabilization splint without clasps (Figure 6-1), a Tanner appliance [36] that provided immediate anterior guidance and posterior disclusion in eccentric movements. The splint was indirectly fabricated in a dental laboratory on a leaf gauge articulation of type IV, well-isolated stone casts and made of warm polymerized acrylic resin. The vertical dimension between the mandibular and the maxillary cast was determined by the amount of leaves used with the leaf gauge, approximately 2 millimeter. All clinical splint criteria are presented in table II. Notwithstanding a meticulously performed mounting procedure, all splints were checked for good fit and occlusion was adjusted intraorally, when necessary. Any eccentric contacts were removed at baseline, checked again at the first follow-up visit after 1 week and at all consecutive control visits. All patients were instructed to wear the splint at least 20 hours a day except during meals and received adjunctive treatment with exercises by a physical therapist.

Figure 6-1. A Tanner appliance

Splint treatment was continued until resolution of signs and symptoms and the patient reported to be pain-free. After re-examination with RDC/TMD, Axis I, the absence of the patient's original diagnosis of disk displacement without reduction had to be confirmed. The timeframe of splint treatment was restricted to a maximum of 12 months. Next to this RDC/TMD assessment, a simple test to evaluate the range of motion of the mandible was performed. To test mouth opening capabilities the patient was asked to open and close without the splint. The difference between maximal unassisted and maximal assisted mouth opening had to be < 4 millimeter. [4] To assess the eccentric range of movement the patient was asked to protrude the mandible as well as to move to the left and right lateral excursions and then to return to the musculoskeletally stable CR position with and to the most posterior position without the splint in position intraorally. Only adequate and smooth motion of the mandible was considered to be an indication that function was properly restored. Thus, the subjective absence of pain, the lack of the TMD diagnosis disk displacement without reduction and a positive range of motion test concluded the treatment sequence. The results of the increase in mouth opening of the 55 patients were compared to a control group of healthy individuals from the simultaneously conducted study [24] that consisted of 27 subjects without history or signs of a temporomandibular disorder. The RDC/TMD can be used as well among non-patient populations to confirm their healthy status. [37]

Table II. Clinical splint criteria.

• The splint does not dislodge with unilateral finger pressure or excursion by the patient
• The patient can place or remove the splint with little effort and no discomfort
• The arch form is stabilized
• Opposing supporting cusp tips contact the splint evenly in free closure and in the musculoskeletally stable centric relation
• The splint contains no metal clasps
• Splint contacts are relatively flat and do not position the mandible
• 0.5 x 0.5 millimeter freedom in centric is evident
• Excursive guidance slightly separate posterior teeth
• Protrusive guidance is bilateral
• Excursive contacts are on cuspids when possible
• Vertical dimension is minimal.
• Splint follows normal anatomic contours of teeth and hard tissue it covers
• Splint finish is smooth and polished.

Criteria first presented by Stanley J. Nelson DDS, MS, Professor, Clinical Sciences Education University of Nevada Las Vegas School of Dental Medicine. Presented at the Annual Meeting of AES in February 2010

The following clinical features were assessed:

- The mean vertical maximal unassisted and assisted mouth opening, measured as the interincisal distance not including the vertical overlap.

- Unassisted mouth opening with and without pain and assisted mouth opening were measured at baseline.

- Unassisted mouth opening with pain, if available without pain were measured at approximately 1 week and a 1-, 2-, 3- and 6-months follow-up control visit.

- At the end of the treatment period maximal unassisted and maximal assisted mouth opening were recorded and the data compared to the data of 27 control subjects.

- Clinical performance of the splint as a measure of the necessity to do repetitive occlusal adjustment and/or resurfacing of the splint in the course of treatment.

- The actual timeframe necessary for treatment with a maximum of 12 months.

For the analysis of the variables a means procedure and a distribution of frequency were applied. Differences in a paired comparison between the patient group, at baseline, at all follow-up visits and at conclusion of treatment, and the control group were tested with a Student's t-test. The effect of the time lapse in the patient group was tested in a mixed model with the patient as the random factor (SAS/STAT, version 9, SAS Institute. Cary, NC).

Results

From 55 patients that received the proposed splint treatment, one patient with a limited mouth opening did not respond adequately and was referred for arthrocentesis. Four patients with limited mouth opening did not conclude treatment after the first follow-up control visit. At conclusion of splint therapy 50 patients reported total resolution of symptoms. This could be objectively confirmed in the control assessment with RDC/TMD for 29 (22 with and 7 without limited opening) patients. In 21 (15 with and 6 without limited opening) patients solitary TMD signs were still present objectively, but the original TMD diagnosis at baseline could not be confirmed anymore. Distribution of age, gender and residual TMD signs at conclusion of splint treatment is listed in table I.

The increase in mouth opening as a function of the time in days is presented in table III. The effect of the time lapse in the patient group, tested in a mixed model, showed all paired comparisons between the 5 points in time were significantly different ($p<.0003$), except between comparison visit 1 (baseline) and 2 ($p=0.4$), visit 3 and 4 ($p=0.44$) and almost significant between visit 4 and 5 ($p=0.0528$).

Table III. Increase of mouth opening in millimeter as a function of the time in days. UMO baseline = unassisted mouth opening without pain, MUMO = maximal unassisted mouth opening with or without pain.

		UMO baseline		MUMO		Increase		Time interval days	
Days	N	M	SD	M	SD	M	SD	M	SD
0-14	21	26.0	5.6	35.5	5.2	9.5	6.2	7.9	2.5
15-40	7	26.5	3.9	35.0	3.0	8.4	2.9	23.2	4.8
41-75	17	27.5	4.8	39.7	5.1	12.2	6.0	56.4	9.6
76-100	13	25.3	5.8	41.2	6.1	15.8	6.3	88.3	7.8
100+	32	25.4	4.7	41.9	4.9	16.5	6.3	196.8	108.7

Paired comparison of mouth opening measurements in Student's t-test between control and patient group differed significantly at baseline ($p<.0001$), all visits in between and at conclusion of treatment ($p<.0001$)

For 3 patients the treatment period lasted less than 3 months (8.1%), for 13 patients between 3 and 6 months (35.1%) and for 17 patients between 6 and 12 months (45.9%), in total 89.1% within a year of splint treatment.

The occlusion of 4 splints had to be adjusted once, all in the first follow-up control visit. For 2 patients cuspid guidance was refined and for 2 patients a premature contact was adjusted. In none of the patients was it necessary to adjust the applied maxillomandibular relationship in musculoskeletally stable CR, nor to resurface the occlusal device during the treatment sequence.

Residual signs of TMD of 50 patients were intracapsular in 13 patients and solitary muscular signs in 10 patients, consequently in 2 patients both an intracapsular and a muscular sign.

Discussion

All splints in this study were fabricated in the musculoskeletally stable CR position. However, the CR position by definition [22] demands a properly aligned disk between the condyle and the eminentia in the articular fossa. Consequently, in TMD patients with a displaced disk CR is by definition impossible to achieve. [21, 23] However, any dysfunctional joint may develop an adapted centric posture, starting from a treatment position. [23] An alternative description of the centric relation position for a dysfunctional joint may be to replace the words 'centric relation' with the words 'musculoskeletally stable' or 'stable orthopedic' position.

In the current prospective case series, mouth opening, clinical performance of the splint and the timeframe of splint treatment were assessed, based upon the presence of the diagnosis disk displacement without reduction. For the treatment of this TMD diagnosis a splint fabricated in chinpoint guided CR worked better than a distraction splint [1], though just significantly different (Confidence interval 1.014 till 8.741, OR 2.875, P-value = 0.0528). Besides the effectiveness of the splint in the reduction of signs and symptoms, mouth opening increased considerably. [1] In the current study mouth opening showed the largest improvement in the first week (7.9 ± 2.5 days) after insertion of the Tanner splint, on average 9.57 ± 6.2 millimeter to 35.5 ± 5.2 millimeter. The results of the chinpoint guided CR splint [1] took 4 weeks for an average of approximately 5 millimeter. The difference may be explained by the fact the latter study uses maximal unassisted mouth opening, 30.5 ± 6.4 millimeter (Schmitter, M, DDS, E-mail, February 16, 2010). In the current study maximal unassisted mouth opening at baseline was 32.4 ± 4.6 millimeter. After the first 2 weeks the rate of mouth opening slowed down. After 1 month the data were 35.3 ± 3 and 36.9 ± 6.9 millimeter respectively. Unfortunately, there were only 7 observations after 1 month in the current study. Mouth opening after three months was 40.1 ± 7.8 compared to 39.7 ± 5.1 millimeter in approximately 2 months in the current study. Consequently, the results of this study are in line with a previously performed study [1] albeit in the current study mouth opening increased quicker.

Mouth opening of the used control group [24] does not significantly differ from the values of healthy individuals. [10] Contrary, mouth opening measurements of all 50 patients with and without limited opening, at baseline and all consecutive control visits differed significantly from mouth opening from the control group [24], even at conclusion of treatment ($p<.0001$). Nevertheless, all patients in the current study concluded treatment with a mouth opening well over 40 millimeter, comparable to the results of the study [1] with the chinpoint guided CR splint, 41.9 ± 4.9 and 43.4 ± 7.0 millimeter respectively. Splint treatment increased limited mouth opening of 37 TMD patients well over 9 millimeter, larger than the smallest detectable difference. [11]

Since imaging was no option for this study as explained before [3], one can only speculate what the exact reason for the significant different mouth opening is. The recent study with a numerical model of static clenching [19] suggested to cause the onset of disk displacement without reduction. The muscles probably responsible for this disk displacement are the lateral pterygoid muscles confirming the myofascial component in the restriction of the mouth opening. Another aspect could be the protective co-contraction as a result of deep pain input. [3] The significantly different mouth opening of these 50 patients with disk displacement without reduction may be explained by a disk displacement further forward and a deteriorating condition. However, such deterioration did not evolve in the current study. The pain emanating from the retrodiskal tissues in the early stages of a complete disk displacement [23], disappeared completely. The retrodiskal tissue may have been converted into fibrous connective tissue and a pseudo disk may have been developed. [23] In future investigations, the disk position must evaluated before, during and at conclusion of splint treatment.

To achieve a stable maxillomandibular relationship the occlusion of a stabilization splint, fabricated in CR, needs to be adjusted in a number of follow-up visits. [27] Recently 3 different RCTs [31-33] have compared two jig-type and a Hawley plate-type appliance respectively to a full-coverage maxillary splint for the treatment of mainly masticatory muscle disorders. The first RCT tested the Nociceptive Trigeminal Inhibition-tension suppression system (NTI-tss) [31], the second a Hawley plate-type named Relax, an appliance that covers the maxillary teeth from cuspid to cuspid [32], and the third the Anterior Midline Point Stop (AMPS). [33] In the first study occlusal adjustment of the NTI-tss was done when required by the patient or deemed necessary by the clinician. [31] In the second study the Relax needed less occlusal adjustment [32] than the stabilization splint. In the third study the AMPS obviously does not need occlusal adjustment as a result of its point contact on the central incisors. [33] The Tanner appliance in the current study does also not need any adjustment of the maxillomandibular relationship in the course of treatment.

The NTI-tss and the Relax are as effective as, the AMPS is more effective than a full coverage maxillary stabilization splint, all for the treatment of mainly masticatory muscle disorders. An important property of the AMPS and even of the Relax or the NTI-tss is that they are or function like a jig that induces the mandible to assume the musculoskeletally stable CR position. The offered position is Dawson's treatment position on the road to an adapted centric posture. [23] That position is identical to the position found with the leaf gauge and used to fabricate the Tanner splints in the present study.

Patient cooperation is an important factor in the success or failure of splint therapy. [2, 31, 33] When a patient does not respond favorably to splint therapy, patient cooperation should be questioned and subsequent treatment compliance should be verified. In the Relax-stabilization splint study no differences in splint comfort were reported. [32] Though not significantly different, a trend for higher comfort was reported for the NTI-tss compared to the stabilization splint. [31] In the AMPS-SS study patients considered the AMPS a convenient appliance, whereas patients in the stabilization splint group complained about bulkiness and needed continuous encouragement to wear the splint. [33] Clearly, they experienced the splint as an obstruction rather than an improvement. The fact that the mandibular splint in this study realized the largest increase in mouth opening in the first week after insertion, points at adequate comfort for the patient and good treatment compliance.

The splint in the present study needed little adjustment after insertion during clinical use and can therefore be regarded as a merely efficient oral appliance. No adjustment of the maxillomandibular relationship was necessary. Adjusting the stabilization splint to a stable position would be a meticulously precise, time consuming work. Even resurfacing of the appliance will take time. [33, 35] Less or no adjustment means quicker to a stable orthopedic position, thus mandibular stability and, in that sense, less of an obstruction.

Out of 50 patients 29 had a total resolution of signs and symptoms, whereas 21 patients still exhibited a single TMD sign. Is has been reported that the prevalence of TMD signs and symptoms in non-patient populations may be as high as 93%.[37]

In the current study the effectiveness of the splint treatment to rapidly increase mouth opening has been demonstrated. Mouth opening of 37 TMD patients with a restricted mouth opening opened well over the smallest detectable difference of 6 to 9 millimeters, not accountable to regression to the mean. Less or no occlusal adjustment make the splint in the current study an efficient one. Since this splint is full-coverage, it does not have any risk of over-eruption of teeth, associated with jig-type splints. Overall the efficacy of this appliance, fabricated in a muscle-determined, stable orthopedic CR position has been demonstrated. However, since this study was supposed to collect non-controlled therapy-related observations, all findings will have to be confirmed in a future RCT, accompanied by appropriate diagnostic tests.

Conclusions

- A Tanner splint in the musculoskeletally stable CR position is effective in reducing the signs of disk displacement without reduction with a quick, enduring mouth opening.

- The degree of mouth opening in the first week can hardly be attributed to regression to the mean.

- The Tanner splint in the musculoskeletally stable CR position seems a good alternative for surgery in the treatment of TMD patients with locking, to be used first.

- The Tanner splint in the musculoskeletally stable CR position is more effective for quick initial mouth opening than a splint, fabricated in the chinpoint guided CR position.

- The Tanner splint in the musculoskeletally stable CR position is more efficient than a splint, fabricated in the chinpoint guided CR position: there is no need to adjust or resurface the occlusion.

- The value of a comfortable occlusal appliance, fabricated in the musculoskeletally stable CR position, may increase the patient's treatment compliance and thus the efficacy of the splint therapy.

- The Tanner splint in the musculoskeletally stable CR position appears a good candidate to be tested in a randomized clinical trial as the appliance of choice for the treatment of several TMD diagnoses, disk displacement without reduction in particular. Disk position needs to be checked with MRI.

- The absence of pain, a normal range of mouth opening and a smooth range of motion in eccentric movements are indicative for good temporomandibular health.

- An alternative description of the centric relation position for a dysfunctional joint may be to replace the words 'centric relation' with the words 'musculoskeletally stable' or 'stable orthopedic' position.

References

1. Schmitter M, Zahran M, Phu Duc JM, Henschel V, Rammelsberg P. Conservative therapy in patients with anterior disk displacement without reduction using two common splints: a randomized clinical trial. J Oral Maxillofac Surg 2005;63:1295-303.

2. Okeson JP. Management of Temporomandibular Disorders and Occlusion. 7th ed. St. Louis: Mosby; 2013. p. 73-7, 243-4, 325-6, 375-6, 378, 384-9.

3. Petersson A. What you can and cannot see in TMJ imaging – an overview related to the RDC/TMD diagnostic system. J Oral Rehab 2010;37:771-8.

4. 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.

5. Zaki HS, Rudy TE, Turk DC, Capirano M. Reliability of Axis 1 Research diagnostic criteria for TMD (abstract 676). J Dent Res 1994;73(special issue):186.

6. List T, Dworkin SF. Comparing TMD diagnoses and clinical findings at Swedish and US TMD centers using Research Diagnostic Criteria for temporomandibular disorders. J Orofac Pain 1996;10:240-53.

7. Leher A, Graf K, PhoDuc JM, Rammelsberg P. Is there a difference in the reliability measurementof temporomandibular disorder signs between experienced and inexperienced examiners? J Orofac Pain 2005;19:58-64.

8. Schmitter M, Ohlmann B, John MT, Hirsch C, Rammelsberg P. Research Diagnostic Criteria for temporomandibular disorders: A calibration and reliability study. J Craniomand Pract 2005;23:212-8.

9. Emshof R, Brandlmaier I, Bertram S, Rudiskh A. Comparing methods for diagnosing temporomandibular joint disk displacement without reduction. J Am Dent Assoc 2002;133:442-451.

10. Agerberg G. Longitudinal variation of maximal mandibular mobility: an intraindividual study. J Prosthet Dent 1987;58:370-3.

11. Kropmans ThJB, Dijkstra PU, Stegenga B, Stewart R, de Bont LGM. The smallest detectable difference of maximal mouth opening in patients with painfully restricted temporomandibular joint function. Eur J Oral Sci 2000;108:9-13.

12. Furto ES, Cleland JA, Whitman JM, Olson KA. Manual physical therapy interventions and exercise for patients with temporomandibular disorders. Cranio 2006;24:283-91.

13. Medlicott MS, Harris SR. A systematic review of the effectiveness of exercise, manual therapy, electrotherapy, relaxation training, and biofeedback in the management of temporomandibular disorder. Phys Ther 2006;86:955-73.

14. Ismail F, Demling A, Hessling K, Fink M, Stiesch-Scholz M. Short-term efficacy of physical therapy compared to splint therapy in treatment of arthrogenous TMD. J Oral Rehabil. 2007;34:807-13.

15. Sembronio S, Albiero AM, Toro C, Robiony M, Politi M. Is there a role for arthrocentesis in recapturing the displaced disk in patients with closed lock of the temporo-mandibular joint? Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008 ;105:274-80.

16. Sato S, Kawamura H. Evaluation of mouth opening exercise after pumping of the temporomandibular joint in patients with nonreducing disk displacement. J Oral Maxillofac Surg 2008;66:436-40.

17. Sato S, Goto S, Kawamura H, Motegi K. The natural course of non-reducing disk displacement of the TMJ: relationship of clinical findings at initial visit to outcome after 12 months without treatment. J Orofac Pain 1997;11:315-20.

18. Sato S, Kawamura H, Nagasaka H, Motegi K. The natural course of anterior disk displacement without reduction in the temporomandibular joint: follow-up at 6, 12, and 18 months. J Oral Maxillofac Surg 1997;55:234-8.

19. Tanaka E, Hirose M, Koolstra JH, van Eijden TM, Fujita R, Tanaka M, Tanne K. Modeling of the effect of friction in the temporomandibular joint on displacement of its disk during prolonged clenching. J Oral Maxillofac 2008;66:462-468.

20. Clark GT. A critical evaluation of orthopedic interocclusal appliance therapy: design, theory, and overall effectiveness. J Am Dent Assoc 1984;108:359-68.

21. Keshvad A, Winstanley RB. An appraisal of the literature on centric relation. Part III. J Oral Rehabil 2001;28:55-63.

22. Glossary of Prosthodontic Terms, 8th ed. J Prosthet Dent 2005;94:22.

23. Dawson PE. New definition for relating occlusion to varying conditions of the

temporomandibular joint. J Prosthet Dent 1995:74:619-27.
24. Zonnenberg AJJ, Mulder J. Reproducibility of 2 methods to locate the centric relation position in healthy individuals and TMD patients. Eur J Prosthodont Rest Dent 2012; 20: 151-158.

25. Ekberg E, Nilner M. Treatment outcome of appliance therapy in temporomandibular disorder patients with myofascial pain after 6 and 12 months. Acta Odontol Scand 2004;62:343-9.

26. Turp JC, Komine F, Hugger A. Efficacy of stabilization splints for the management of patients with masticatory muscle pain: a qualitative systematic review. Clin Oral Invest 2004;8:179-95.

27. Al-Ani MZ, Gray RJM, Robin J, Davies SJ, Stephen J, Sloan P, Glenny AM. Stabilization splint therapy for the treatment of temporomandibular myofascial pain: a systematic review. J Dent Educ 2005;69:1242-50.

28. Forssell H, Kalso E, Koskela P, Vehmanen R, Puukka P, Alanen P. Occlusal treatments in temporomandibular disorders: A qualitative systematic review of randomized controlled trials. Pain 1999;83:549-60.

29. Kreiner M, Betancor E, Clark GT. Occlusal stabilization appliances. Evidence of their efficacy. J Am Dent Assoc 2001;132:770-7.

30. Schuman S, Nohr A, Hagen B, Jones DL, Montgomery M. Comparative efficacy of maxillary and mandibular splints for TMD pain (abstract 1405). J Dent Res 1991;70 (special issue):441.

31. Jokstad A, Mo A, Krogstad BE. Clinical comparison between two different splint designs for temporomandibular disorder therapy. Acta Odontol Scand 2005;63:1-9.

32. Al Quran FAM, Kamal MS. Anterior midline point stop device (AMPS) in the treatment of myogenous TMDs: Comparison with the stabilization splint and control group. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:741-7.

33. Nilner M, Ekberg EC, Doepel M, Andersson J, Selovuo K, Le Bell Y. Short-term effectiveness of a prefabricated occlusal appliance in patients with myofascial pain. J Orofac Pain 2008;22:209-18.

34. Türp JC, Sedivy R, Schlaeppi MR, Spranger H, Endler C. Grenzen und Nutzen nichtkontrollierter therapiebezogener Fallbeobachtungen (Limits and benefits of non-controlled therapy-related observations). Forsch Komplementmed 2010;17:336-42.

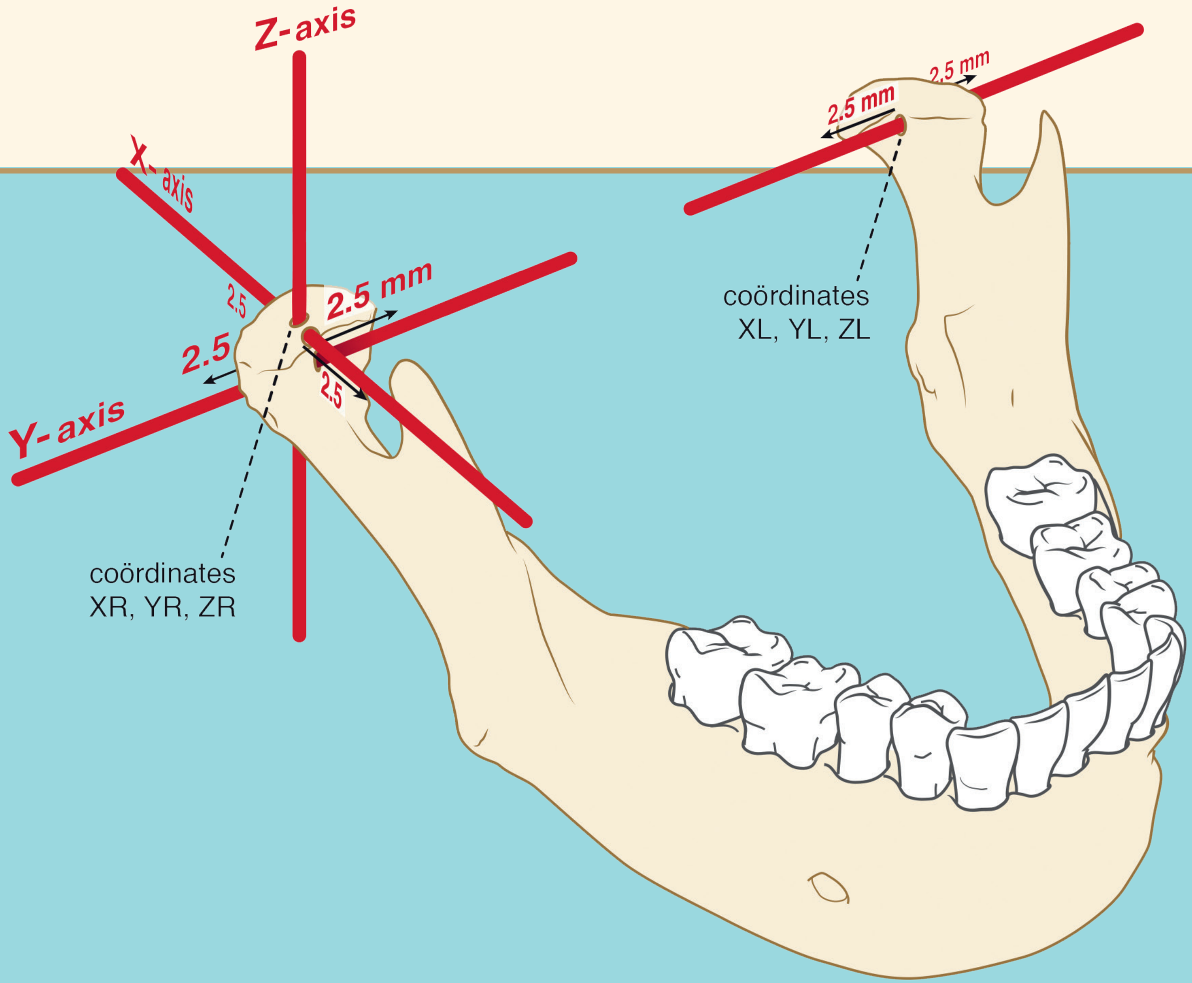
35. Petursson A. What you can and cannot see in TMJ imaging – an overview related to the RDC/TMD system. J Oral Rehabil 2010;37:771-78.

36. Tanner HM. The Tanner Mandibular Appliance. J Colo Dent Assoc 1996;75:14-18.

37. Rantala MA, Ahlberg J, Suvinen TI, Savolainen A, Könönen M. Symptoms, signs, and clinical diagnoses according to the research diagnostic criteria for temporomandibular disorders among Finnish multi-professional media personnel. J Orofac Pain 2003;17:311-6.

Chapter 7

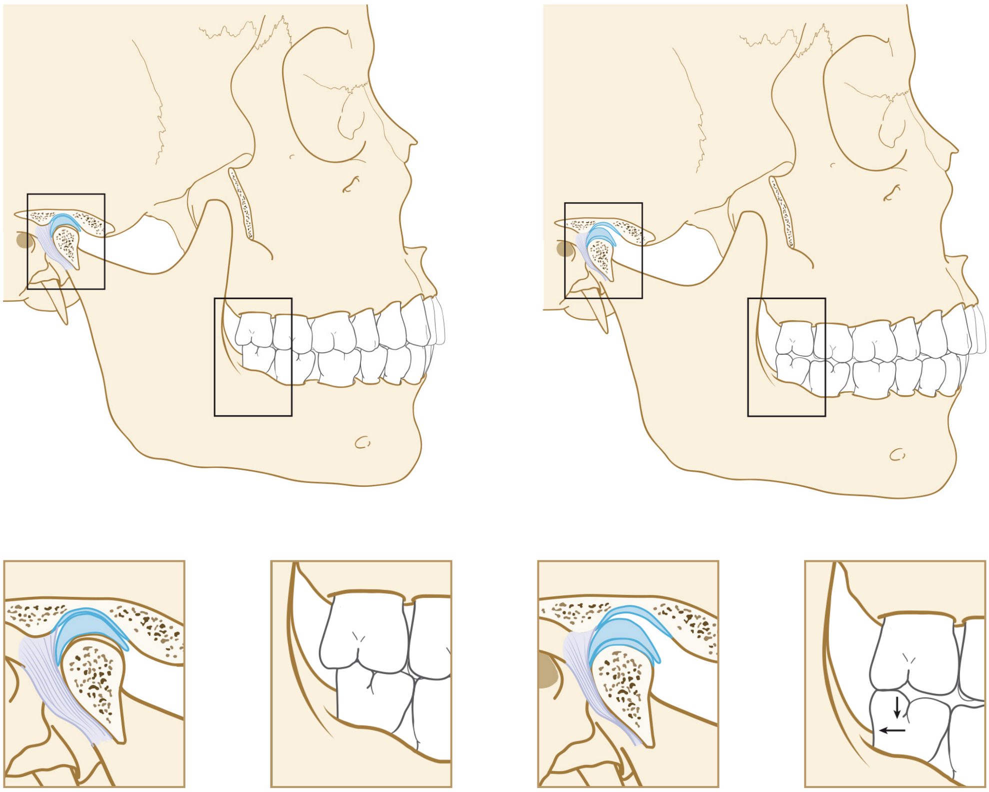
General discussion



General discussion

The method to locate centric relation with the leaf gauge at the end of a forward backward movement of the mandible was first used by Williamson (Williamson, 1980) and McHorris. (McHorris, 1986) The implementation of a forward backward movement into the method to locate the musculoskeletally stable position confirms the fact that the lateral pterygoid muscles counteracts normal condylar movement backwards. (Boucher, 1961, 1962) Critics point at possible distalizing of the mandible as a result of forceful manipulation. Hypothetically McHorris considered this phenomenon impossible: forcefully distalizing will rather fracture the mandibular collum than stretch the contracted lateral pterygoid muscles. (McHorris, 1986) Dawson criticized the guided closure method to determine the retruded contact position (RCP) long ago. (Dawson, 1989) The retruded contact position will position the mandible approximately half a cusp width (fig. 7-1) backwards and down from the optimal joint position. (Celenza, 1973)

Figure 7-1. The retruded contact position: guided closure forces the mandible half a cusp backwards and impinges upon the orthopedic stability of the joints.



The guided closure method may therefore be considered obsolete. In the proposed technique with the leaf gauge the operator gives verbal instructions to the patient: close on your back teeth, move your lower jaw forward, go all the way back, bite hard and relax. The mandible will not go any further backwards than the lateral pterygoid muscles and the related ligaments will permit.

Dawson postulated 4 criteria that must be fulfilled to achieve centric relation. It is considered impossible to achieve the CR position in TMD patients, since one or more of the criteria of CR (Dawson, 1995) cannot be fulfilled. However, in many patients an adapted centric posture can be accomplished.

1. The disc is properly aligned on both condyles.
2. The condyle-disc assemblies are at the highest point possible against the posterior slopes of the eminentiae.
3. The medial pole of each condyle-disc assembly is braced by bone.
4. The inferior lateral pterygoid muscles have released their contraction and are not active.

Critically approaching criterion 4, it would be better to say 'ending the lengthening contraction' instead of 'release their contraction'. A better choice would be to mention the full resting length of the inferior head of the lateral pterygoid muscle, because of its eccentric functioning like a rope that controls the condyle to go back to the fossa. (Koole, 1998, Murray et al, 2001)

Although adequate studies are not available, the conviction exists that centric relation is impossible in the TMD diagnosis disc displacement without reduction. However, a solution for this problem would be to use the term therapeutic or treatment reference position that, after appropriate treatment, may lead to an adapted centric posture as Dawson proposed. (Dawson, 1995) In this context Okeson prefers musculoskeletally stable position or stable orthopedic position. (Okeson, 2013 p. 75)

As mentioned above, centric relation is still the final solution for the reorganized approach in the occlusion although its definition has changed several times in the past and is expected to change again in the future. (Keshvad and Winstanley, 2001) To date it is unknown which CR position is the valid CR position. Does a reliable and easily reproducible CR position exist? Many dentists experience difficulties in locating, verifying, recording and transferring centric relation to an articulator. However, with proper training centric relation can be achieved on a consistent basis. With routine practice the operator learns to trust his centric relation records. Another reason why dentists do not use the centric relation position is whether centric relation is a physiologic position, in particular whether the CR position is part of the mandibular movement pattern. (McKee, 2005) Several studies showed the CR position is part of the mandibular motion in deglutition. (Gibbs et al, 1980, Mahan et al, 1983) Location of the centric relation position with a leaf gauge in the current study utilizes a lateral pterygoid dominated forward-backward movement of the mandible and muscle contraction of the elevator muscles. Without any operator guidance the patient incorporates the centric relation position into the physiologic mandibular envelope of function.

The available literature provides reliability studies of different methods to locate and record centric relation. Chinpoint guidance (Ingervall et al, 1971, Helkimo et al, 1973, Piehslinger et al, 1993) and bimanual manipulation (McKee, 1997, 2005) are well documented. The chinpoint guided method is not suitable to test reproducibility of the musculoskeletally stable centric relation position. Chinpoint guidance is based upon unstrained location of the CR position. The musculoskeletally stable position is a position in which strained elevator muscles position the condyles on the discs in their respective fossae. As mentioned before, Okeson (Okeson, 2013 p. 74-76) states that the most recent definition of the centric relation position is synonymous to the musculoskeletally stable position as defined in the Glossary. (GPT 8, 2005) And second, there are 2 methods to locate the musculoskeletally stable position: with bimanual manipulation or with a leaf gauge (Okeson, 2013 p. 195) The first method is a manual manipulation technique of the mandible, the second is a technique with a leaf gauge and active muscle contraction by the patient upon the operator's request. The former method proved to be a reliable method as mentioned above (McKee, 1997, 2005), from the latter method exist a few instructional articles. (Long, 1973, Woelfel, 1986, Carroll et al, 1988)

Originally, the outline of the current study has been designed to contribute to the knowledge of the ongoing dispute whether (any aspect of) the occlusion could be an etiologic factor for the onset of a temporomandibular disorder. Recent literature (Okeson, 2013 p. 116 – 118) points to the occlusal factor centric slide. Centric slide is defined as the mandibular trajectory from the initial occlusal contact while the mandible is in centric relation, into maximal intercuspal position or maximum intercuspation. The maximal intercuspal position is a reliable and easily reproducible position. Unfortunately, centric relation is subject to discussion and change ever since Posselt proposed guided closure to achieve the closed-pack position over 6 decades ago. To date the Glossary of Prosthodontic Terms describes 7 different definitions of centric relation. The most recent definition of centric relation fits the musculoskeletally stable centric relation position. A construct validity of a method to achieve this specific centric relation position was chosen. Subsequently, a methodologically sound study about the reproducibility of this method was designed. Such a study is not available in the literature. This study is also necessary to conclude on the etiology of the occlusal factor centric slide. For this purpose 5 studies were designed and performed with the following conclusions.

Address to the aims of the study

1. The current study demonstrated that the muscle-determined method to locate centric relation with a leaf gauge is a reproducible and reliable method resulting in a musculoskeletally stable or stable orthopedic position of the mandible. The found position is reliable for healthy individuals as well as for TMD patients. (Chapter 2 and 3)
2. There is no evidence that the static nor the dynamic occlusal factor centric slide is an etiologic factor for a temporomandibular disorder. Centric slide seems an occlusal factor and needs to be addressed as such. (Chapter 4 and 5)

3. The therapy with the specific stabilization splint reduced signs as pain, restricted mouth opening and disturbed mandibular movement considerably. (Chapter 6)

Future perspectives

The 2 methods to locate centric relation in the current study lead to the same position in healthy individuals. Contrary, in 3 distinct defined TMD diagnoses discussed within the framework of this thesis, the chinpoint guided method leads to a different centric relation position compared to a muscle-determined method with a leaf gauge. In a prospective cohort type study treatment with a specific stabilization splint, fabricated in the musculoskeletally stable position, delivered quite interesting therapy-related non-controlled observations. The observations were most outstanding in the patient group with the TMD diagnosis disc displacement without reduction. These non-controlled observations should be incorporated in a RCT study design to definitely validate the musculoskeletally stable centric relation position. Moreover, it is mandatory to validate this position, defined with the construct validity, in a future RCT as the preferable position for diagnosis and treatment. For healthy individuals the term centric relation could be maintained, for patients with a TMD diagnosis the musculoskeletally stable position should be used. Besides CR the term MS could be used in the English language. However, the MS position could be used for healthy individuals as well. A well designed RCT, confirming the outcome of the current study, would bring a breakthrough in the discussion which intermaxillary relationship brings about, in the near future, the preferable position for restorative procedures in general, for the splint treatment of TMD patients in particular.

For the reliability study discussed in Chapter 4, a power analysis was performed in Chapter 3 with the 6 variables that define the intercondylar axis. The 3-dimensional displacement of the mandible, in the form of this axis as a pars pro toto, was the aim of the study to test the reproducibility of 2 different methods to locate the centric relation position. Chapter 5 discusses the found centric slides in the articulator mountings and the centric slides found with the millimeter ruler. The statistical difference between the disc displacement without reduction group and the other groups tends towards significance ($P = .528$). A new power analysis of the data of the former group may reveal in a future study a significant difference in the factor centric slide between a control group and a patient group with disc displacement without reduction, hence producing centric slide as a causal (co-)factor for this diagnosis. This potentially statistical significant difference explains possibly part of the 4 till 27.1 % occlusal influence in TMD as postulated by Seligman and Pullinger. (Seligman and Pullinger, 2000)

An appropriate design RCT could potentially explain the significantly smaller mouth opening at conclusion of splint treatment. The set-up of a cohort study to obtain therapy-related observations does not automatically imply the use of MRI for research purposes. (Petersson, 2010) However, since the current study revealed its data on mouth opening in different stages, appropriate use of MRI may enlighten what happens to the disc in various stages of the splint treatment.

Summary

Chapter 2 describes the measuring procedure to locate the musculoskeletally stable centric relation position. A sample of 15 subjects, 6 men and 9 women, without any signs of TMD ruled out with the RDC/TMD, was selected. In one session three examiners each took 3 sequential interocclusal records with a leaf gauge to mount a set of casts into an articulator for each patient. In a split-cast procedure (SAM Axiosplit) 12 out of 15 subjects fitted criteria of precision set beforehand: 3 out of 3 wax records for all 3 examiners. After exchange of the mounted casts from the articulator to the Condymeter III, the distribution of the x-, y- and z-coordinates was measured, in total 6 variables that constitute the intercondylar axis that may be seen as the pars pro toto for mandibular displacement. The variance components of these data, expressed in MIVQUE estimates, were 0 for the examiners, smaller than 0.04 for the subjects and 0.06 millimeters for the measuring technique (error). Scheffe's testing to rule out type I errors confirms precision.

Chapter 3 reports the mandibular displacement for the 6 variables of the intercondylar axis between 0 and 0.137 millimeter. A sample of 60 TMD patients was diagnosed with the RDC/TMD as follows: 1 patient with trauma, 13 with myofascial pain, 23 patients with myofascial pain and capsulitis, 9 with disc displacement without reduction and 14 with osteoarthritis. The trauma patient was excluded. Statistical analysis demonstrates no differences in the variance components between the other 4 diagnostic subgroups and the added control group from Chapter 2. Scheffe's testing to rule out type I errors confirms precision. Though the methods to locate the centric relation position are not the same, the outcome in this study is comparable and similar to the results of McKee's study, be it for healthy individuals as well as for the 4 distinct TMD groups.

Chapter 4 reports a comparison of potential differences between 2 methods to locate the centric relation position in healthy individuals and 3 groups of TMD patients. The first method is chinpoint guidance to locate the centric relation position, the second method the experimental technique with the leaf gauge to determine the musculoskeletally stable position. Although the variance component in the chinpoint guided method is larger than in the method with the leaf gauge, there are no significant differences between the 6 variables ($P<.2$). The values of the 6 variables varied between 0.006 ± 0.175 and -0.02 ± 0.140 millimeters. This outcome confirms the contemporary opinion in the literature that the method to locate centric relation is not decisive. This outcome means the intercondylar axes of both methods actually coincide, at least in healthy individuals.

Contrary to the method with the leaf gauge, chinpoint guidance uses no occlusal stop. Consequently, precision of the chinpoint guided method could be influenced by the thickness of the wax record and the operator's mandibular manipulation. The method with the leaf gauge uses a fixed amount of leaves. Mandibular manipulation is avoided by oral instruction of the patient. Again, there were no significant differences between

the 2 methods (P<.2) in healthy individuals, meaning the operator's manipulation plays a negligible role and confirms the outcome in Chapter 2, the MIVQUE estimates, expressing the variance component between examiners is 0.

In the 3 distinct TMD groups no significant differences were found between the 2 methods to locate centric relation, the patient group and the point in time, before and at conclusion of splint treatment. The data confirm comparable accuracy of both methods. Age, gender and duration of treatment did not influence the outcome. However, by adding the control group to the patient groups, the 2 methods, at baseline and at conclusion of stabilization splint treatment, showed a significant difference in half of the variables. All differences were well within the value of variable XR in Chapter 3, the variable upon which the power analysis was performed. The extremely small significant statistical differences could indicate a causal relationship of an unknown factor in TMD patients. Neither splint treatment influenced the differences, nor is known whether these differences existed before the onset of TMD. Their magnitude however, appears to be of limited clinical impact.

A rather conspicuous result was found in the split-cast analysis of both the articulator mountings, obtained with the 2 wax record sets. In TMD patients the chinpoint guided centric relation position did not coincide with the musculoskeletally stable position determined with the leaf gauge before the start of splint treatment in the majority of the patients. The 2 methods to locate centric relation lead to 2 different positions in TMD patients. After splint treatment both positions were coincident in most patients, which suggests that the TMD patients start to behave as control subjects. This finding again confirms the general opinion that various techniques to locate centric relation result in the same position in healthy individuals.

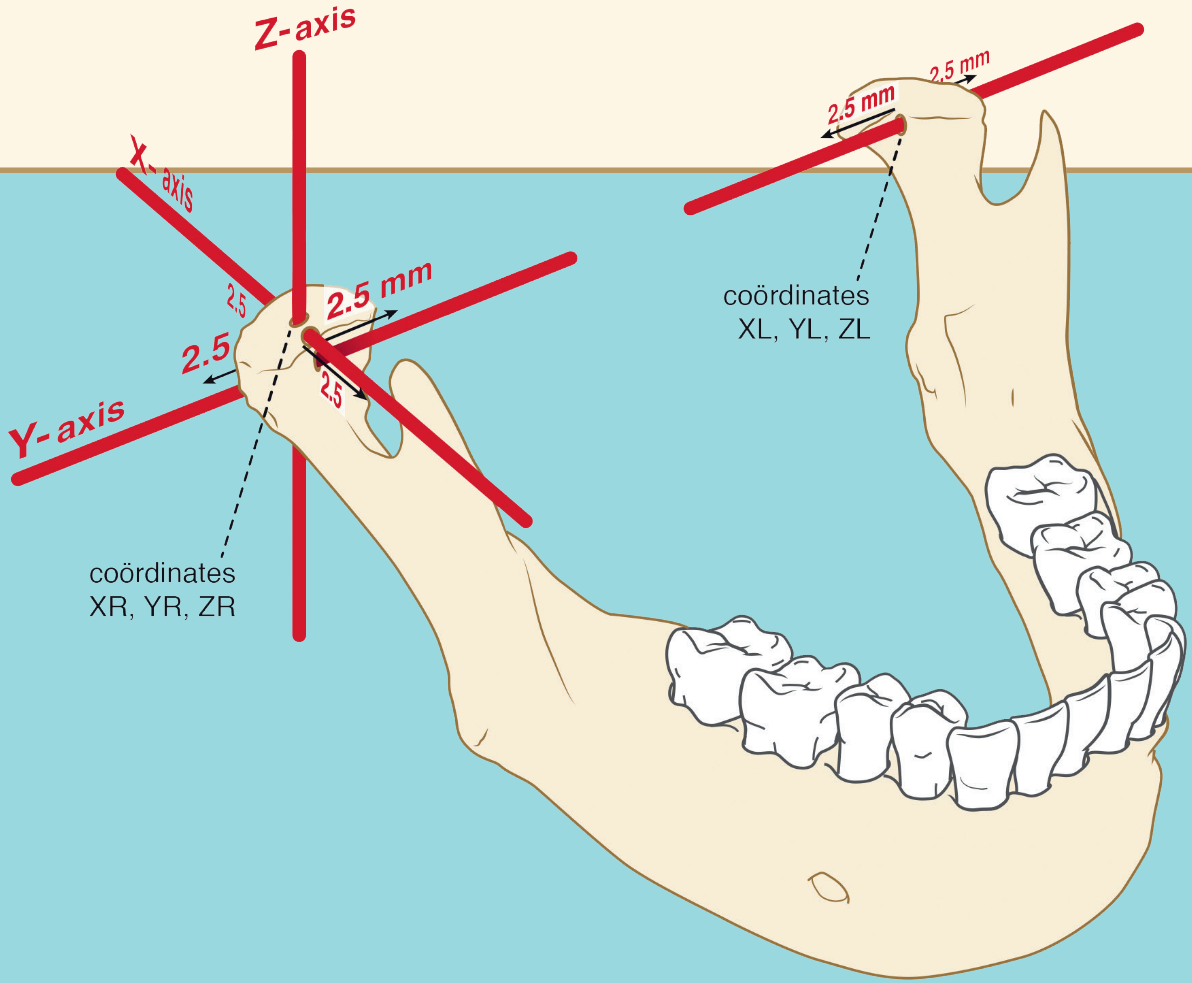
Chapter 5 is a sequel of the study in Chapter 4. The articulator mountings also offered the opportunity to assess centric slide and compare the articulator mountings to the intraoral measurement of centric slide with a flexible millimeter ruler. TMD patientscan not be differentiated from healthy individuals based on the magnitude of their centric slide. The magnitude of centric slide in TMD patient groups with myofascial pain or osteoarthritis is similar to the slide in control subjects, well within the normal range between 0 and 1.5 millimeter. Splint treatment increased the magnitude of centric slide in the internal derangement group. The centric slide in this patient group tends towards significance, specifically in the data of the variables collected at conclusion of splint treatment (1.97 ± 1.30 millimeter). However, the data showed a large range (0.03 – 5.32 millimeter), a large standard deviation and a substantial overlap with the other groups.

Chapter 6 reports the specific observations during stabilization splint treatment of patients with a disc displacement without reduction. The study enrolled 55 patients, 42 with a limited mouth opening and 13 without limited mouth opening, their diagnosis confirmed clinically with the RDC/TMD. From 42 patients with a limited mouth opening

5 patients were excluded. All patients had a complete natural dentition and received a full-arch mandibular stabilization splint: a Tanner appliance, fabricated in the dental laboratory. Clinical performance of the Tanner appliance was observed in a maximal timeframe of 12 months. Increase in mouth opening, duration of treatment, occlusal adjustment and residual signs of TMD were monitored during treatment. The increase in mouth opening was quicker than a comparable study in the literature. Mouth opening measurements of all 50 patients, from baseline, via all control visits to conclusion of treatment were significantly smaller, compared to mouth opening in healthy individuals. However, all patients concluded treatment with a mouth opening greater than 40 millimeter. Splint treatment of the 37 actually locking patients increased mouth opening well over 9 millimeter, being the smallest detectable difference to differentiate this opening from regression to the mean. The maxillomandibular relationship of the Tanner appliance did not change over time. The efficacy of this appliance, fabricated in the musculoskeletally stable centric relation position combines effectiveness and efficiency which makes it eligible to be tested in a RCT.

Chapter 8

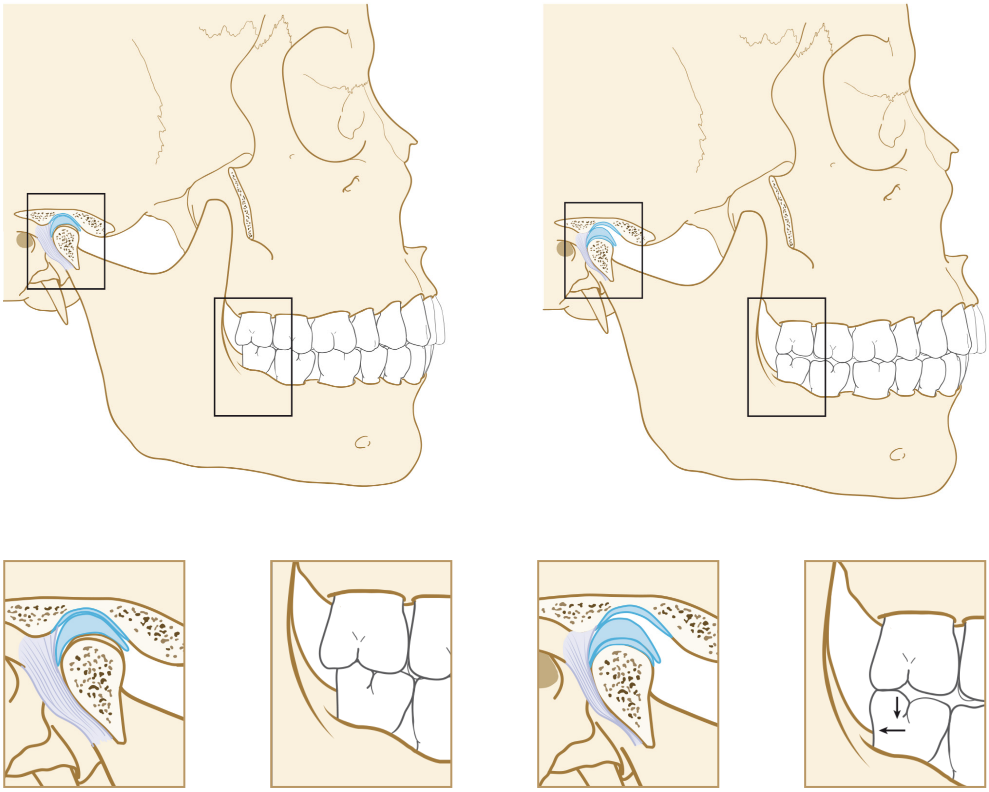
Algemene discussie



Algemene discussie

De methode om centrale relatie te bepalen met een leaf gauge aan het einde van een voorachterwaartse beweging van de onderkaak werd voor het eerst gebruikt door Williamson (Williamson, 1980) en McHorris. (McHorris, 1986) Het inbrengen van een voorachterwaartse beweging in de methode om de musculoskelettaal stabiele positie te bepalen bevestigt het feit dat de Mm. pterygoideï de normale achterwaartse beweging van de condylen antagoneren. (Boucher, 1961, 1962) Critici wijzen op de mogelijkheid dat de mandibula met kracht naar dorsaal kan worden gebracht. McHorris beschouwde dit verschijnsel als hypothetisch en onmogelijk: de mandibula met kracht naar dorsaal brengen zal eerder tot een collumfractuur leiden dan dat de samengespannen Mm. laterales pterygoideï zullen toegeven. (McHorris, 1986) Dawson bekritiseerde de guided closure methode om de geretrudeerde kaakrelatie te bepalen reeds lang geleden. (Dawson, 1989) Deze geretrudeerde kaakrelatie zal de mandibula ongeveer een halve knobbelbreedte naar achteren en naar beneden verplaatsen, weg van de optimale gewrichtpositie. (Celenza, 1973)

Figuur 8-1. De *retruded contact position:* de *guided closure* methode dwingt de onderkaak een halve knobbelbreedte naar achteren, naar beneden en beinvloedt zo de orthopedische stabiliteit van de kaakgewrichten.



Om die reden mag de guided closure methode als obsoleet worden beschouwd. Met de voorgestelde methode met de leaf gauge geeft de behandelaar mondeling instructies aan de patiënt: Sluit op uw achterste kiezen, beweeg uw onderkaak (op geleide van dit instrumentje, de leaf gauge dus) naar voren, ga helemaal terug, bijt hard en ontspan. De mandibula zal niet verder naar dorsaal gaan dan de Mm.pterygoideï en de gerelateerde ligamenten zullen toestaan.

Dawson formuleerde 4 eisen waaraan moet worden voldaan om centrale relatie te bereiken. Het wordt voor onmogelijk gehouden de centrale relatie positie te bereiken bij TMD patiënten, omdat één of meer criteria van centrale relatie niet kunnen worden vervuld. Echter, bij veel patiënten kan een aangepaste centrale relatie verhouding worden bereikt.

1. De discus moet juist gepositioneerd zijn op beide condylen.
2. Het condylus-discus complex aan beide zijden bevindt zich op het hoogst mogelijke punt tegen de dorsale helling van de eminentia.
3. De mediale pool van elk condylus-discus complex afzonderlijk wordt ondersteund door bot.
4. De onderste kop van M. pterygoideus lateralis heeft de contractie beëindigd en is niet actief.

Als we het 4e criterium kritisch beschouwen, zou het beter zijn om te zeggen dat de Mm. pterygoideï hun spierverlengende contractie beëindigen. Een nog betere keus zou kunnen zijn tot de volledige lengte in rust van de M. pterygoideus lateralis, omdat deze spier excentrisch functioneert zoals een touw dat de condylus gecontroleerd laat teruggaan naar de fossa. (Koole, 1998, Murray et al, 2001)

Alhoewel adequate studies ontbreken, bestaat de overtuiging dat centrale relatie onmogelijk is bij de TMD diagnose discus verplaatsing zonder reductie. Het zou echter een mogelijkheid zijn om de term therapeutische of behandelpositie te gebruiken die, na de juiste therapie, kan leiden tot een aangepaste centrale relatie verhouding zoals Dawson heeft voorgesteld. (Dawson, 1995) In deze context geeft Okeson de voorkeur aan de musculoskelettaal stabiele of stabiele orthopedische positie. (Okeson, 2013 p.75)

Zoals boven vermeld is centrale relatie nog steeds de beste optie voor de reorganisatie van de occlusie alhoewel de definitie diverse malen is gewijzigd in het verleden en de verwachting is dat hij weer zal worden aangepast in de toekomst. (Keshvad en Winstanley, 2001) Tot vandaag is onbekend welke centrale relatie positie als gevalideerd kan worden beschouwd. Bestaat een betrouwbare en gevalideerde centrale relatie positie eigenlijk wel? Veel tandartsen ondervinden problemen bij het bepalen, verifiëren, vastleggen en overbrengen van de centrale relatie naar een articulator. Echter, met de juiste training kan centrale relatie worden bepaald op een consistente manier. Met het regelmatig oefenen leert de behandelaar zijn centrale relatie wasrelaties vertrouwen. Een andere reden waarom tandartsen geen centrale relatie gebruiken is omdat ze betwijfelen of het wel een fysiologische positie is, in het bijzonder of de positie wel deel uitmaakt van het mandibulaire bewegingspatroon. (McKee, 1997, 2005) Diverse studies toonden aan dat de centrale relatie positie wel degelijk deel uitmaakt van het mandibulaire bewegingspatroon bij slikken. (Gibbs et al, 1980, Mahan et al, 1983) Het bepalen van de centrale relatie positie met een leaf gauge in deze studie maakt gebruik van een door de M. pterygoïdeus lateralis gedomineerde voorachterwaartse beweging en contractie van de heffers van de mandibula. Zonder enige geleiding van de behandelaar incorporeert de patiënt de centrale relatie positie in het fysiologische kauw- en bewegingspatroon van de onderkaak.

De beschikbare literatuur voorziet in betrouwbaarheidssstudies van verschillende methoden om centrale relatie te bepalen en vast te leggen.. Kinpunt geleiding (Ingervall et al, 197, Helkimo et al, 1973, Piehslinger et al, 1993) en bimanuele manipulatie (McKee, 1997, 2005) zijn goed gedocumenteerd. Kinpunt geleiding is echter niet geschikt om de reproduceerbaarheid van de musculoskelettaal stabiele positie te toetsen. De methode is gebaseerd op het ontspannen bepalen van de centrale relatie positie. De musculoskelettaal stabiele positie is een positie waarbij aangespannen elevatoren de condylen in hun respectievelijke fossa positioneren. Zoals al eerder vermeld, stelt Okeson (Okeson, 2013 p 74-76) dat de meest recente definitie van centrale relatie in de Glossary (GPT 8, 2005) synoniem is aan de musculoskelettaal stabiele positie. Vervolgens, zegt hij, zijn er 2 methoden om deze positie te bepalen: met bimanuele manipulatie of met een leaf gauge (Okeson, 2013 p. 195) De eerstgenoemde methode is een handvaardige manipulatie van de onderkaak, de laatste een techniek met een leaf gauge en actieve spieraanspanning van de patiënt op uitnodiging van de behandelaar. Eerstgenoemde methode bleek een betrouwbare methode als voormeld (McKee, 1997, 2005), van laatstgenoemde methode bestaan er enkele artikelen met een beschrijving van de toepassing van de leaf gauge. (Long, 1973, Woelfel, 1986, Carroll et al, 1988)

Oorspronkelijk werd de huidige studie ontworpen om een bijdrage te leveren aan het voortdurende dispuut dat (enig aspect van) de occlusie een oorzakelijke factor zou kunnen zijn voor het ontstaan van temporomandibulaire stoornis. Recente literatuur (Okeson, 2013 p. 116-118) wijst op de occlusale factor centric slide. Centric slide wordt gedefinieerd als de bewegingsafloop van de mandibula vanuit het eerste occlusale contact in centrale relatie naar de maximale occlusie. De maximale occlusie is een betrouwbare en eenvoudig te reproduceren positie. Ongelukkigerwijs is centrale relatie onderhevig aan discussie en verandering sinds Posselt zo'n 60 jaar geleden zijn guided closure voorstelde om de closed-pack positie te bereiken. Vandaag de dag beschrijft de Glossary of Prosthodontic Terms 7 verschillende definities van centrale relatie naast elkaar. De meest recente definitie past bij de musculoskelettaal stabiele positie. In deze studie werd gekozen voor een construct validity om de musculoskelettaal stabiele positie te bepalen. Vervolgens werd een gedegen methodologische studie over de reproduceerbaarheid van deze methode ontworpen. Een vergelijkbare studie is niet beschikbaar in de literatuur. Deze studie is tevens noodzakelijk om etiologische conclusies te kunnen verbinden aan de occlusale factor centric slide. Voor dit doel werden 5 deelstudies ontworpen en uitgevoerd met de volgende conclusies.

Bespreking van de doelstellingen

1. De huidige studie toonde aan dat de spierbepaalde methode om centrale relatie te bepalen met een leaf gauge een reproduceerbare en betrouwbare methode is die resulteert in een musculoskelettaal stabiele, ook wel stabiele orthopedische positie. De gevonden positie is betrouwbaar voor gezonde proefpersonen en voor TMD patiënten (hoofdstuk 2 en 3)
2. Er is geen bewijs dat de occlusale factor centric slide een etiologische factor is voor een temporomandibulaire stoornis. Centric slide lijkt een occlusale factor en dient als zodanig te worden beschouwd. (hoofdstuk 4 en 5)
3. De therapie met de specifieke stabilisatiesplint reduceerde klachten als pijn, beperkte mondopening en verstoorde mandibulaire bewegingsafloop aanzienlijk. (hoofdstuk 6)

Toekomstig onderzoek

De 2 methoden om centrale relatie te bepalen in de onderliggende studie leiden tot dezelfde positie bij gezonde proefpersonen. Daarentegen, bij 3 nauwkeurig omschreven TMD diagnoses die besproken werden in het kader van deze dissertatie, leidt kinpunt geleiding tot een andere centrale relatie positie vergeleken met een spierbepaalde methode met een leaf gauge. In een prospectieve cohort studie leverde behandeling met een nauwkeurig omschreven stabilisatiesplint die vervaardigd werd in de musculoskelettaal stabiele centrale relatie positie, een aantal interessante aan deze therapie gerelateerde waarnemingen op. Ze waren het meest opmerkelijk in de patiënten groep met de TMD diagnose discus verplaatsing zonder reductie. Deze waarnemingen dienen te worden ingebouwd in een gerandomiseerd klinisch studie om de musculoskelettaal stabiele centrale relatie positie te valideren. Het is bovendien noodzaak om deze positie, op basis van construct validity, in een toekomstig gerandomiseerd klinisch onderzoek te valideren als de voorkeurspositie voor diagnostiek en behandeling. Voor gezonde proefpersonen zou de term centrale relatie kunnen worden gehandhaafd, voor TMD patiënten moet de musculoskelettaal stabiele positie worden gebruikt.
Naast CR kan dan de term MS in het Engels worden gebruikt. Of SO voor stabiele orthopedische positie. Echter deze MS positie kan ook voor gezonde proefpersonen worden gebruikt. Een goed gedefinieerde gerandomiseerde klinische studie die de bevindingen van de onderhavige studie bevestigt, zou een doorbraak kunnen betekenen in de discussie welke intermaxillaire relatie in de nabije toekomst de voorkeurspositie voor restauratieve tandheelkundige procedures in het algemeen zou kunnen zijn, en voor de behandeling met een opbeetspalk voor TMD patiënten in het bijzonder.

Voor de betrouwbaarheidsstudie die besproken wordt in hoofdstuk 4, werd een power analyse met de 6 variabelen die de intercondylaire as vormen, in hoofdstuk 3 uitgevoerd. De 3-dimensionele verplaatsing van de mandibula, in de vorm van deze as als pars pro toto,was het doel van deze studie om de reproduceerbaarheid te toetsen van 2 verschillende methoden om de centrale relatie te bepalen. Hoofdstuk 5 bespreekt de gevonden waarden voor centric slide in de beide articulator montages en die werden gevonden met het flexibele meetlatje. Het statistische verschil tussen de patiënten groep met discus verplaatsing zonder reductie en de andere patiënten en controle groepen tendeert naar significantie (P = .528) Een nieuwe power analyse van de eerstgenoemde patiëntengroep zou in een toekomstige studie een significant verschil kunnen opleveren tussen de controlegroep en de patiënten groep met discus verplaatsing zonder reductie, bijgevolg van centric slide een causale (co)factor maken voor deze diagnose. Deze potentiële statistische significantie zou mogelijk een deel van de 4 tot 27,1 % occlusale invloed verklaren zoals gepostuleerd door Seligman en Pullinger. (Seligman en Pullinger, 2000)

Een goed ontworpen gerandomiseerde klinische studie zou een verklaring kunnen geven voor de significant kleinere mondopening aan het eind van de behandeling met de stabilisatiesplint in de patiënten groep met discus verplaatsing zonder reductie. De opzet van een cohort studie om therapie gerelateerde waarnemingen te verzamelen, houdt niet automatisch het gebruik van MRI in. (Petursson, 2010) Echter, omdat de onderliggende studie de waarden van de mondopening in verschillende stadia aantoonde, zou een goed gebruik van MRI kunnen laten zien wat er met de discus gebeurt tijdens de verschillende stadia van de behandeling met de stsbilisatiesplint.

Historisch perspectief centrale relatie

Volgens de 8e editie van de Glossary of Prosthodontic Terms gepubliceerd in 2005 zijn er 7 verschillende definities van de centrale relatie. In de eerste versie van de Glossary beschrijft de definitie van centrale relatie de kinpunt geleide techniek. Kinpunt geleiding verschaft de behandelaar de mogelijkheid de meest geretrudeerde positie van de mandibula ten opzichte van de maxilla vast te leggen, waarbij de beide condylen in hun achterste, ongedwongen positie in de fossa liggen, van waaruit laterale bewegingen kunnen worden gemaakt bij een willekeurige mondopening (Posselt, 1952, GPT 1, 1956). Deze omschrijving heeft model gestaan voor de Nederlandse situatie. Tijdens een consensus overleg van de Nederlandse tandheelkundige faculteiten in1968 (Steenks, 1982, p.11) werd de volgende definitie voor centrale relatie afgesproken: Onder centrale relatie verstaat men de relatie van de mandibula ten opzichte van de schedel waarvan het Frankforter vlak horizontaal verloopt en waarbij de capitae mandibulae zich in hum achterste, ongedwongen, meest dorsale stand in de fossae articulares bevinden. Volgens sommigen moet daar nog aan toegevoegd worden 'bij de juiste verticale dimensie'. (Derksen, 1971, p.42) Deze definitie is sindsdien niet meer aangepast en is derhalve nog steeds geldig binnen de Nederlandse tandheelkunde. Er zit overigens enige frictie in deze definitie die spreekt over de meest geretrudeerde onderkaakpositie en de beide condylen in hun achterste, ongedwongen positie in de fossa: een contradictio in terminis. Geretrudeerd betekent hier geforceerd naar achteren tegenover ongedwongen in de fossa en is een van de redenen voor de langdurige discussie over centrale relatie. In 2005 is centrale relatie gedefinieerd als de intermaxillaire relatie waarbij de condylen articuleren met de dunste avasculaire portie van hun respectievelijke discus met het gewricht in de bovenste voorste positie tegen de eminentia van de fossa articularis. Deze positie is onafhankelijk van tandcontact (GPT 8, 2005).

Samenvatting

Een methodologisch correcte studie over de reproduceerbaarheid en de validiteit van de methode om de musculoskelettaal stabiele centrale relatie positie te bepalen ontbreekt in de literatuur. Een studie naar de reproduceerbaarheid van de meetmethode is noodzakelijk voordat in een gerandomiseerde klinische studie de getoetste positie kan worden gevalideerd. Zo'n studie is tevens noodzakelijk om de grootte van de centric slide te bepalen. Bovendien is het kwalificeren van het etiologische aspect van centric slide een tweede doelstelling van deze studie.

1. Het ontwikkelen van een reproduceerbare methode centrale relatie te bepalen, te verifiëren, vast te leggen en over te brengen in een articulator bij gezonde proefpersonen wordt beschreven in Hoofdstuk 2.
2. De gevonden data betreffende de centrale relatie in Hoofdstuk 2 werden getoetst op variabiliteit onder 4 groepen patiënten met een specifieke TMD diagnose in Hoofdstuk 3. De studie bood de mogelijkheid een power analyse uit te voeren naar het aantal patiënten benodigd per onderzoeksgroep om de gecontroleerde klinische studie van Hoofdstuk 4 te kunnen uitvoeren.
3. Hoofdstuk 4 rapporteert een dubbelblind gecontroleerde klinische studie om 2 methoden om de centrale relatie te bepalen te toetsen op reproduceerbaarheid. De kinpunt geleide centrale relatie werd vergeleken met de musculoskelettaal stabiele centrale relatie aan gemonteerde gipsmodellen in een articulator. Het bepalen van de centrale relatie met beide methoden werd 2 keer uitgevoerd in de patiënten groepen, vooraf en na behandeling met een opbeetspalk; het bepalen van beide centrale relaties in de controle groep werd één maal uitgevoerd./
4. Als bijproduct van Hoofdstuk 4, rapporteert Hoofdstuk 5 de grootte van de centric slide. De centric slide werd in de mond gemeten met een flexibel latje met millimeterverdeling. De gevonden waarden werden vergeleken met de centric slides gemeten aan de gemonteerde gipsmodellen in de articulator. De studie toont ook aan dat de statische/dynamische factor centric slide al of niet een etiologische factor is voor een temporomandibulaire aandoening.
5. Hoofdstuk 6 documenteert de ongecontroleerde klinische waarnemingen en waarden van de behandeling met een opbeetspalk. De patiënten groep met de diagnose discusverplaatsing zonder reductie kreeg een stabilisatie opbeetspalk die gemaakt was in de musculoskelettaal stabiele centrale relatie positie.

References – Literatuur

1. Beyron HL. Occlusion: point of significance in planning restorative procedures. J Prosthet Dent 1973;30:641.

2. Boucher LJ, Jacoby J. Posterior border movements of the human mandible. J Prosthet Dent 1961;11:836-841.

3. Boucher LJ. Anatomy of the temporomandibular joint as it pertains to centric relation. J Prosthet Dent 1962;12:462-72.|

4. 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;76:282-287.

5. 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.

6. Celenza FV. The centric position: replacement and character. J Prosthet Dent 1973;30:591-598.

7. Clinics in physical therapy. TMJ disorders: management of the craniomandibular complex. Ed. by Kraus SL. Churchill Livingstone, New York; 1988.

8. Dawson PE. Evaluation, diagnosis and treatment of occlusal problems. 2nd ed. St Louis: CV Mosby Co, 1989:28-39.

9. Dawson PE. New definition for relating occlusion to varying conditions of the temporomandibular joint. J Prosthet Dent 1995:74:619-627.

10. Derksen AAD. Inleiding tot bouw en functie van het kauwstelsel, 2e druk. Oosthoek Uitgeversmaatschappij, Utrecht; 1971, p.42.

11. Dubner R, Ren K, Sessle BJ. Sensory mechanisms of orofacial pain. In: Treatment of TMDs: Bridging the gap between advances in research and clinical patient management. Ed. by Greene CS and Laskin DM. Quintessenz Publishing Co Inc, Chicago; 2012: p.8-14.

12. 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.

13. Gibbs CH, Lundeen HC, Mahan PE. Movements of the molar teeth and mandibular condyles during chewing (Abstract) J Dent Res 1980;59:915.

14. Glossary of Prosthodontic Terms. 8th ed. J Prosthet Dent 2005;94:22.

15. Goulet JP, Lavigne GJ, Lund JP. Jaw pain prevalence in French-speaking Canadians in Quebec and related symptoms of temporomandibular disorders. J Dent Res 1995;74:1738-1744.

16. Helkimo M, Ingervall B, Carlsson GE. Comparison of different methods in active and passive recording of the retruded position of the mandible. Scand J Dent Res 1973;81:265-271.

17. Ingervall B, Helkimo M, Carlsson GE. Recording of the retruded position of the mandible with application of varying external pressure to the lower jaw in man. Archs Oral Biol 1971;16:1165-1171.

18. Kabcenell JL. Effect of clinical procedures on mandibular position. J Prosthet Dent 1964;14:266-278.

19. Keshvad A, Winstanley RB. An appraisal of the literature on centric relation. Part III. J Oral Rehabil 2001;28:55-63.

20. Keshvad A, Winstanley RB. Comparison of the replicability of routinely used centric relation registration techniques. J Prosthodont 2003;12:90-101.

21. Koole P. Masticatory muscle function: a multichannel electromyographic investigation. Thesis Rijksuniversiteit Groningen, the Netherlands;1998.

22. Kraus SL. TMJ disorders: Management of the craniomandibular complex. Churchill Livingstone, New York;1988.

23. Laskin DM. Temporomandibular disorders: A term past its time? J Am Dent Assoc 2008;139:124-128.

24. De Leeuw, R, Klasser GD. Orofacial pain: Guidelines for assessment, diagnosis, and management, 5th Ed. Quintessenz Publishing Co Inc, Chicago: 2013.

25. Lobbezoo F, van Denderen RJ, Verheij JG, Naeije M. Reports of SSRI-associated bruxism in the family physician's office. J Orofac Pain 2001;15:340-346.

26. Long JH. Locating centric relation with a leaf gauge. J Prosthet Dent 1973;28:608-10.

27. Mahan PE, Wilkinson TM, Gibbs CH, Mauderli A, Brannon LS. Superior and inferior bellies of the lateral pterygoid muscle EMG activity at basic jaw positions. J Prosthet Dent 1983;50:710-718.

28. McHorris WH. Centric Relation: Defined. J Gnathology 1986;5:15,16,21.

29. McKee JR. Comparing condylar position repeatability for standardized versus non-standardized methods of achieving centric relation. J Prosthet Dent 1997;77:280-284.

30. 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;94:389-393.

31. 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.

32. Okeson JP. Management of Temporomandibular Disorders and Occlusion. 7th ed. Elsevier; 2013.

33. Petersson A. What you can and cannot see in TMJ imaging – an overview related to the RDC/TMD doagnostic system. J Oral Rehabil 2010;37:771-778.

34. Piehslinger E, Celar A, Celar R, Jäger W, Slavicek R. Reproducibility of the condylar reference position. J Orofac Pain 1993;7:68-75.

35. Posselt U. Studies in the mobility of the human mandible. Acta Odont Scand 1952;10:19-160.

36. Pullinger AG. Establishing better biological models to understand occlusion: Part I: TM joint anatomic relationships. J Oral Rehabil 2013;40:296-318.

37. Pullinger AG, Seligman DA, Gornbein JA. A multiple logistic regression analysis of the risk and relative odds of temporomandibular disorders as a function of common occlusal features. J Dent Res 1993;72:968-979.

38. Pullinger AG, Seligman DA. Quantification and validation of predictive values of occlusal variables in temporomandibular disorders using a multifactorial analysis. J Prosthet Dent 2000;83:66-75.

39. Rinchuse DJ, Kandasamy S. Centric relation: a historical and contemporary orthodontic perspective. J Am Dent Assoc 2006;137:494-501.

40. Sessle BJ, Lavigne GJ, Lund JP, Dubner R. Orofacial Pain: From Basic Science to Clinical Management, 2nd Ed. Quintessenz Publishing Company, Chicago; 2008.

41. Sessle BJ. A Focus on the Research Diagnostic Criteria for Temporomandibular Disorders. Editorial. J Orofac Pain 2009;23:5.

42. Solberg WK, Woo MW, Houston JB. Prevalence of mandibular dysfunction in young adults. J Am Dent Assoc 1979;98:25-34.

43. Steenks MH, The GL, Aaftink HM. Kaakrelatie bij de behandeling van musculoskelettale stoornissen met een stabilisatie opbeetplaat. Ned Tijdschr Tandheelkd 2005;112:279-282.

44. Stegenga B. Osteoarthritis of the Temporomandibular Joint Organ and Its Relationship to Disc Displacement. J Orofac Pain 2001;15:193-205.

45. Türp JC, Schindler HJ, Rodiger O, Smeekens SA, Marinello CP. Vertikale und horizontale Kieferrelation in der rekonstruktiven Zahnmedizin. Schweiz Monatschr Zahnmed 2006;116:403-411.

46. Von Korff M, Dworkin SF LeResche L, Kruger A. An epidemiologic comparison of pain complaints. Pain 1988;32:172-183.

47. 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.

48. Woelfel, JB. New device for accurately recording centric relation. J Prosthet Dent 1986;56:716-727.

49. Xie Q, Li X, Xu X. The difficult relationship between occlusal interferences and temporomandibular disorder – insights from animal and human experimental studies. J Oral Rehabil 2013;40:279:295.

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Curriculum vitae

Personal data:

Family name	: Zonnenberg
First, given name and initials	: Adrianus J.J.
Spouse	: Bangma, Ghislaine Dominique
Date of birth	: 28 July 1951
Place of birth	: The Hague, the Netherlands
Nationality	: Dutch
Gender	: Male
BIG-registration	: 59025110402
Address	: Velserhooftlaan 1
Postal code	: 2071 AJ
City	: Santpoort-Noord, the Netherlands
Telephone	: +3123-5490619
E-mail	: zonneber@xs4all.nl

- Born in The Hague, the Netherlands on July 28, 1951.
- Graduated Gymnasium β in Sneek on June 14, 1969.
- Graduated from the Dental School at the Rijksuniversiteit of Groningen, the Netherlands on June 14, 1975.
- Start private office in IJmuiden, the Netherlands, December 1975
- Start current practice in Santpoort-Noord, the Netherlands, June 1985
- Held a position at the Center of Special Dental Care, department of TMD within the ACTA premises of the University of Amsterdam from February 1999 until May 2007.

- Member of the American Equilibration Society's evidence based taskforce since 2006, the Guidelines Committee. The AES Guideline Committee is a committee with 10 AES-members (8 Americans, a Canadian and a Dutchman) and is currently working on a systematic review of systematic reviews. The PICO-question for the systematic review of systematic reviews is:

- In patients that demonstrate a Temporomandibular Disorder, will a stabilization orthopaedic appliance, compared with other or no treatment provide an improvement in the clinical signs and symptoms. Scientific support is granted by Rick Niederman of the Forsyth Institute from Boston, EBD by Derek Richards from Oxford, UK, Jan Clarkson from Dundee, Scotland and Debora Matthews from Halifax, Canada. The systematic review of systematic reviews will be published on the website of the American Equilibration Society (AES) in 2014.

Specialties:

- EPA-recognition in prosthodontics since December 3, 2010

- EAO-certificate in implant-based therapy since October 11, 2012

- NVGPT-recognition in orofacial pain and dysfunction since 1996 (tandarts-gnatholoog)

- NVOI-recognition in Implants from 2003-2008 (tandarts-implantoloog)

- Adhesive, esthetic dentistry

Membership Dutch professional organisations:

- NVGPT (Nederlandse Vereniging voor Gnathologie en Prothetische Tandheelkunde): TMD and Prosthodontics

- (co) Founder of the Nederlands Vlaamse Vereniging voor Restauratieve Tandheelkunde (Dutch-Flemish Society for Restorative Dentistry, officially founded January 2001). Personal initiative . Served as the Secretary of the Organization from 2000 till 2004, served as the Treasurer of NVVRT since September 2004 and left office of the Board in December 2006. Awarded Honorary Member of the NVVRT in December 2006.
- Member of NTG, het Nederlands Tandheelkundig Genootschap since 2007

NMT (Nederlandse Maatschappij ter bevordering van de Tandheelkunde): Dutch national professional organisation.

Membership International professional organisations:

- American Equilibration Society (AES), since 1990
- European Association of Osseointegration (EAO), since 1998
- American Academy of Fixed Prosthodontics (AAFP), since 2003
- European Prosthodontic Association (EPA), since 2003

Membership/founder in 1986 of the Craniomandibular Health Foundation Holland, in Haarlem, the Netherlands, a study-group on TMJ and Occlusion that ended its activities in 1991. The study group presented 3 lectures at the Foundation of Orthodontic Research (FOR), also named the "Robert Ricketts Society" at the Hilton Hotel, Anaheim CA in May 1989. Titles of the published proceedings of these lectures:

- The introduction of the passive rotation axis as a diagnostic and a therapeutic instrument
- A dynamic, diagnostic precision model
- Treatment in the dynamic diagnostic precision model

In February 2002 the Chair of the Scientific Investigation Committee of the American Equilibration Society (AES) attributed a grant for a study "The Centric Slide in Temporomandibular Disorders".

- AES Scientific Program Chair for the Annual Meeting in Chicago, Ill. in February 2014.
- Chair of the Scientific Investigation Committee (SIC) of the American Equilibration Society since 2012.

List of publications:

- Zonnenberg AJJ, Engels PA, Valk JWP, Van Wonderen UGT. The Intermaxillary Relationship with the Aid of a Modified Axiography. J Craniomand Pract 1989;7:305-311.

- Zonnenberg AJJ, Van Wonderen UGT, Valk JWP, Engels PA. Clinical Implications of a New Method in Registration Technique. J Craniomand Pract 1990;8:120-130.

- Zonnenberg AJJ. Gemodificeerde Axiografie: Een nieuwe toepassingsmogelijkheid in de Registratietechniek. NVG-bulletin 1990;3:32-35.

- Valk JWP, Zonnenberg AJJ, Van Maanen CJ, Van Wonderen UGT. The biomechanical effects of a sagittal split ramus osteotomy (SSRO) on the relationship of the mandible, the hyoid bone, and the cervical spine. Am J Orthod Dentofac Orthop 1992;102:99-108.

- Zonnenberg AJJ. Gemodificeerde Axiografie: Toepassingsmogelijkheden bij patiënten met craniomandibulaire dysfunctie. NVG-bulletin 1992;10:21-24.

- Van Maanen CJ, Valk JWP, Zonnenberg AJJ. Craniomandibulaire dysfunctie: Dysbalans in de statiek? Nederlands Tijdschrift voor Manuele Therapie 1992;11:90-96.

- Zonnenberg AJJ, Van Maanen CJ, Elvers JWH, Oostendorp RAB. Intra-/Interrater Reliability of Measurements On Body Posture Photographs. J Craniomand Pract 1996;14:326-331.

- Zonnenberg AJJ, Van Maanen CJ, Oostendorp RAB, Elvers JWH. Body Posture Photographs as a Diagnostic Aid for Musculoskeletal Disorders Related to Temporomandibular Disorders (TMD). J Craniomand Pract 1996;14:225-232.

- Zonnenberg AJJ, van der Kuij P, Sulkers HR. TMD: Van controverse in de jaren 90 naar consensus in het nieuwe millennium. Tandartspraktijk 2002; 10: 2-7.

- Zonnenberg AJJ, van der Kuij P, Snel LC, Een tandarts buiten zijn beroepscompetentie: Ned. Tandartsenblad 2003; 58, nr. 7:18-19.

- Zonnenberg AJJ. TMD: Het raffinement van occlusale factoren. Tandartspraktijk 2003; 9: 24-28.

- TMD-patiënten gerichter verwijzen: Slijtage zelf behandelen met composiet. Ned. Tandartsenblad 2003;58, nr. 20:17-19. Interview gnathologie met Karel Gosselink

- Zonnenberg AJJ, Mulder J, Sulkers HR, Cabri R. Reliability of a Measuring-Procedure to Locate a Muscle-Determined Centric Relation Position. Eur J Prosthod Rest Dent 2004;12:125-128.

- Zonnenberg AJJ, Mulder J. Variability of the centric relation position in TMD-patients. Eur J Prosthod Rest Dent 2006;14:32-37.

- Zonnenberg AJJ. Provisionals; Erosie: een complex probleem. Tandartspraktijk 2006; 5: 4 – 7.

- Bengt Öwall, Richard Welfare, Pavlos Garefis, Wieslaw Hedzelek, John Hobkirk, Flemming Isidor, Vjekoslav Jerolimov, Asbjörn Jokstad, Warner Kalk, Mats Kronström, Pieter van der Kuij, Regina Mericske-Stern, Ignace Naert, Timo Närhi, Krister Nilner, Gregory Polyzois, Jürgen Setz, Atýlla User and Adriaan Zonnenberg. Specialisation and Specialist Education in Prosthetic Dentistry in Europe. Eur J Prosthodont Rest Dent 2006;3:105-110.

- De Calessco-kroon. Tandartspraktijk 2007;1: 42-44.

- Review #1492 CRANIO.

- Immediate dentin sealing. Met Jip Kreyns. De Tandartspraktijk 2007;5:32-37.

- Met adhesief kan steeds meer?. Tandartspraktijk 2008;2:25-29.

- Poster presentation: Immediate Implant Placement with Temporary Restoration, All in One. World Tour Maastricht.

- Verslag World Tour Maastricht, NVOI-bulletin december 2008

- Volledig keramische restauraties: de kliniek en het onderzoek. Tandartspraktijk 2008;8:22-25.

- Een geluk bij een ongeluk. Tandartspraktijk-Exkies 2009;2: 25-29.

- Commentary S-09-014 Journal of Evidence Based Dentistry 2009. Cascos-Romero J, Vázques-Delgado E, Vázques-Rodriguez E, Gay-Escoda C. The use of tricyclic antidepressants in the treatment of temporomandibular joint disorders: Systematic review of the literature of the last 20 years. Med Oral Patol Oral Cir Bucal 2009;14:3-7.

- Loodbesmetting: Reëel of…. Tandartspraktijk 2009;5:41-42.

- Het gebruik van een opbeetspalk voor de behandeling van TMD. Tandartspraktijk 2009;8:22-25.

- Dit nooit meer. In co-auteurschap met Jip Kreyns Tandartspraktijk 2010;1: 29-31.

- Indirecte tandkleurige kronen in het posterieure gebied. Tandartspraktijk-Exkies 2010;2: 57-60.

- Zonnenberg AJJ, Mulder J. Reproducibility of 2 methods to locate centric relation in healthy individuals and TMD patients. Eur J Prosth Rest Dent 2012;20:151-158.

- Zonnenberg AJJ, Mulder J. The incidence of centric slides in healthy individuals and TMD patients. Eur J Prosth Rest Dent 2013;21:109-113.

- Zonnenberg AJJ, Mulder J. The efficacy of a specific stabilization splint. J Craniomand & Sleep Practice 2014;32:68-74.